ISSN: 0973-4929, Vol. 19, No. (**3**) 2024, Pg. 1061-1076

Current World Environment

www.cwejournal.org

A Critical Review on the Indoor Air Quality Status of Schools in India

NIYATHI VIJAY* and JAYA DIVAKARAN SARASAMMA

Department of Environmental Sciences, University of Kerala, Thiruvananthapuram, India.

Abstract

The quality air in the indoor environment significantly impacts anthropological health and well-being. Suboptimal environmental air quality can lead to respiratory and other diseases among students worldwide. The objective of this study is to scientifically evaluate and summarize the available data on Indoor Air Quality in Indian school settings, based on a review of relevant research papers. From the 172 articles analysed, there are only 36 articles related to the Indian perspectives on indoor air quality. In an Indian scenario, thermal comfort inside a school classroom is directly proportional to the natural ventilation. The review of the available research articles illustrates that occupants all over India are adapted to a temperature range of 17 - 33.7º C, with a difference in climate. Case studies on indoor air quality in schools have consistently identified eight key pollutants of concern. Carbon monoxide (CO), Particulate matter (PM), Nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), Ozone (O_3), Volatile Organic Compounds (VOCs), and Bioaerosols. Climate change may worsen indoor air quality and cause new problems as the frequency of adverse outdoor conditions changes. Further research is essential to study indoor air pollution in schools and its associated health impacts, utilizing standardized protocols and methodologies to ensure comparable and reliable data

Article History

Received: 27 September 2024

Accepted: 16 December 2024

Keywords

Indoor Air Quality, Natural Ventilation; Particulate Matter; Thermal Adaptation.

Introduction

Indoor air quality (IAQ) significantly impacts human health and well-being. Suboptimal environmental air quality can lead to respiratory and other diseases among students worldwide. The current pandemic-dominated era requires more urgent actions to determine its impact burden. Recently, India has been the center of attention regarding the deteriorating air quality in winter. Not just in Delhi, but most of the northeast states started suffering from smog. The deteriorating outdoor environment has a vital role in the poor quality of the indoor

CONTACT Niyathi Vijay niyathi@keralauniversity.ac.in Department of Environmental Sciences, University of Kerala, Thiruvananthapuram, India.

© 2024 The Author(s). Published by Enviro Research Publishers.

This is an Open Access article licensed under a Creative Commons license: Attribution 4.0 International (CC-BY).

Doi: https://dx.doi.org/10.12944/CWE.19.3.3

air. The presence of pathogens such as bacteria, viruses, mold spores, and dust mites poses a significant health risk, especially for individuals with compromised immune systems. Developing nations, such as India, are experiencing acute pressures from air pollution and climate change. A notable knowledge gap exists regarding the interconnected and synergistic effects of weather patterns, climate variability, air pollution, and human health outcomes.[1,2]

India ranked 179 out of 180 in the Environment Performance Index (EPI) 2022 with an EPI score of 7.8[3] and Indoor Air Pollution (IAP) is among the important 10 leading causes of illness in developing countries.[4] Furthermore, it is the next leading environmental health threat after inadequate water, sanitation, and hygiene, accounting for roughly twice as many deaths as urban outdoor air pollution.[5] Although there were thousands of studies on Indoor Air Quality, there are very few related to school environments, especially in India. Schools are vital social infrastructures and the second-most important indoor environment for children, after their homes.[6] Unlike adult workplaces, schools present distinct health challenges due to children's hygiene practices and shared resources, such as pencils, which can amplify the spread of illnesses. Healthy learning environments necessitate school buildings with proper ventilation, filtered air, and openable windows to ensure students' and staff's well-being.[7] Unfortunately, many Indian schools struggle with subpar indoor air quality.[8] Classrooms, despite the absence of typical indoor pollution sources like smoking and cooking, often exhibit surprisingly high pollutant concentrations. Research studies consistently showed that classrooms tend to have higher indoor air pollutant levels than residential and commercial buildings.[9,10] Particulate matter pollution is an important risk factor to the quality of indoor air in many schools, originating from a range of contributors including chalk residues, soil particles, cleaning operations, pupil activity, combustion emissions, vehicular exhaust, and industrial releases, with previous research identifying traffic emissions and occupant behavior as the key drivers of indoor air pollution in educational settings.[11-29]

This paper aims to comprehensively review and synthesize existing research on the Indoor Air Quality (IAQ) status of Indian school environments, published between 2008 and 2022. This study provides a foundational framework for future researchers by summarizing the current state of knowledge. It enables them to identify key indoor air pollutants and explore strategies to mitigate their impact, particularly from outdoor sources. Additional investigations are required to examine indoor air pollution in educational settings and its corresponding health consequences, employing uniform protocols and methodologies to yield consistent and dependable data.

Materials and Methods

A comprehensive literature review was conducted by searching various academic repositories and online platforms, including Web of Science, Scopus, Google Scholar, ResearchGate, Science Direct, and SAGE Journals, to prepare this article. Important keywords like indoor air quality, school environment, India, indoor air pollution, classroom air quality, and a combination of these keywords were used to sort out the important manuscripts from the list. Pre-classification is done in the first classification stage based on the title, area, and abstracts. After initial screening, irrelevant articles were excluded, and the remaining studies were thoroughly reviewed in their entirety.

Although there are numerous articles based on indoor air quality/pollution around the world, very few are tangled with Indian classroom conditions. Figure 1 displays the geographical distribution of the available number of articles related to indoor air quality studies on school buildings from various regions of India.

From the 172 articles analysed, there are only 36 articles linked to the Indian perspectives of indoor air quality. The papers are classified into three groups based on the aim and objective for easy comparison of available articles. They are (i) Review Papers, (ii)Thermal comfort and Architectural perspectives, and (iii) Indoor air quality case studies from different parts of India. After a comprehensive examination of the reviewed articles, the extracted data are systematically organized and integrated, yielding a cohesive review that informs conclusive findings and identifies avenues for future investigation.

