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Article

Assessment on Sources of PM & TVOCs in School Buildings and Effects on Health of Student: A Systematic Review

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Abstract: Ensuring sustainable indoor environments in school buildings is essential for safeguarding student health and well-being. Indoor air pollution from particulate matter (PM) and total volatile organic compounds (TVOCs) has emerged as a critical issue exacerbated by modern building materials and occupant behaviors. The rising prevalence of respiratory illnesses among students highlights the urgent need for improved indoor air quality (IAQ) standards, particularly as climate change influences air pollution dynamics. This review explores the sources of PM and TVOCs in elementary and primary school buildings and their health implications through a systematic review of literature published between 2010 and 2024. It also considers studies conducted during the COVID-19 pandemic when indoor air conditions shifted due to online learning periods. Out of 325 identified articles, the predominant sources of TVOCs were found to be cleaning activities, chemicals, furniture, and occupant behavior. PM sources encompassed classroom activities, building attributes, instructional materials, and external factors. The findings reveal that average $PM_{2.5}$ and PM_{10} concentrations frequently exceed recommended health thresholds, posing risks such as reduced lung function, respiratory distress, and a higher prevalence of asthma among students. This review underscores the necessity of integrating IAQ management into sustainable building practices and climate adaptation strategies. By emphasizing long-term health monitoring, air dynamics analysis, and pollutant exposure assessments, it advocates for proactive policies to enhance school environments to ensure resilience against future climate-related air quality challenges.

Keywords: indoor air quality; IAQ; particulate matter; volatile organic compounds; school buildings

1. Introduction

Indoor air quality (IAQ) is a critical factor influencing human health, with poor IAQ linked to respiratory diseases, cardiovascular conditions, and various chronic health issues. In general, individuals spend much of their daily time indoors, up to 80–90%, exposing them to IAQ-related symptoms and risks (Ferreira and Barros, 2022, Wei et al., 2022). High levels of indoor pollutants such as volatile organic compounds (VOCs), particulate matter (PM), inorganic compounds, physical chemicals, and biological elements can have detrimental impacts on the human body (Tran et al., 2020). Recent studies have shown a rise in contaminants levels over the years in both qualitative and quantitative IAQ variations (Kempton et al., 2022, Wei et al., 2022). Piscitelli et al. (2024) stated that issues affecting the cleanliness of the air in buildings such as homes, workplaces, and schools are central to indoor air quality concerns. Poor IAQ is often associated with the presence of chemical, physical, and biological indoor pollutants.

Among the general population, susceptible groups such as infants, young people, the elderly, or

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individuals with chronic respiratory or cardiovascular conditions face a greater risk of poor IAQ (Mata et al., 2022a). Particularly, children who spend nearly 30% of their time inside school buildings, and 70% of that time within classrooms on learning days, exhibit heightened susceptibility to inadequate IAQ (Azoulay et al., 2025). This vulnerability stems from their developmental stage, during which they inhale a proportionally higher volume of air relative to their body size (Konstantinou et al., 2022, Tran et al., 2023). Additionally, developing immune systems and organs make young students highly susceptible to poor IAQ (Bungau et al., 2024). Schools as integral parts of urban infrastructure should provide safe and healthy indoor environments to support student well-being and cognitive performance. However, increasing concerns about IAQ in educational settings highlight the urgent need to address indoor air pollutants, particularly as climate change intensifies air pollution variability. Recently, researchers have focused more on IAQ to improve the comfort, health, and well-being of building occupants, especially students in schools (Megahed and Ghoneim, 2021).

Although there are previous studies carried out by many researchers on IAQ in school buildings, there is less concern about the sources of indoor air pollutants and the effects on the health of student in primary and elementary schools. Additional research is warranted to delineate the underlying factors contributing to indoor air pollution, while concurrently assessing the extent of exposure and resultant health implications for students within educational facilities (De Gennaro et al., 2013, Ferreira and Cardoso, 2013). Another study emphasized the importance of monitoring health symptoms in relation to specific pollutant concentrations (Pegas et al., 2011a). Mohammadyan et al. (2017) further corroborated these findings, conducting a comprehensive analysis of indoor air pollutant origins, encompassing particulate matter and VOCs. Based on Madureira et al. (2016) findings, analyzing the health risks on students especially with bigger sample sizes and sampling points in the school environment is needed. Moreover, Li et al. (2020) concluded that more research on the IAQ in different cities and seasonal conditions are needed to broad environmental conditions. In addition, Peng et al. (2017) confirmed about conducting investigations to identify the association between seasonal factors and IAQ. Therefore, identifying source contributions in school buildings is crucial to reducing the exposure of students to indoor pollutants (Bennett et al., 2019).

People frequently focus on resolving the symptoms of poor IAQ without addressing the underlying cause, which is indoor air pollutants. There is a dearth of evidence from prior research focusing on the sources of indoor air pollutants in the school buildings. The information obtained from previous research was not clear enough to point out the key sources of indoor air pollutants. Reducing or eliminating sources of indoor air pollutants can help minimize health problems (Mata et al., 2022b). Thus, this study aimed to identify the sources of PM & TVOCs in the school buildings. While more investigations were conducted on IAQ buildings such as schools, offices, and hospitals, there are fewer concerns on the impact of respiratory particulates and physical parameters of IAQ on the health of students (Sadrizadeh et al., 2022). The health risks on the students who are vulnerable to poor IAQ in schools especially in different seasons were urged by previous studies. Hence, this study also focused analyzing the impact of respiratory particulates and physical parameters of IAQ on the health of students in the school buildings. The essence of this study was on the sources PM & TVOCs and the impact on the health of the students in the elementary and primary school buildings. For this purpose, a systematic review was carried out for relevant articles in the existing scientific database from 2010 to 2024. A systematic review approach was adopted to consolidate findings across diverse studies, identify consistent patterns, highlight research gaps, and ensure a comprehensive and unbiased synthesis of evidence related to PM and TVOCs exposure in primary schools.