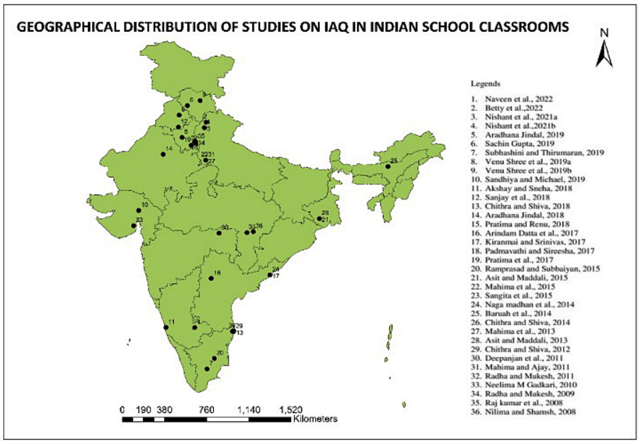

Fig. 1: The Topographical Spreading of studies on IAQ in Classrooms environments of Indian Schools

In the absence of India-specific Indoor Air Quality (IAQ) standards, the analyzed studies relied on international guidelines, including ASHRAE Standard 62.1-2004 for CO_2 assessment, US EPA guidelines for $PM_{2.5}$, PM_{10}, and VOCs monitoring, and WHO standards for evaluating $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO concentrations. Table 1 summarizes the IAQ standards based on WHO (2005), ASHRAE(1992), and EPA(2011).

Table 1: IAQ Standards: A summary

Variables	WHO[30]	ASHRAE Standard 55[31]	US EPA[32]
PM_{10} (24-hr)	50µg/m^3	– –	150µg/m^3
$PM_{2.5}$ (24-hr)	25µg/m^3	– –	65µg/m^3
SO_2 (24-hr)	20µg/m^3 200 µgm^{-3} (1-hr) 40 µgm^{-3}	– –	140ppb
NO_2	(annual)	– –	53ppb (annual) 100ppb (1-hr)
CO (8-hr)	10 ppm	9 ppm	9 ppm
CO_2 (8-hr)	– –	1000 ppm	
Humidity	– –	30% – 65%	
Temperature	– –	20-23.6°C (winter) 22.8-26.1°C	(summer) – –

Results

Review Articles

Existing scientific literature reveals a scarcity of review studies on indoor air quality in schools worldwide. Notably, a thorough search yielded only four studies specific to India, focusing on the quality of indoor air in Indian School classrooms.

The paper on the Indoor Environmental Quality (IEQ) parameters[33] provides a comprehensive analysis of existing literature on naturally ventilated educational facilities, with a specific focus on thermal comfort, air purity, ventilation effectiveness, visual ambiance, and acoustic tranquility. In this study, the IEQ has been divided into four categories for easy analysis of the corresponding articles. The components include, Thermal Comfort, Acoustic Comfort, Visual Comfort, and IAQ. From this study, it is evident that for naturally ventilated school buildings, there aren't any widely acknowledged codes or comfort standards. The next review paper[34] presents a systematic review of research conducted over the past fifteen years on IEQ parameters in Indian school classrooms, providing an inclusive summary of the existing knowledge on IEQ parameters in Indian educational settings. Building-associated illness (BAI) is a significant concern explored in these studies. BAI encompasses two distinct types: Sick Building Syndrome (SBS) and Building-Related Illness (BRI).[35] The paper relies on Indoor Environmental Quality and its parameters that are published in around37 journals. It includes Thermal Comfort (TC), Visual Comfort (VC), Acoustic Comfort (AcC), and Indoor Air Quality (IAQ).[35]

Indoor Air Quality (IAQ)

IAQ is defined as the multidimensional measure of air characteristics within enclosed spaces, encompassing physical, chemical, and biological factors. The Central Pollution Control Board's Indoor Air Pollution Report[36] defines indoor air quality (IAQ) broadly, encompassing both airborne pollutants and ambient conditions such as temperature and humidity, which together influence occupant well-being and performance. Indoor Air Quality is compromised by inadequate HVAC systems, chemical emissions from building materials, higher occupant density, and extended indoor residence times. These problems contribute to the buildup of indoor air pollutants, comprising a range of chemicals, organic compounds, and microorganisms, such as dust, mold, fungi, bacteria, gases, vapors, and unpleasant odors.

Acoustic Comfort (AcC)

Acoustic comfort pertains to a building's ability to safeguard its inhabitants from ambient noise, fostering an uninterrupted and secure sonic environment conducive to effective communication.[33] Building noise is classified into two distinct types: (i) structure-borne noise (physical contact) and (ii) airborne noise (air transmission), each requiring unique mitigation strategies.[37] Several acoustical factors contribute to acoustic comfort, including: (i) noise frequency, (ii) noise source characteristics, (iii) noise duration, and (iv) temporal variability.[38]

Thermal Comfort (TC)

According to ASHRAE,[39] thermal comfort refers to a psychological state of well-being, where an individual feels content with their thermal surroundings, a subjective assessment that varies from person to person. The factors that predominantly shape Thermal Comfort (TC) are air moisture levels (Relative Humidity), the temperature of surrounding surfaces, the ambient air temperature, and the rate of air circulation.[33] Two parameters that affect TC individually are metabolic rate and clothing.[40]

Visual Comfort (VC)

Visual comfort is defined as a subjective response to the quantity and quality of illumination within a specific environment at a particular time. Illuminance, Surface reflectance, Uniformity Ratio, and Glare are the major parameters that are relevant for the visual comfort of an indoor building.[41] Research indicates that visual discomfort in educational settings is associated with negative health effects, including frequent headaches, eye fatigue, and compromised visual acuity.

Research review[6] on the existing literature examines the association between the quality of air inside educational settings and the health and welfare of children, and it summarizes the major air quality management practices for indoor air around the world. The findings reveal that particulate matter levels exceeded the acceptable threshold, standing out as a prominent concern among indoor air pollutants (PM_{10} = 50μgm^{-3} and $PM_{2.5}$ = 25 μgm^{-3}) in many schools.[1,11-29] Besides this, the paper emphasizes that comprehensive knowledge of indoor pollutant sources, emission rates, dispersion patterns, toxicological properties, chemical characteristics, and associated health risks is essential for assessing the effectiveness and cost-efficiency of IAQ control measures in schools.

Researchers published a review paper in 2018[42] including the analysis of research papers, media reports, and reports of the Government and International Organizations based on the poor school environment and its possible effect on people. The paper's conclusion underscores the alarming correlation between inadequate school indoor environments and detrimental health consequences for children, as supported by international scientific research.

Thermal Comfort/ Architectural Perspectives

Thermal comfort is a crucial aspect of indoor environmental quality,[43] and ensuring the thermal comfort of occupants in classrooms is of paramount importance. In India, naturally ventilated (NV) public school classrooms are prevalent, making thermal comfort highly susceptible to outdoor environmental conditions. Notably, India lacks standardized thermal comfort guidelines, unlike the ASHRAE Standard 55. A review of 37 articles revealed that 11 papers, published between 2008 and 2022, specifically addressed thermal comfort issues in Indian school classrooms.