The objectives of this study are to identify the main sources of $PM_{2.5}$, PM_{10}, and TVOCs in primary and elementary school buildings, to evaluate the concentrations of these pollutants reported in school environments and to analyze the impact of IAQ parameters on the health outcomes of students. The remainder of this paper is organized as follows: Section 2 describes the materials and methods, including the search strategy, inclusion and exclusion criteria, and study selection process. Section 3 presents the results and discussion, focusing on sources of indoor pollutants, pollutant concentrations, and associated health impacts. Section 4 concludes the study by summarizing key findings and providing recommendations for improving indoor air quality management in primary schools.

2. Material and Methods

2.1. Data Source

In this systematic review, systematic research was done to identify the sources of PM & TVOCs and to analyze the impact on the health of students in the primary and elementary school buildings. The data sources were obtained from various possible scientific databases available on the internet for published articles in Scopus, Web of Science, Google, Pubmed, Cochrane, and Embase search engine for in the past 14 years, within the period of 2010 to 2024. Various combinations of the following keywords: ‘indoor air quality’, ‘IAQ, ‘PM’, ‘TVOCs’, ‘student’, ‘educational building’, ‘health issue’, ‘sources of indoor air pollutant’, ‘primary school’, ‘elementary school’, ‘health risk’ and ‘impact of indoor air quality on health on students’ were used as searching strategy. To narrow our findings, the Cochrane Handbook for Systematic Reviews of Interventions' pre-formulated very sensitive search filters (database-specific) was employed (Higgins et al., 2011). Following the screening of titles and abstracts, the bibliographies of all publications included were searched for additional investigations. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards were followed in this study (Liberati et al., 2009). This study is based solely on the analysis of publicly available data from existing literature. No direct research involving human or animal subjects was conducted. Therefore, ethical approval and informed consent were not required.

2.2. Inclusion and Exclusion Criteria

Each article was reviewed within the scope of this study research. Firstly, screening was carried out by reviewing the title of the published articles in the databases, and a total of 325 articles were identified. Amongst all the articles, after reviewing for the keywords, abstract, and contents, any possible articles were only included if the studied population was the students in the school building which included the elementary school, preschool, primary school, and secondary school. However, in the real situation, from the screening process based on inclusion and exclusion criteria, the articles of preschool and secondary school students as studied population were very limited. Thus, to narrow down the scope, the sample population in this study only focused on the primary and elementary school students. The inclusion criteria comprised studies that investigated IAQ parameters ($PM_{2.5}$, PM_{10}, TVOCs) in primary and elementary school environments, reported measured pollutant concentrations, or analyzed health outcomes among students. Exclusion criteria were studies focusing on preschool, secondary school, university populations, pollutants unrelated to PM or TVOCs, or studies lacking sufficient quantitative data. The general flow diagram of study selection for the systematic review is shown in Figure 1.