The study[43] on the thermal conduct evaluation inside an architectural studio classroom in Tumkur, Karnataka was done by a questionnaire survey. The research revealed that participants demonstrated significant adaptability to elevated indoor temperatures through behavioral adaptations, including utilization of ceiling fans, natural ventilation, lightweight attire, selective shading, and hydration. The researchers[44] studied the behaviors of Students to the change in thermal conditions in 12 primary schools in Dehradun City in Uttarakhand. Thermal comfort was determined by questionnaire surveys and the building characteristics were also noted. The questionnaire encompassed a comprehensive data collection approach, gathering information on participant characteristics (age and gender), clothing details via a checklist, and subjective thermal perceptions through two specialized metrics: the 7-point Thermal Sensation Vote (TSV) assessing thermal sensation (from +3= Very hot, to -3 =Very cold), and the 5-point Thermal Preference Vote (TPV) evaluating thermal preference (from +2= Much warmer to -2 = Much cooler). The results indicate a notable divergence between children's subjective thermal assessments and objective physical environmental measurements, highlighting the complexity of pediatric thermal comfort.

A study[45] was conducted on the Computational Fluid Dynamics (CFD) simulation to investigate the effects of window and courtyard orientation on ventilation and thermal conditions within learning spaces of an educational building in Madurai. CFD is used as a tool to assess the numerical investigation of two different wind directions. The study found that improved thermal comfort and natural ventilation in Madurai buildings can be achieved through courtyard design optimization: 1:2 aspect ratio, strategic opening orientation, and controlled opening percentage.

A study[46,47] conducted in non-air conditioned secondary school buildings across three Jawahar Navodaya Schools in Ambala, Chandigarh, and Panchkula, India, revealed that approximately 80% of students had acclimatized to higher temperatures. Notably, the comfort temperature range for the students in these classrooms spanned from 16°C to 33.7°C. The thermal comfort model study revealed a significant disparity, with a substantial majority (78%) of indoor operative temperatures meeting comfort standards, while a notable minority (22%) fell short of acceptable ranges. The study concludes that children employ seasonal adaptive strategies to cope with indoor temperature fluctuations, utilizing fans and cross-ventilation during summer and monsoon seasons, and layering clothing for insulation during winter.

Researchers[48] carried out a study on the IAQ of Schools in India with an architectural perspective and reported that the air quality inside the building should be taken care of from the building design onwards. Effective communication and collaboration among building owners, architects, engineers, and consultants from the outset of construction is essential for achieving improved indoor air quality in designed buildings. By prioritizing building design and operation, we can fulfill our mission of providing safe and healthy environments for future generations, ultimately encouraging their wellness and improvement of life. The survey-based study[49] investigated the thermal conditions of non-air-conditioned classrooms in Tiruchirapalli, Tamilnadu. The results revealed that a significant majority (82%) of the participants reported being thermally comfortable, with their perceived thermal sensations leaning towards the cooler side.

The comprehensive study[50,51] on thermal comfort and occupant adaptive behavior in classrooms and laboratories situated in a composite climate zone in India revealed a strong correlation between indoor and outdoor temperatures, with an optimal comfort temperature range of 20-31°C. Notably, students employed various adaptive strategies to mitigate thermal discomfort, including adjusting clothing levels, modifying posture, and relocating to well-ventilated areas. A comparative analysis of thermal satisfaction levels in naturally ventilated and air-conditioned rooms revealed distinct differences. However, interestingly, the data indicated that the type of ventilation system did not significantly impact learning performance. Some researchers[52] investigated the thermal adaptability in naturally ventilated school classrooms in Assam, revealing optimal temperature ranges of 22-23.5°C in winter and 27.3-30.7°C in summer. The occupant's adaptation to changing temperatures is mainly attained by changes in clothing patterns followed by the use of fans and closing/opening of windows.

IAQ Case Studies from Different Parts of India

IAQ studies have been receiving augmented attention in the areas of research, government, and Policymaking due to their adverse health effects and occupants' discomfort.[53] The Central Pollution Control Board's (CPCB, India)[54] Indoor Air Pollution Report defines Indoor Air Quality (IAQ) as the complex interplay of indoor environmental factors, encompassing pollutant levels, temperature, and humidity, which collectively impact the comfort and efficiency of the occupants inside the building. The concentration of pollutants in the indoor environment is affected by a complex interplay of factors including indoor air volume, pollutant emission rates from various sources, removal rates through chemical reactions or settling, air exchange rates with the outdoors, and ambient outdoor pollutant concentrations. These factors interact to determine the levels of indoor pollutants, highlighting the need for a comprehensive approach to managing indoor air quality.[55]

Schools constitute a vital component of a society's social infrastructures, serving as the primary setting for socialization and a significant environment for children outside of the home.[7] Good indoor air quality in classrooms is vital for the health and well-being of students and teachers. Moreover, it plays a critical role in optimizing academic performance, alertness, concentration, and overall comfort.[3] Common indoor air pollutants detected in educational settings encompass a range of contaminants, including suspended particles, oxides of sulphur, ozone, carbon monoxide, oxides of nitrogen, volatile organic chemicals, and airborne biological agents. These pollutants pose significant health risks to students, teachers, and staff, emphasizing the need for effective IAQ management in schools. A condensed form of the sources of air pollutants in schools' indoor environments is given in Table 2.

Table 2: Major Pollutants and their sources in the school indoor environment

Pollutant	Sources
Particulate Matter (PM)	Chalkdust, New furniture, Cleaning, Kids moving around, Smoking and burning
Carbon Monoxide (CO)	Heaters, woodstoves, and smoking
Nitrogen Dioxide (NO_2)	Gas appliances, heaters, wood-burning stoves, and smoking
Ozone (O_3)	Generators, photocopiers, paints, plasters, and laser printers
Volatile Organic Compounds (VOCs)	Furniture, resins, adhesives, glues, paints, fiberboard, computers, Photocopiers, printers, plywood, carpets, cosmetics and cleaning products
Bioaerosols	Human occupants, ventilation system, and air-conditioner

Particulate Matter (PM)

The particulate matter is an atmospheric aerosol comprising a diverse range of solid and liquid particles, including organic and inorganic compounds. PM pollution is a prominent indoor air pollutant in numerous schools, posing a significant threat to indoor air quality.[7] Based on the size of the particle present in the air, PM can be classified as, Total Suspended Particulate Matter (<100 μm), PM_{10} (<10μm), and $PM_{2.5}$ (<2.5μm).

Carbon Monoxide (CO)

CO is a potent fragrance-free toxin, that is generated through incomplete combustion of fossil fuels, primarily from indoor sources including water heaters, gas and wood stoves, and smoking activities. The intrusion of vehicle emissions into a building's ventilation network can lead to heightened indoor CO levels, putting occupants at risk of serious health problems.[56]

Nitrogen dioxide (NO_2)

Nitrogen dioxide (NO_2), a toxic atmospheric pollutant, is primarily produced during high-temperature combustion processes, where nitrogen and oxygen react to form a water-soluble, reddish-brown gas characterized by its pungent, acrid smell. Due to its detrimental effects on the environment and human health, NO_2 emissions warrant close monitoring and regulation.[57] The NO_2 levels are often elevated by the use of gas-powered devices, kerosene heaters, and tobacco smoking, posing a considerable risk to the air quality of the indoor environment and human comfort.[56]

Sulphur dioxide (SO_2)

Sulphur dioxide (SO_2) is a colourless, pungent gas detectable at concentrations as low as 0.5 ppm. Primarily emitted through the combustion of sulphur-containing fuels, SO_2 is a vital component in atmospheric chemistry, serving as a key precursor to the formation of sulphate aerosols, which significantly influence cloud properties, acid rain, and air quality. These sulphates are a key component of respirable particulate matter, posing significant air quality and health concerns.[51]

Ozone (O_3)

The formation of ground-level ozone, a significant secondary air pollutant, occurs through photochemical reactions involving hydrocarbons, nitrogen oxides, and ultraviolet radiation from sunlight, with profound implications for atmospheric chemistry, human health, and environmental sustainability.[56] This reaction can harm small plants, animals, and humans. Generally, indoor ozone concentration is less than the outdoor concentration unless there is a contributor like photocopiers, laser printers and electrostatic air cleaners.[6]

VOCs

Organic compounds, defined by the presence of hydrogen and carbon atoms in their molecular structure. VOCs are characterized by relatively low boiling points, ranging from 50°C to 260°C, making them prone to evaporation at room temperature, with examples including acetone, benzene, and formaldehyde.[53]

Bioaerosols

Bioaerosols are airborne particles or fragments obtained from plants or animals, microorganisms, or their byproducts, including live or dead bacteria, viruses, fungi, toxins, allergens, and cellular components.[6]

A summary of the available articles discussing indoor air pollution in school buildings in India from 2008 to 2022 and their major findings are given in Table 3.

Table 3: The summary of the results of IAQ studies of school buildings in India.

Methodology	Major Findings	Limit exceeding standards Yes/ No
Sampling was done in 50 schools with 333 classrooms in Ahmedabad.[57] The air quality monitoring equipment used for sampling included an Airveda monitor, a Total Volatile Organic Comp -ound (TVOC) meter, and a formalde-hyde meter (Dienmern model 106B). These devices were positioned on a desk within the classroom to collect	TVOC and formaldehyde concentrations were below the threshold limit. $PM_{2.5}$ and PM_{10} concentrations were above the threshold limit with relatively low humidity.	Yes

accurate and representative air quality data.		
Two schools were selected, one in a rural area and one in a residential area of Hamirpur, Himachal Pradesh[58] Measuring instruments were centrally located within the classroom and outdoors, maintaining 1mtr from the floor to facilitate accurate data comparison.	The $PM_{2.5}$ concentration was above the permissible limit (ranged from 283-568 μg/m^3). Schools near national highways exhibited higher particulate matter levels than their counterparts near rural roads. The high concentration of pollutants in urban environments is largely a consequenceof intense vehicular activity and corresponding emission releases.	Yes
Eight schools were selected for the study in Hamirpur, Himachal Pradesh[15] The instruments were strategically positioned opposite the blackboard, 2 meters from the wall and centered in the classroom. To capture data within the breathing zone of seated students, the instruments were placed at a height of approximately 0.8 meters above the floor level.	The mean concentration of indoor $PM_{2.5}$ was 281.67μg/m3 and is much more than the prescribed limit i.e. 35 μg/m^3. Small classroom sizes and crowded conditions are major causes of indoor $PM_{2.5}$ and CO_2 levels.	Yes
Particulate matter concentrations in Amritsar, Ludhiana, Mandi Gobindgarh in Panjab59 were assessed using an advanced aerosol monitoring system based on real-time optical light scattering technology.	The burning of rice crop residues led to a pronounced increase in particulate matter levels, with PM_{10} and $PM_{2.5}$ concentrations rising by 87% to 123% relative to the wheat crop residue burning period.	No
Measuring instruments were centrally located within the classroom and outdoors, at a height of 1 metre above the ground to facilitate accurate data comparison Continuous monitoring of CO_2 in 11 (government, private) schools in Ahmedabad, Gujarat[60] using Airveda CO_2 logger	The ventilation rates in naturally ventilated classrooms varied between 61.5 l/s and 15.6 l/s per person, whereas air-conditioned classrooms had much lower rates, fluctuating between 0.9 l/s and 1.0 l/s per person. Air-conditioned classrooms exhibit inadequate indoor airflow, failing to meet the standard ventilation rates per person outlined in BIS/ASHRAE guidelines	Yes
Two schools in Manipal, Karnataka[61] were selected for the study PM (APM 50 particulate sampler), NO_2 (APM 433 gaseous pollutant sampler), CO_2, temp, and relative humidity (MCH-383SD handy meter) for 24 hrs were monitored	PM concentrations were high when occupied (>45 μg/m^3) CO_2 concentration in classrooms over 1000 PPM during the winter season due to the small size of classrooms and higher occupancy rate as per ASHRAE standards.	Yes