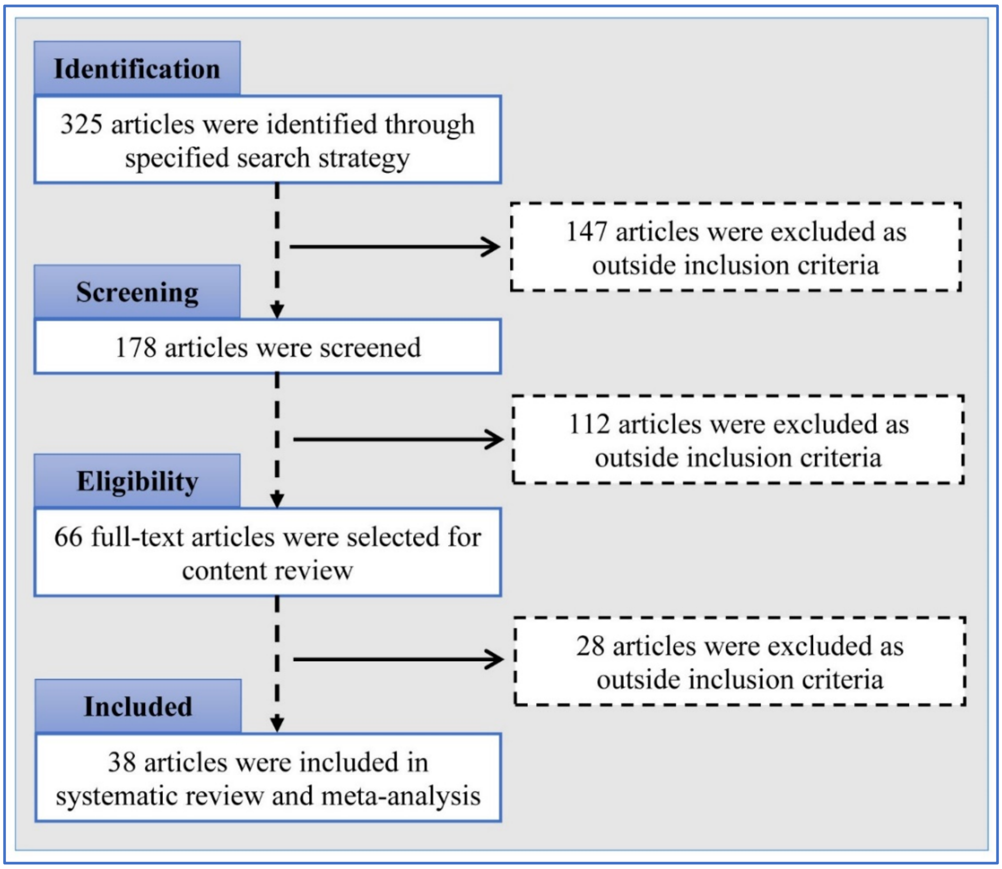

Figure 1. Study selection for the systematic review of PM & TVOCs sources in primary school buildings and their effects on the health of student based on PRISMA guidelines.

In the study to identify the PM & TVOCs sources of the school buildings, published articles were reviewed and included if the indoor sources of indoor air pollutants could be identified. However, due to lack of information from the articles for various IAQ parameters, the parameters studied were scoped down which only focused on the particulate matters ($PM_{2.5}$, PM_{10}) and TVOCs. There was a total of 17 studies that fulfilled the inclusion and exclusion criteria which had the potential to be further analyzed in the qualitative synthesis, which is summarized in Table 1. Specifically, 17 studies reported data on $PM_{2.5}$ concentrations, 21 studies reported data on PM_{10} concentrations, and 16 studies reported data on TVOCs concentrations. Several studies contributed data for multiple parameter categories.

Table 1. Seventeen independent published articles from 2010-2024 in the identification of indoor air pollutant sources in the educational school buildings.

Titles	Articles/References
A preliminary study of indoor air quality conditions in Dubai public elementary schools.	(Behzadi and Fadeyi, 2012)
Analysis of the indoor air quality in Greek primary schools.	(Dorizas et al., 2013)
Children exposure to atmospheric particles in indoor of Lisbon primary schools.	(Almeida et al., 2011)
Indoor Air Quality in Naturally Ventilated Italian Classrooms.	(Fuoco et al., 2015)
Indoor air quality investigation of the school environment and estimated health risks: Two-season measurements in primary schools in Kozani, Greece.	(Kalimeri et al., 2016)
Indoor Air Quality in Primary Schools.	(Canha et al., 2012)
Occupancy Implications on Indoor Air Quality (IAQ) In Selected Primary School Classrooms Around Kuantan, Pahang.	(Hazrin et al., 2016)
Sources of indoor air pollution at a New Zealand urban primary school; a case study.	(Bennett et al., 2019)
Source apportionment of CO_2, PM_{10} and VOCs levels and health risk assessment in naturally ventilated primary schools in Porto, Portugal.	(Madureira et al., 2016)
Source apportionment and health risk assessment of PM_{10} in a naturally ventilated school in a tropical environment.	(Mohamad et al., 2016)
Sources of indoor and outdoor $PM_{2.5}$ concentrations in primary schools.	(Amato et al., 2014)
The effect of ventilation on air particulate matter in school classrooms.	(Trompetter et al., 2018)
Variations and characteristics of particulate matter, black carbon and volatile organic compounds in primary school classrooms.	(Li et al., 2020)
Indoor air quality and the associated health risk in primary school buildings in Central Europe - The InAirQ study	(Szabados et al., 2021)
Evaluation of air quality in indoor and outdoor environments: Impact of anti-COVID-19 measures	(Ninyà et al., 2022)
Interventions for improving indoor and outdoor air quality in and around schools	(Rawat and Kumar, 2023)
The effect of post-COVID-19 ventilation measures on indoor air quality in primary schools	(Eichholtz et al., 2024)
Total Articles	**17**

On the other hand, to study the impact of physical and chemical parameters of IAQ on the health of students in the school buildings, published articles were reviewed and included if data on the physical (temperature, relative humidity and air velocity), chemical (TVOCs, $PM_{2.5}$, and PM_{10}) and biological (airborne bacteria) parameters were given. However, not all data for each IAQ parameter were provided in each article and yet the statistical value and units of those parameters were not standardized. Thus, the scope of the parameters in this study was mainly focused on the physical (temperature and relative humidity) and chemical parameters. The most significant inclusion criterion was the data of IAQ parameters which was used to indicate the pollutant concentrations in the primary and elementary school environments. After standardizing the statistical value and units of the chemical parameters for each eligible article, only mean value and standard deviation (SD) of the parameters were extracted. A total of 21 studies were considered.

2.3. Data Extraction

In the study to identify the sources of indoor air pollutants in the school buildings, for every eligible study, the information about the title of the article, the name of the author, the year of publication, the types of indoor air pollutants, and their respective sources were extracted and tabulated. For the second part, data were extracted and tabulated in two different tables. Information about the article and author, country, season, site characteristics, school ventilation, and number of schools were extracted and tabulated for study characteristics. While in primary schools around the globe, data on the IAQ and their concentration levels (mean ± SD), parameters and their respective units, as well as the author and year were extracted and tabulated. In addition, types and sources of pollutants were extracted and tabulated with a total of six studies were considered. The types of pollutants for both $PM_{2.5}$ and PM_{10} and their respective sources were tabulated together. However, the sources which contribute to each pollutant was identified separately through this study. A total of 16 studies were considered.