Airborne fungal samples were collected using the open plate method, with a 15-minute exposure period, once weekly, at a height of 0.6 meters above floor level, from schools located in Vishakhapatnam, Andhra Pradesh.[62]	The predominant fungal genera identified were *Aspergillus sp, Alternaria sp, Rhizopus, Cladosporium sp, Penicillium sp,* and *Curvularia sp*, with *Aspergillus sp* and *Cladosporium sp* exhibiting dominance in one play school, indicating potential allergenic risks.	-
Six schools were selected for the study in Delhi[63] Sampling was done using a digital IAQ monitor-Rave IAQ 3007R by placing it 1mtr above ground level.	$PM_{2.5}$ concentration was much higher (73.04 μgm^{-3} to 273.42 μgm^{-3}) than recommended levels ie.,60 $\mu g/m^3$ (NAAQS India) in all the schools. The average $PM_{2.5}$ concentrations in schools on non-working days were lower (53.53 µg/m3 to 132.01 µg/m3)than the mean concentrations on working days.	Yes
The study was done in 3 non-residential and one school buildings in Delhi[64] using a low-volume sampling pump (Model 224-PCXR8).	The educational building demonstrated superior indoor air quality compared to other non-residential buildings, with concentrations of CO_2 (672 ppm), $PM_{2.5}$ (22.8 $\mu g/m^3$), and VOC (0.08 ppm) substantially lower than those recorded in comparable structures.	No
Three different types of chalk were used in this study[65] conducted in Gujarat. The structural and chemical composition of the chalks were studied by SEM by EDX.	The estimated potential dose of PM_{10} and $PM_{2.5}$ was significantly higher (> 100 μgm^{-3} in PM_{10} and > 60 μgm^{-3} in $PM_{2.5}$) for gypsum chalk than calcium carbonate chalk, with children in the 6-11 age range being most susceptible.	No
10 schools in Agra,[66] UP were selected for the sampling. The sampling unit was placed opposite the board, about 1 meter above the ground level.	PM values are higher at roadside schools (81.85 $\mu g/m^3$) than at residential area schools (78.33 $\mu g/m^3$). The PM_{10} exceeds 4-13 and $PM_{2.5}$ exceeds 8-26 times for indoors and the PM_{10} and $PM_{2.5}$ concentration exceeds 4-12 and 7-23 times for outdoors when compared with standards.	Yes
30 schools (15 primary and 15 secondary) in Visakhapatnam[67] were selected for this study Samples were collected by open plate method (15 minutes) twice a day from the breathing zone	The spatial dispersal of microorganisms showed that bacterial levels were highest in classrooms, toilets, and canteens, while fungal levels were more pronounced in libraries and classrooms.	-
Two naturally ventilated schools in Chennai, Tamil Nadu[68] were selected for the study.	The study found that PM concentrations in the roadside classroom had substantially higher levels (PM_{10} : 149.79 μgm^{-3}, $PM_{2.5}$:	Yes

A portable optical Grimm dust monitor was used for PM measurements and the inlets of the samplers were positioned 1 meter above the floor.	62.26 μgm^{-3}, PM_1: 29.41 μgm^{-3}) than Class -room B (PM_{10}: 69.28 μgm^{-3}, $PM_{2.5}$: 49.36 μgm^{-3}, PM_1: 24.66 μgm^{-3}), which is situated at a greater distance from the road. Indoor PM_{10} concentrations violated the CPCB- 24-hour average and NAAQS limit of 100 μg/m³ in all seasons except summer 2011.	
Ten schools in Agra,[16] UP were selected for the study The particulate matter sampler was positioned within the classroom, approximately 1 meter above the ground level.	Indoor and outdoor PM_{10} and $PM_{2.5}$ levels consistently exceeded WHO air quality standards during winter (238.97 μgm^{-3}-PM_{10} & 90.06 μgm^{-3} -$PM_{2.5}$). Roadside schools experienced decreased levels in summer, and moderate levels during monsoons, largely attributable to heavy traffic flow during peak hours, persisting throughout the sampled year	Yes
Naturally ventilated classrooms in one school from Chennai, Tamilnadu[25] were selected for the study Particulate matter was monitored using a GRIMM dust monitor (Model-1.107), and an IAQ meter was used to record temperature, relative humidity, CO, and CO_2 levels.	IAQ assessments indicated frequent violations of NAAQS, with PM10 levels beyond standards 60% of the time and $PM_{2.5}$ concentration beyond standards 27% of the time. The average PM_{10} level was 266±178 μgm^{-3} in winter and, it was 249±179 μgm^{-3} in summer. The levels of finer particulate matter fractions and carbon monoxide indoors were significantly influenced by ambient particle concentrations, primarily emitted by traffic sources.	Yes
The study was done in a local classroom in a school in Nagpur.[69] Gypsum and $CaCO_3$ chalks were used to study the impacts on children	The 'Clean Write' chalk outperformed the other two tested chalks in terms of particulate matter (PM) emissions, producing the lowest levels of PM_1 (0.33 g/h), $PM_{2.5}$ (0.58 g/h), and PM_5 (0.86 g/h), although it was not the lowest emitter of PM_{10}. Utilizing marker pens and white marker boards for classroom writing is a recommended strategy.	-
A three-storied naturally ventilated school building in Delhi[70] was selected for this study. An environmental dust monitor (model 107) was used to monitor the PM and CO_2.	Across all sampling intervals, including weekdays and weekends, the mean indoor concentrations of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ were found to be higher than their corresponding outdoor levels. A statistically significant linear relationship was found between Respirable Suspended	No

	Particulate Matter (RSPM) concentrations and ventilation rates.	
Four schools in Agra, UP were selected for the study with 2 naturally ventilated classrooms from each school.[16] The sampler was positioned inside the classroom, at a height of approximately 1 meter above the floor level.	In winter, the mean PM_{10} was 524.76 μgm^{-3}, $PM_{2.5}$:240.95 μgm^{-3}, ; and $PM_{1.0}$: 259.51 μgm^{-3}, at roadside schools Particulate matter (PM) levels spiked during periods of heightened physical activity, specifically several minutes before and after school, as well as during breaks. Elevated CO_2 concentrations in classrooms correlated with inadequate ventilation rates in densely occupied spaces with limited mobility.	-
Three schools in Chhattisgarh[71] were selected for this study. An Envirotech dust sampler (model APM 821) was employed for Respirable Particulate Matter (RPM) sampling, positioned 1 meter above floor level.	All the values of RPM exceed the Indian standard for PM_{10} (60 $\mu g/m^3$ for residential areas). The school located downwind of the steel plant recorded the highest ratio of indoor tooutdoor PM_{10} concentrations (0.62).	Yes
A three-storied naturally ventilated school building in Delhi[21] was selected for this study. An environmental dust monitor (model 107) was used to monitor the PM and CO_2	The Indoor/Outdoor (I/D) ratios for particles of all sizes surpassed 1, demonstrating inadequate protection from outdoor pollutants. The higher PM_{10} I/O ratio indicates indoor emission sources and strong correlations between occupant activities and indoor concentrations during weekdays.	Yes
A total of 441 children, comprising 259 boys (59%) and 182 girls (41%), aged 7-15 years, from Delhi, took part in this questionnaire-based survey.[72] A handy air sampler (model APM-821) with a flow rate of 1 Lpm was used for the SPM measurement.	SO_2, NO_2, and SPM levels were notably elevated in areas where solid fuels such as coal, wood, kerosene, and cow dung cakes were used for cooking purposes.	No
Three schools in Chhattisgarh[73] were selected to estimate the respirable particulate matter (RPM) levels.	For schools situated downwind of a steel plant, ambient outdoor pollution is the primary source of particulate matter. Schools near National Highways are predo -minantly influenced by indoor sources and road traffic dust	-

Discussion

Addressing poor indoor air quality in schools is crucial, as neglecting this issue can exacerbate health concerns. A proactive approach is vital for safeguarding the well-being of students and staff. The existing studies reveal that occupants in India are adapted to a temperature range of 17 - 33.7°C, despite varying climates. In non-ventilated classrooms, temperature adaptation occurs through changes in clothing, fan usage, window operation, and hydration.