2.4. Data Analysis

For the qualitative synthesis, the mean values of the PM & TVOCs were analyzed by comparing the highest and lowest concentration levels amongst the published articles. The data analysis involved several steps. First, eligible studies were selected based on inclusion and exclusion criteria. Second, numerical data such as mean values and standard deviations for PM2.5, PM10, and TVOCs were extracted from the articles. Third, the extracted values were organized into tables to summarize pollutant concentrations and reported health symptoms. Fourth, the mean values were compared against international and national indoor air quality standards to assess exceedances. Fifth, for studies reporting health risks, odds ratios (OR) were extracted or calculated where possible and a forest plot was constructed to visualize the association between pollutant exposure and asthma outcomes. The overall strategy combined qualitative synthesis (descriptive analysis) and quantitative comparisons where data allowed.

This comparison enabled the identification of factors that might influence the concentration levels of PM and TVOCs parameters. Details including article information, PM and TVOCs parameters, and reported health symptoms were tabulated to assess the impact of indoor air pollutants on the health of primary and elementary school students. A total of twelve article were considered. The most reported health symptoms of the students were also identified. For the quantitative synthesis, data from nine studies were included. The statistical mean value of the parameters of the particulate matters ($PM_{2.5}$ and PM_{10}) was extracted from each eligible article and was plotted. The mean values from each article were compared against the recommended threshold establish by three major standards :the United States Environmental Protection Agency (NAAQS/USEPA) (NAAQS, 1990), World Health Organization 2005 (WHO guidelines) (Organization, 2006), and Industry Code of Practice on Indoor Air Quality 2010 by Department of Occupational Safety and Health, Malaysia (ICP-IAQ/Malaysia) (Safety and Health, 2010), which are shown in plotted figures. By comparing the mean value with these standards, the concentrations of the particulate matters which caused an impact on the health of primary and elementary school students were determined.

A forest plot was constructed to compare three studies investigating the association between indoor air quality (IAQ) and health risks among primary and elementary school students. However, this study focused solely on asthma symptoms, the most prevalent health issue documented in the literature. The choice between risk ratio (RR) and odds ratio (OR) depended on the study type; RR could not be calculated for case-control trials due to the lack of available data on the total number of exposed individuals, necessitating the use of OR. Conversely, in cohort studies, both RR and OR could be employed since the number of exposed individuals was ascertainable (Ranganathan et al., 2015). In this analysis, OR was utilized to gauge the strength of association between exposure and outcome across the three studies, reflecting the data availability.

While this systematic review followed PRISMA guidelines to ensure transparency, certain methodological limitations and potential biases should be acknowledged. Selection bias may exist as only peer-reviewed studies from major databases were included, potentially overlooking insights from grey literature. Publication bias could also influence the findings, as studies with significant results are more likely to be published. Measurement bias may occur due to differences in IAQ assessment methods, sampling seasons, and school infrastructure across studies. Additionally, reporting bias could be present if incomplete data on IAQ parameters were provided. These limitations were carefully considered during the analysis and interpretation of results.

3. Results and Discussion

3.1. Sources of PM & TVOCs in Primary Schools

Indoor air pollutants in primary schools originate from various sources, largely influenced by the physical characteristics of enclosed spaces such as laboratories, libraries, and art rooms. The composition of the indoor air pollutants is quite complex which mainly depends on different microenvironments that may cause a variation on their concentration levels and their sources. While indoor sources are significant, outdoor sources also contribute substantially to indoor pollutant levels. In this study, the sources of indoor air pollutants from the cross-sectional studies are mainly focused on the TVOCs, $PM_{2.5}$, and PM_{10} with their major sources in primary schools are summarized in respective tables and discussed in the following subsections.

3.1.1. Sources of Total Volatile Organic Compounds (TVOC)

TVOCs are used in scientific literature to represent the total concentration of all measurable indoor VOCs (Wallenius et al., 2022). The sources of TVOCs in the primary school buildings from six studies are summarized in Table 2. Kalimeri et al. (2016) investigated the VOC concentration levels in terms of formaldehyde, benzene, trichloroethylene, pinene, limonene which was tested using diffuse samplers in two primary and one kindergarten schools in Kozani, Greece, during both heating and non-heating periods. It was found in their study that the indoor sources of VOCs were the emission from the building materials, while the possible other indoor sources were the products from washing, do-it-yourself, books, stationery, furniture and wall coverings.

Table 2. Sources of TVOCs in primary school buildings.

Sources	Articles/References
Detergent and air freshener spray.	(Behzadi and Fadeyi, 2012)
Marker in whiteboards. Possible indoor sources: -Cleaning items, do-it-yourself things, new and stationary books, furniture, and wall coverings.	(Dorizas et al., 2013)
Indoor sources: -Building material emissions. Possible other sources: -Furniture, cleaning agents, office appliances, personal care items, handicraft products, markers for dry erase, fluid for type-writer correction, toys, and activities of inhabitants.	(Kalimeri et al., 2016)
Ventilation, whiteboard pen, and lower number of cleanings.	(Almeida et al., 2011)
Major sources: - Occupant behavior. - Maintenance or cleaning activities in schools. - High density of occupants. Identified sources: -Floor surface material (PVC/vinyl, linoleum).	(Madureira et al., 2016)
Estimated Sources: - Anthropogenic emissions (emissions from the nearby industrial park or solvent evaporation). - Vehicle exhaust (few main roads and a highway nearby the school campus).	(Li et al., 2020)
Indoor sources: - Solvent in paints, coatings, adhesives, and cleaning agent	(Szabados et al., 2021)
Indoor sources: - Solvent in sanitizer product, and cleaning agent	(Ninyà et al., 2022)

These findings of cleaning products are consistent with Behzadi et al. (2012), who conducted a preliminary inspection in public primary school buildings, using walkthrough inquiry and objective calculation as their techniques into the IAQ conditions of a classroom and found that detergent and air freshener spray were contributors to the high concentrations of TVOCs during certain periods of class activities in schools. Studies from other two researchers found that the maintenance or cleaning activities in schools (Madureira et al., 2016), with a low numbering of cleanings were the sources that contributed to the increase of VOCs (Almeida et al., 2011). Moreover, solvents in sanitizer products and cleaning agents were also identified as indoor sources contributing to elevate VOC levels in school environments (Ninyà et al., 2022). Additionally, previous studies reported that daily use of whiteboards contributed to increased VOC levels, with emissions likely from chalks and whiteboard pens (Almeida et al., 2011, Dorizas et al., 2013).

VOC concentration levels in schools were strongly influenced by occupant activities, behaviors, and high densities, even more than by floor materials such as polyvinyl chloride (PVC or vinyl) and linoleum (Madureira et al., 2016). There were also other possible sources for the VOCs in schools found in several studies such as office supplies, personal care products, art products, dry erase markers, correction fluid for typewriters, and toy products (Kalimeri et al., 2016). Additionally, solvent in paints, coatings, adhesives, and cleaning agents were also significant indoor sources (Szabados et al., 2021). External factors contributing to VOC levels encompass penetration through the ventilation system into indoor space (Canha et al., 2012), as well as anthropogenic emissions, such as those from nearby industrial park or solvent evaporation, and vehicle exhaust from main roads and highway nearby (Li et al., 2020).

Indoor sources have been proposed as the most appropriate contributors to the indoor volume, as the indoor sum exceeds the outdoor amounts, among the sources of both indoor and outdoor TVOC sources (Behzadi and Fadeyi, 2012, Madureira et al., 2016) which could up to ten times higher (Chithra and Nagendra, 2018). This is supported by studies demonstrating higher concentration of formaldehyde and acetaldehyde in school indoor environments compared to outdoor settings (Madureira et al., 2016). Another study indicated that the outdoor environment closely influenced the VOC profile of the classrooms in schools through an inter-comparison analysis conducted between both indoor and outdoor samples (Li et al., 2020). Based on the six reviewed studies, the main sources contributing to high TVOC levels in primary schools were cleaning activities, cleaning products, and furnishings, followed by occupant behaviors and densities.

3.1.2. Sources of particulate matters (PM)

The sources of particulate matters in terms of $PM_{2.5}$ and PM_{10} in primary school buildings from 13 studies are summarized in Table 3. Five studies have established correlations between particulate matter ($PM_{2.5}$ and PM_{10}) and various student activities within classrooms. These activities include the resuspension of particles due to students' movements on carpets, such as walking, chasing, and running, as well as during cleaning routines. Additionally, dust resuspension from materials containing silicon, aluminum, calcium, and iron within classrooms has been identified as a contributing factor (Li et al., 2020, Behzadi and Fadeyi, 2012, Bennett et al., 2019, Hazrin et al., 2017, Kalimeri et al., 2016).

Table 3. Sources of PM in primary school buildings.

Pollutants	Sources	Articles/References
$PM_{2.5}$ and PM_{10}	Re-suspensions from students' activity on carpet.	(Behzadi and Fadeyi, 2012)
$PM_{2.5}$ and PM_{10}	Chalk in blackboard.	(Dorizas et al., 2013)
$PM_{2.5}$	Possible sources: - Products for cleansing, perfumes, personal care products (chemical reactions between ozone and terpenes).	(Almeida et al., 2011)
PM_{10}	Children movement and recreational activities.	(Fuoco et al., 2015)
$PM_{2.5}$ and PM_{10}	Main sources: - Sources of the outdoor climate (e.g., traffic). - Re-suspension of dust from activities of pupils.	(Kalimeri et al., 2016)
$PM_{2.5}$ and PM_{10}	Possible sources: - Activities of the children such as walking and running. Clear sources: -Students doing the cleaning routine.	(Hazrin et al., 2016)
$PM_{2.5}$ and PM_{10}	Indoors primary sources:	(Bennett et al., 2019)

	- Marine aerosol (salt from the sea (magnesium, sulphur, calcium, and potassium). - Dust from the school (silicon, aluminum, calcium, and iron). - Traffic PM (black carbon and sulphur). Minor sources: -Unmeasured components most likely organic matter, fibers, and skin cells. Primary Drivers of PM2.5: -Outdoor pollutant penetration inside and emissions from traffic (i.e. motor vehicle emissions and road dust). Largest Proportion of PM10: -Crustal sources, soil is monitored on shoes from outside and re-suspended during classroom events.	
PM_{10}	Major sources: -Burning of biomass, non-combustion motor vehicles and indoor practices and crustal sources, road dust, sea spray and industrial activity. Potential sources: -Outdoor pollutants from the emissions of vehicle and industrial sources.	(Mohamad et al., 2016)
PM_{10}	Major sources: - Occupant behavior, High density of occupants. - Maintenance or cleaning activities in schools. Mixed sources: - Indoor activities (students particulate matter resuspension). - Potential transport from outside into classroom environment. Potential sources: - Unique features of the school and classrooms (the number of open windows in the heating season, the visible damp spots on the wall or ceiling, and the presence of a laboratory room). - Occupant activities - Degradation or peeling of coating materials in the walls, ceiling (e.g., paint).	(Madureira et al., 2016)
$PM_{2.5}$	Major Indoor sources: - Resuspension soil particles and particles Ca-rich (chalk and building deterioration). - Comprising organic (skin flakes and clothes fibers). Outdoor sources: -Poor building insulation reduced, traffic pollution penetration, secondary sulphate and organic matter, metallurgy, sea spray, and particulate heavy oil combustion. Other sources: -Organic/Textile/Chalk source and mineral source at paved playground schools.	(Amato et al., 2014)
PM_{10}	Sources: -Marine and traffic PM penetration from the outdoors. Major sources: -Crustal sources (soil on footwear from outside and re-suspended during activities).	(Trompetter et al., 2018)
$PM_{2.5}$ and PM_{10}	Major sources: Outdoor. Other possible sources: - Rapid accumulation of indoor pollutants. - Student activities (e.g., chasing and running). - Chalk dust from blackboards.	(Li et al., 2020)