Indoor air quality studies across India identify particulate matter, CO, VOCs, NO_2, SO_2, ozone, and biological agents as common pollutants in school environments. Sampling units are typically positioned 1 meter above the floor, opposite the blackboard, to measure pollutants at students' breathing zones. Case studies consistently highlight the profound influence of outer environments on the quality of indoor air. A significant majority of these studies conclude that schools situated near dense traffic areas exhibit substantially higher pollutant concentrations compared to those located in residential areas. Thus, roads with heavy traffic, children's movements, and poor ventilation rates of the classrooms can be considered as the major indoor air quality problems in schools. Poor air quality can lead to increased illness, absenteeism, and respiratory issues.

The absence of globally adopted codes and Indian standards for optimal Environmental Quality of Indoor environments in non-air conditioned school classrooms highlights a critical knowledge gap. To address this, further scientific research is necessary to establish accurate comfort limits and develop a more exact, standardized procedure that accounts for diverse climatic conditions.

Moreover, the impact of air pollution on schools warrants further investigation. Prioritizing school infrastructure upgrades can significantly enhance the learning environment, reduce disease transmission, and promote student well-being and academic performance.

Additionally, acoustic and visual comfort in schools have been overlooked, despite their importance in optimizing student performance and productivity. The development and implementation of standardized protocols and recognized models for assessing multiple comfort factors are vital for optimizing school IEQ. Therefore, developing generic methodologies and guidelines for aural and visual comfort is a pressing need.

Conclusion

This systematic review conducts a thorough investigation of existing studies on indoor environmental quality (IEQ) in Indian school classrooms employing natural ventilation strategies. The analysis concentrates on five crucial IEQ dimensions: thermal well-being, indoor air pollution, airflow rates, visual ergonomics, and aural comfort. India's ventilated school buildings remain an understudied context within the broader field of IEQ research, underscoring the importance of localized investigations.

The study points out that indoor air quality is a critical aspect that needs to be carefully considered and addressed at the design and planning stage, even before construction begins. Proactive planning and incorporation of good ventilation design, material selection, and other strategies can help prevent indoor air quality issues, ensuring a healthier indoor environment from the outset. The paper highlights the scarcity of research on indoor air quality in Indian school buildings, emphasizing the need for urgent attention to this critical issue. The available studies underscore the presence of poor indoor air quality, which can have severe implications for the health, well-being, and academic performance of students. The review also identifies significant knowledge gaps, including the lack of standardized protocols for monitoring indoor air quality and the need for studies examining the influence of climate, air pollution, and ventilation strategies on indoor air quality. To address these gaps, future research should prioritize comprehensive and longitudinal studies, incorporating multidisciplinary approaches to inform evidence-based policies and practices that promote healthier indoor environments in Indian schools.

Acknowledgement

The authors are thankful to the Registrar, University of Kerala for providing the library facilities for this study. Also acknowledge the Head of the Department of Environmental Sciences, Dr. Sabu Joseph, Professor for the help rendered during the study period.

Funding Sources

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Conflict of Interest

The author(s) do not have any conflict of interest.

Data Availability Statement

This statement does not apply to this article.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required

Author Contributions

- **Niyathi Vijay:** Conceptualization, Methodology, Data collection, Analysis, Writing- Original Draft.
- **Dr. Jaya Divakaran Sarasamma:** Supervision-Review and Editing.

References

1. Agarwal, N., Nagendra, S.S. Modelling of particulate matter distribution inside the multilevel urban classrooms in a tropical climate for exposure assessment. *Building and Environment*.2016;102:73-82.
2. Karar, K., Gupta, A. K., Kumar, A., and Biswas, A. K. Seasonal variations of PM10 and TSP in residential and industrial sites in an urban area of Kolkata, India. *Environ. Monitor.Assess.*2006; 118:369–381.
3. Wolf, M. J, Emerson, J. W., Esty, D. C., de Sherbinin, A., Wendling, Z. A. Environmental Performance Index Report. New Haven, CT: Yale Center for Environmental Law & Policy. 2022; 1:67-77.
4. Census of India (2011). Census of India, Government of India, Office of the Registrar General and Census Commissioner, New Delhi.
5. Smith KR, Mehta S. The burden of disease from indoor air pollution in developing countries: comparison of estimates. *Int J Hyg Environ Health* 2003; 206:279-289.
6. Chithra, V.S., and Shiva Nagendra, S.M. A review of scientific evidence on indoor air of school building: pollutants, sources, health effects, and management. *Asian journal of Atmospheric Environment.* 2018; 12 (2):87-108.
7. Christine Oliver, and Bruce W. Shackleton. The Indoor Air We Breathe: A Public Health Problem of the '90s. *Public Health Reports.* 1998;113(5):398–409.
8. The Hindu (9 October, 2022). Investing in indoor air quality improvements in schools will reduce COVID-19 transmissions and help students learn.
9. Oeder, S., S. Dietrich, I. Weichenmeier, W. Schober, G. Pusch, R.A. Jçrres, R. Schierl, D. Nowak, H. Fromme, H. Behrendt, and J.T.M. Buters. Toxicity and elemental composition of particulate matter from outdoor and indoor air of elementary schools in Munich, Germany. Indoor Air.2012; 22:148–158.
10. Lee, S.C., H. Guo, W.M. Li, and L.Y. Chan. Inter-comparison of air pollutant concentrations in different indoor environments in Hong *Kong. Atmos. Environ.* 2002;36:1929–1940. doi:10.1016/S1352-2310(02)00176-0
11. Mazaheri, M., Reche, C., Rivas, I., Crilley, L.R., Álvarez- Pedrerol, M., Viana, M., Tobias, A., Alastuey, A., Sunyer, J., Querol, X., Morawska, L. Variability in exposure to ambient ultrafine particles in urban schools: Comparative assessment between Australia and Spain.*Environment International.* 2016; 88, 142-149.
12. Van der Zee, S.C., Strak, M., Dijkema, M.B.A., Brunekreef, B., Janssen, N.A.H. The impact of particle filtration on indoor air quality in a classroom near a highway. *Indoor Air* 2016. doi:10.1111/ina.12308
13. Demirel, G., Özden, Ö., Döğeroğlu, T., Gaga, E.O. Personal exposure of primary school children to BTEX, NO2, and ozone in Eskişehir, Turkey: Relationship with indoor/outdoor concentrations and risk assessment. *Science of The Total Environment.* 2014; 473, 537-548.
14. Buonanno, G., Fuoco, F.C., Morawska, L., Stabile, L. Airborne particle concentrations at schools measured at different spatial scales. *Atmospheric Environment.* 2013;67: 38-45.
15. Venu Shree, Bhanu M. Marwaha and Pamita

Awasthi. Indoor air quality (IAQ) investigation in primary schools at Hamirpur (India).*J. Indian Chem. Soc.* 2019b;96:1455-1460.