PM_{10}	Sources: -Traffic PM penetration from the outdoors. Major sources: -Vehicle emissions from busy roads or highways. -Resuspension of road dust due to vehicular movement.	(Rawat and Kumar, 2023)

Previous research has indicated that while carpets typically serve as floor coverings to dampen noise in classrooms and other public spaces, it also tend to accumulate dust and solid particles, particularly in high-traffic areas prone to frequent movement by large numbers of people. Consequently, carpets can become difficult to clean effectively in these re-entrained regions (Trompetter et al., 2018). For those schools which used whiteboard and chalks as their teaching materials in classrooms, the chalks contribute to the sources of particulate matters ($PM_{2.5}$ and PM_{10}) (Dorizas et al., 2013, Li et al., 2020). In this issue, research suggested simple ways to eliminate particles produced in-class activities by replacing the chalk with a projector for teaching or whiteboards or other appropriate boards as teaching materials (Peng et al., 2017).

However, a case study by Bennett et al. (2019) for the indoor air pollution sources in an urban primary school in New Zealand found that the indoors primary sources for particulate matters ($PM_{2.5}$ and PM_{10}) were mainly from marine aerosol (sea salt which contained magnesium, sulphur, potassium, and calcium) and traffic PM (black carbon and sulphur). Similarly, Rawat et al. (2023) highlighted that vehicle emissions from busy roads and resuspended road dust were major contributors to PM_{10} levels. Minor sources such as organic matter, fibers, and skin cells also contributed to indoor particulate matter concentrations. Moreover, the researchers identified primary drivers of $PM_{2.5}$ levels through their case study, pinpointing the infiltration of outdoor pollutants into school premises and traffic-related pollution, encompassing emissions from motor vehicles and ground dust, as significant factors. Meanwhile, for PM_{10}, the largest proportion which contributed to this was from crustal origins, soil monitored from outside on student boots, and suspended again during classroom activities. This is similar to the findings from a research by Lee et al. (2015) who identified that the main source of PM was from outdoor, while another possible source was the rapid accumulation of indoor pollutants.

Based on previous studies, there are other sources that contributed to the increasing level of PM concentrations in the primary schools. For $PM_{2.5}$, several possible sources such as cleaning products, perfumes, and products for personal care where there were chemical reactions between ozone and terpenes, were found in the study in primary schools in Libson (Almeida et al., 2011). Another study by Amato et al. (2014) which studied the sources of indoor and outdoor concentrations of $PM_{2.5}$ in Barcelona elementary schools identified that the major indoor sources were from the resuspension of soil particles, calcium-rich (Ca-rich) particles such as degradation of chalk and construction and also the mixed source containing organic (e.g. skin flakes, clothes fibers, and possible condensation of VOCs). While for the outdoor sources, poor building insulation reduced, traffic pollution penetration, secondary sulphate and organic matter, metallurgy, sea spray, and particulate heavy oil combustion were found as the contributors to the concentration of $PM_{2.5}$. Organic, textile, and chalk were also other sources in the classrooms and the presence of minerals sources in schools with paved playgrounds were identified in their study.

For PM_{10}, there are several studies that identified their sources in primary school buildings. Indoor activities of students in the classrooms have been identified as one of the main sources that lead to the increasing concentration level of PM_{10} (Mohamad et al., 2016), which might due to the resuspension of particulate matters from students during the activities (Madureira et al., 2016). It is undeniable that outdoor sources also play a vital role as one of the sources for PM_{10}, such as vehicle pollution and industrial sources of outdoor pollutants have been identified as potential source (Mohamad et al., 2016). The transport of outdoor pollutant into classroom setting has been recognized as mixed source (Madureira et al., 2016), while the infiltration of marine and traffic PM from outdoors into the classrooms, along with the crustal sources where the soil tracked indooron footwear and re-suspended during activities are identified as major sources (Mohamad et al., 2016, Trompetter et al., 2018). A study also found that besides the maintenance and cleaning activities in schools, occupants themselves also play a significant source for PM_{10} in school classrooms in terms of occupant's behavior, high density of occupants, and occupants's activities (Madureira et al., 2016). Additionally, they discovered that unique characteristics of classrooms and schools, such as the number of windows open during the heating season, the presence of noticeable damp spots on walls or ceilings, and the existence of laboratory rooms, serve as potential sources of PM_{10} within school classrooms. Furthermore, the deterioration or peeling of coating materials, such as paint on walls, was identified as another contributing factor.

Another study found that road dust, sea spray and industrial operation, burning of biomass, and motor vehicles without combustion contributed as major sources in the school building with natural ventilation system (Mohamad et al., 2016). However, this differs from the finding in another research which indicated that the outdoor environment possessed no influence to the indoor environment from the finding that indoor concentrations of PM_{10} are far greater than those in the outer levels (Dorizas et al., 2013). A previous study also found that several components have lower air concentrations for the classrooms that faced a street compared to those facing interior patio (Canha et al., 2012). While the movement of children within the school classrooms and recreational activities also identified as sources that increasing the concentration level of PM_{10} (Fuoco et al., 2015). Overall, the key sources of PM are the occupational activities and cleaning activities inside the classrooms, followed by the building characteristics and teaching materials including degradation of paint in wall and ceiling and chalk utilization. Lastly, outdoor sources, particularly traffic emissions, representing the most significant external contributor to indoor PM levels.

Previous research findings indicated that window conditions, including the opening and closing of windows and doors, as well as the adequacy of ventilation systems, significantly influenced indoor PM levels (Dorizas et al., 2013, Jovanović et al., 2014, Li et al., 2020) in which the air purifier posed a great positive impact by reducing the indoor PM concentrations up to nearly 1/3 (Li et al., 2020). A study also suggested that less air movement produced by the ventilation system may lead to the accumulation of some components in the indoor environment (Canha et al., 2012). However, the analysis regarding the correlation between air movement and chemical parameters falls outside the scope of this study, and we have deferred this aspect for future research endeavors.

3.2. Impact of IAQ on Health of Students in Primary Schools

3.2.1. Mean Values of IAQ

Table 4 summarizes research characteristics such as country, season, site, school ventilation, and the number of schools from a total of 22 different studies across the world that focus on IAQ in primary schools. From the 22 studies, there is a total of seven studies conducted in Portugal followed by five studies which are conducted in China. The rest of the studies are conducted in Greece, France, Korea, India, Taiwan, Serbia, Iran, and Malaysia as well. All of the 22 studies are conducted in the four-season countries except for a study conducted in hot and humid all the year in Malaysia by Jalaludin (2014). From the standpoint of site characteristics, it is evident that the majority of studies (20 in total) have concentrated on primary schools located in urban areas, whereas only a small number of studies (2 in total) have been conducted in rural settings.

Table 4. Research characteristics of the selected existing studies on IAQ across the world.

Region	Season	Site Characteristics	School ventilation	Number of school samples	Articles/References
Athens, Greece	Spring	Urban	Natural	9	(Dorizas et al., 2013)
Clermont-Ferrand, France	- Winter (Jan-March) - Spring (March-June)	Urban	Natural	10	(Canha et al., 2016)
Beijing, China	- Winter (Jan) - Autumn (Sep)	Urban	-	1	(Zhang et al., 2019)
Seoul, Korea	Autumn	Urban	Natural	116	(Lee et al., 2015)
Lisbon, Portugal	- Autumn (Nov) - Spring (May)	Urban	Natural	3	(Almeida et al., 2011)
Pune, India	- Winter (Dec-Jan) - Spring (Feb-March) - Summer (April-May)	Urban	Natural	2	(Jan et al., 2017)
Guangzhou, China	- Summer (April-Sep) - Autumn (Oct-Nov)	Rural	-	5	(Gui et al., 2020)
Seoul, Korea	- Spring (June) - Summer (July-Aug) - Autumn (Sep)	Urban	-	9 (3 Groups; 3schools/group)	(Lee et al., 2015)

Porto, Portugal	Winter (Nov)	Urban	Natural	2	(Madureira et al., 2016)
Northern Portugal	-	Urban and Rural	-	-	(Branco et al., 2020)
Coimbra, Portugal	- Fall/Winter - Spring/Summer	Urban and Rural	-	51	(Ferreira and Cardoso, 2014)
Porto, Portugal	Winter	Rural	Natural	20	(Madureira et al., 2015)
Korea	-	Urban	-	82	(Kim et al., 2010)
Kaohsiung City, Taiwan	- Spring (April) - Winter (Feb)	Urban	-	3	(Yen et al., 2020)
Wuhan, China	- Autumn - Winter	Urban	Natural	1	(Cai et al., 2015)
Zajecar, Serbia	Winter	Urban	Natural	1	(Jovanović et al., 2014)
Tai'an, China	(End of Nov-Dec); morning, afternoon	Urban	Natural	4	(Peng et al., 2017)
Porto, Portugal	Winter; Daytime, Nighttime	Urban	Natural	11	(Madureira et al., 2012)
Sari, Iran	- Autumn - Winter - Spring	Urban	Natural	6	(Mohammadyan et al., 2017)
Libson, Portugal	- Spring - Autumn - Winter	Urban	Natural	14 (3 as representative)	(Pegas et al., 2011b)
China	- Spring (May) - Summer (June-Aug) - Autumn (Sep-Nov) - Winter (Dec)	Urban	-	1	(Chen et al., 2018)
Klang Valley, Malaysia	Hot and Humid	Urban	Natural	3	(Jalaludin, 2014)

It has been underscored that the consistency of indoor air concentrations significantly impacts the health outcomes of school children (Jalaludin, 2014). This could be attributed to the adverse effects of urbanization on indoor air quality (Lee et al., 2015), potentially placing elementary school children at heightened risk of exposure to air pollutants from both indoor and outdoor sources. Furthermore, outdoor air pollution is closely linked with urbanization (D'Angiulli, 2018). Other findings from previous researches suggested that urban planning played an important role in reducing the children from being exposure to traffic emissions (Amato et al., 2014, Fuoco et al., 2015) as there were different specific air pollutant sources in different areas that might result in a vary of air pollutants in schools (Zhang et al., 2019). Whereas, for the rural areas, the concentration indoor air quality might be not as higher as those in urban areas as the surrounding buildings and mountains nearby the schools' areas have blocked the dispersion of the air pollutants (Lee et al., 2015).