16. Mahima Habil and Ajay Tanejaa. Children's Exposure to Indoor Particulate Matter in Naturally Ventilated Schools in India, *Indoor Built Environ.* 2011;20(4):430–448
17. Raysoni, A.U., Stock, T.H., Sarnat, J.A., Montoya Sosa, T., Ebelt Sarnat, S., Holguin, F., Greenwald, R., Johnson, B., Li, W.W. Characterization of traffic-related air pollutant metrics at four schools in El Paso, Texas, USA: Implications for exposure assessment and siting schools in urban areas. *Atmospheric Environment.* 2013;80:140-151.
18. Zwoździak, A., Sówka, I., Krupińska, B., Zwoździak, J., Nych, A. Infiltration or indoor sources as determinants of the elemental composition of particulate matter inside a school in Wrocław, Poland. *Building and Environment.* 2013;66:173-180.
19. Tran, D.T., Alleman, L.Y., Coddeville, P., Galloo, J.C. Elemental characterization and source identification of size resolved atmospheric particles in French classrooms. *Atmospheric Environment.* 2012;54:250-259.
20. Guo, H., Morawska, L., He, C., Zhang, Y.L., Ayoko, G.,Cao, M. Characterization of particle number concentrations and PM2.5 in a school: influence of outdoor air pollution on indoor air. *Environmental Science and Pollution Research.* 2010;17(6): 1268-1278.
21. Goyal, R. and Khare, M. Indoor-outdoor concentrations of RSPM in classroom of a naturally ventilated school building near an urban traffic roadway. *Atmos Environ*., 2009;43 : 6026–6038.
22. Yang, W., Sohn, J., Kim, J., Son, B., Park, J. Indoor air quality investigation according to age of the school buildings in Korea. *Journal of Environmental Management*. 2009;90(1): 348-354.
23. Lee, S.C., Chang, M. Indoor and outdoor air quality investigation at schools in Hong Kong. *Chemosphere.* 2000; 41(1): 109-113.
24. Agarwal, N., Nagendra, S.S. Modelling of particulate matters distribution inside the multilevel urban classrooms in tropical climate for exposure assessment. *Building and Environment.* 2016; 102: 73-82.
25. Chithra, V.S. and Shiva Nagendra, S.M. Indoor air quality investigations in a naturally ventilated school building located close to an urban roadway in Chennai, *India. Build. Environ.* 2012;54:159–167.
26. Diapouli, E., Chaloulakou, A., Mihalopoulos, N., Spyrellis, N. Indoor and outdoor PM mass and number concentrations at schools in the Athens area. *Environmental Monitoring and Assessment.* 2008;136(1-3):13-20.
27. Fromme, H., Diemer, J., Dietrich, S., Cyrys, J., Heinrich, J., Lang, W., Kiranoglu, M., Twardella, D. Chemical and morphological properties of particulate matter(PM10, PM2.5) in school classrooms and outdoor air. *Atmospheric Environment.* 2008;42(27):6597-6605.
28. Stranger, M., Potgieter-Vermaak, S.S., Van Grieken, R. Characterization of indoor air quality in primary schools in Antwerp, *Belgium. Indoor Air.* 2008; 18(6): 454-463.
29. Poupard, O., Blondeau, P., Iordache, V., Allard, F. Statistical analysis of parameters influencing the relationship between outdoor and indoor air quality in schools. *Atmospheric Environment* 2005; 39(11): 2071-2080
30. WHO. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: global update 2005: summary of risk assessment. World Health Organization, Geneva, Switzerland.
31. ASHRAE. 1992. Thermal environmental conditions for human occupancy. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA. Standard 55.
32. US EPA (2011). IAQ and Climate readiness. U.S. Environmental Protection Agency, Washington, DC.
33. Nishant Raj Kapoor, Asok Kumar, Chandan Swaroop Meena, Anuj Kumar, Tabish Alam, Nagesh Babu Balam and Aritra Ghosh. A Systematic Review on Indoor Environmental Quality in Naturally Ventilated School Classrooms: A Way Forward. Hindawi-*Advances in Civil Engineering,* 2021.
34. Nishant Raj Kapoor, Asok Kumar, Tabish Alam, Anuj Kumar, Kishor S. Kulkarni and Paolo Blecich. A Review on Indoor Environment Quality of Indian School Classrooms. *Sustainability.* 2021;13, 11855: 1-43.

35. Raj, N.; Kumar, A.; Kumar, A.; Goyal, S. Indoor Environmental Quality: Impact on Productivity, Comfort, and Health of Indian Occupants. In Proceedings of the International Conference on Building Energy Demand Reduction in Global South(BUILDER'19), New Delhi, India, 13–14 December 2019; 1–9.
36. CPCB (2014). Indoor air pollution: monitoring guidelines. http://www.cpcb.nic.in/Proto-Ind_AirPollution_June2014.pdf. Last accessed on 15 January 2023.
37. Arun Sharma, Radha Goyal and Richie Mittal (eds.). Indoor Environmental Quality, *Lecture Notes in Civil Engineering*. 2020; 60: 1-8.
38. Hopkins, C. Sound insulation, Butterworth-Heinemann, Imprint of Elsevier, Oxford. 2007.
39. ANSI/ASHRAE. Thermal Environment Conditions for Human Occupancy. *Standard* 55.2004.
40. Liang,H.H.,Chen,C.P.,Shih,W.M.,Lo,S.C. and Liao,H.,Y. "Satisfaction of occupants toward indoor environment quality of certified green office buildings in Taiwan," *Building and Environment,* 2014; 72: 232–242.
41. TERI. Guidelines for optimum visual comfort derived from key performance parameters New Delhi: *The Energy and Resources Institute*. 2012;3-4.
42. Pratima Singh and Renu Arora. Indoor Air Quality I Schools. International Journal of Engineering and Scientific Research. 2018;6(3):139-144.
43. Naveen K. Khambadkone, Prabhukumar Madhumati and Mavukere Nanjundappa Ranganath. Thermal comfort evaluation in architectural studio classrooms – A summer study in a warm to moderate Indian climate. *Indoor and Built Environment.* 2022;31(9): 2331–2365
44. Betty Lala., Murtyas, S., & Hagishima, A. Indoor thermal comfort and adaptive thermal behaviors of students in primary schools located in the humid subtropical climate of India. *Sustainability.* 2022;14(12): 7072.
45. Subhashini, S. and Thirumaran, K. CFD simulations for examining natural ventilation in the learning spaces of an educational building with courtyards in Madurai. Building Serv. *Eng. Res. Technol.*, 2019; 41(4):466–479.
46. Jindal, A. Investigation and analysis of thermal comfort in naturally ventilated secondary school classrooms in the composite climate of India. Archit. *Sci. Rev.* 2019;62:466–484.
47. Jindal, A. Thermal comfort study in naturally ventilated school classrooms in composite climate of India. *Build. Environ.* 2018;142:34–46.
48. Padmavathi, P. and Sireesha. (2015). Indoor Air Quality in Schools –An Architectural Perspective. *International Journal of Engineering and Management Research.* 2015;5(1): 31-36.
49. Vittal R and Gnanasambandam S. Perceived thermal environment of naturally ventilated classrooms in India. *Create Space.* 2016; 3: 149–165.
50. Asit Kumar Mishra and Maddali Ramgopal. A Thermal comfort field study of naturally ventilated classrooms in Kharagpur, India. Building and Environment. 2015;92: 396-406.
51. Asit, K.M. and Maddali, R. Thermal comfort in undergraduate laboratories- A field study in Kharagpur, India. *Building and Environment.* 2014;71: 223-232.
52. Plabita Baruah, Manoj Kumar Singh and Sadhan Mahapatra. 2014. Thermal Comfort in Naturally Ventilated Classrooms. 30th International Plea Conference. 16-18 December, CEPT University, Ahmedabad.
53. Goyal, R., Khare, M., Kumar, P. "Indoor Air Quality: Current Status, Missing Links and Future Road Map for India", *Journal of Civil & Environmental Engineering.* 2012; 2 (4):1-5.
54. Central Pollution Control Board Annual Report 2015-16. Ministry of Environment, Forest & Climate Change. Prepared & Published by: PR Division, *Central Pollution Control Board, Delhi.* Website: www.cpcb.nic.in
55. Maroni, M., Seifert, B., Lindvall, T. (Eds.), 1995. Indoor Air Quality a Comprehensive Reference Book. Elsevier, Amsterdam.U.S. EPA (2011) IAQ and climate readiness. U.S. Environmental Protection Agency, Washington, DC.
56. Jones, A.,P. Indoor Air Quality and Health. Atmospheric Environment. 1999;33:4535-4564.
57. Sneha Asrani and Dipsha Shah. Assessing the indoor air quality of municipal schools

in Ahmedabad. 2020. Technologies for sustainable development- Mahajan, Patel and Sharma (eds). *Taylor & Francis group, London.* ISBN 978-0-367-33737-7.

58. Venu Shree, Bhanu M. Marwaha and Pamita Awasthi. Indoor Air Quality Investigation at Primary Classrooms in Hamirpur, *Himachal Pradesh, India. Hydro Nepal.* 2019a;24:45-48.
59. Sachin Gupta. Agriculture Crop Residue Burning and Its Consequences on Respiration Health of School-Going Children Global Pediatric Health. 2019; 6: 1–8.
60. Sandhiya Jayakumar and Michael G Apte. IOP Conf. Series: *Materials Science and Engineering.* 2019. 609 032046.
61. Akshay Arun Bhalekar and Sneha R. Assessment of indoor & outdoor air Quality of school buildings located Close to urban roadway in Manipal(Karnataka). International *Journal of Civil Engineering and Technology (IJCIET).* 2018;9(7):61–73.
62. M. Kiranmai Reddy and T. Srinivas. Mold Allergens in Indoor Play School Environment. *International Conference on Recent Advancement in Air Conditioning and Refrigeration,* RAAR 2016, 10-12 November 2016, Bhubaneswar, India. Energy Procedia. 2017;109:27 – 33.
63. Pratima Singh, Renu Arora and Radha Goyal. (2017). Indoor air quality assessment in selected schools of Delhi-NCR, India. *International Journal of Applied Home Science.* 2017;4 (5&6): 389-394.
64. Arindam Datta, R. Suresh, Akansha Gupta, Damini Singh and Priyanka Kulshrestha. “Indoor air quality of non-residential urban building in Delhi”, *International Journal of Sustainable Built Environment.* 2017;6: 412–420.
65. Goel, S.; Patidar, R.; Baxi, K.; Thakur, R.S. Investigation of particulate matter performances in relation to chalk selection in classroom environment. *Indoor Built Environ.* 2015;26:119–131.
66. Mahima Habil, David D, Massey and Ajay Taneja. Exposure from particle and ionic contamination to children in schools of India. *Atmospheric Pollution Research.* 2015;6:719-725.
67. Naga Madhan Mohan, Ramprasad & Maruthi Y.,A. Microbiological air quality of indoors in primary and secondary schools of Visakhapatnam, *India.* 2014;3(8): 2319-7706.
68. Chithra, V.S., Nagendra, S.M.S. Characterizing and predicting coarse and fine particulates in classrooms located close to an urban roadway. *J. Air Waste Manag. Assoc.* 2014;64: 945–956.
69. Deepanjan, M, Gajghate, P.,P. and Chalapati, C.,V.,R. Assessment of Airborne Fine Particulate Matter and Particle Size Distribution in Settled Chalk Dust during Writing and Dusting Exercises in a Classroom. *Indoor Built Environ.* 2012;21(4):541–551.
70. Radha Goyal and Mukesh Khare. Indoor air quality modeling for PM10, PM2.5, and PM1.0 in naturally ventilated classrooms of an urban Indian school building. *Environmental Monitoring and Assessment,* 2011; 176: 501-516
71. Neelima M. Gadkari. Study of personal–indoor–ambient fine particulate matters among school communities in mixed urban–industrial environment in India. *Environ Monit Assess.* 2010;165:365–375.
72. Raj Kumar, MD, Jitendra K. Nagar, PhD, Harsh Kumar, MA, Alka S. Kushwah, MA, Mahesh Meena, MBBS, Pawan Kumar, MBBS, Neelima Raj, PhD, M. K. Singhal, MD, and S. N. Gaur, MD. Indoor Air Pollution and Respiratory Function of Children in Ashok Vihar, Delhi: An Exposure-Response Study. *Asia-Pacific Journal of Public Health.* 2008;20(1): 36-48.
73. Nilima Gadkari and Shamsh Pervez. Source apportionment of personal exposure of fine particulates among school communities in India. *Environ Monit Assess.* 2008;142:227–241.