Previous research has shown that school building characteristics can significantly impact indoor air quality parameters. A study by Yang et al. (2015) found that indoor air concentrations were influenced by surrounding environments and school remodeling, with remodeling activities leading to elevated TVOC levels. This highlights the need to consider the unique characteristics of each elementary school when assessing IAQ (Madureira et al., 2015). According to Table 4, the number of sampled schools across the 22 research studies varies considerably, ranging from 1 to 116. However, the majority of studies opted for a modest number of schools (below 20) as their study population. This selection was primarily influenced by the objectives and scope of the studies, aiming to conduct research within a suitable study population size that would allow the findings to better represent the broader primary school population concerning IAQ topics

Table 5 summarizes the IAQ parameters (VOCs, $PM_{2.5}$, and PM_{10}) and their concentration levels in mean and standard deviation (SD) values for the 22 research studies in primary schools in different regions of the world for the past 14 years.

Table 5. Concentration levels of PM & TVOCs (mean ± SD) in primary schools across the world.

Parameters (unit)	**Extracted Data**	**Articles/References**
VOCs (ppm) **$PM_{2.5}$ (µg/m³)** **PM_{10} (µg/m³)**	VOCs: 14 = 1.0±1.1; 1 = 1.1±1.0; 4 = 1.1±1.0; 3 = 1.5±1.1; 18 = 0.2±0.2; 12 = 6.4±9.0; 2 = 6.6±6.8; 8 = 7.8±6.4; 11 = 15.5±8.7 $PM_{2.5}$: 14 = 20.25±11.43; 1 = 26.88±11.06; 4 = 14.32±6.09; 3 = 20.43±6.52; 18 = 26.42±5.40; 12 = 16.73±5.84; 2 = 21.60±8.97; 8 = 7.17±3.68; 11 = 7.61±2.47 PM_{10}: 14 = 316.23±212.06; 1 = 430.56±219.44; 4 = 223.21±108.25; 3 = 286.09±175.27; 18 = 360.05±214.59; 12 = 192.87±84.69; 2 = 206.85±91.15; 8 = 91.78±63.30; 11 = 92.87±21.97	(Dorizas et al., 2013)
$PM_{2.5}$ (µg/m³)	$PM_{2.5}$ = 23 ± 7	(Canha et al., 2016)
$PM_{2.5}$ (µg/m³) **PM_{10} (µg/m³)**	$PM_{2.5}$: 81.1 ± 35.8 (Heating period) 71.4 ± 34.0 (Non heating period) PM_{10}: 113 ± 47.0 (Heating period) 108 ± 51.3 (Non heating period)	(Zhang et al., 2019)
PM_{10} (µg/m³) **TVOCs (µg/m³)**	PM_{10}: 124 ± 41 TVOCs: 42.3 ± 9.9	(Lee et al., 2015)
$PM_{2.5}$ (µg/m³) **PM_{10} (µg/m³)**	$PM_{2.5}$ = 10 PM_{10} = 30 – 146	(Almeida et al., 2011)
$PM_{2.5}$ (µg/m³) **PM_{10} (µg/m³)**	$PM_{2.5}$ = 135.8 PM_{10} = 263.9	(Jan et al., 2017)
$PM_{2.5}$ (µg/m³) **PM_{10} (µg/m³)**	$PM_{2.5}$ = 39.06 ± 1.12 PM_{10} = 60.95 ± 3.49	(Gui et al., 2020)
$PM_{2.5}$ (µg/m³) **PM_{10} (µg/m³)**	PM_{10}: Group A = 46.4; Group B = 67.2; Group C = 69.7 $PM_{2.5}$: Group A = 26.2; Group B = 43.1; Group C = 45	(Lee et al., 2015)
$PM_{2.5}$ (µg/m³) **PM_{10} (µg/m³)**	$PM_{2.5}$: S1 = 69±29; S2 = 60±24 PM_{10}: S1 = 119±57; S2 = 92±40	(Madureira et al., 2015)
TVOC (µg/m³) **$PM_{2.5}$ (µg/m³)** **PM_{10} (µg/m³)**	**Urban:** **TVOCs = 84.5±80.3** **PM2.5 = 42.8±13.1** **PM10 = 66.9±19.2** **Rural:** **TVOCs = 128.2±189.2** **PM2.5 = 57.0±29.7** **PM10 = 91.6±39.0**	(Branco et al., 2020)

VOCs (ppb) **$PM_{2.5}$ (µg/m^3)** **PM_{10} (µg/m^3)**	Fall/Winter: $PM_{2.5}$ = 0.08 ± 0.04 PM_{10} = 0.12 ± 0.05 VOCs = 97.82 ± 73.72 Spring/Summer: $PM_{2.5}$ = 0.10 ± 0.03 PM_{10} = 0.11 ± 0.03 VOCs = 90.51 ± 65.66	(Ferreira and Cardoso, 2014)
TVOCs (µg/m^3) **$PM_{2.5}$ (µg/m^3)** **PM_{10} (µg/m^3)**	TVOCs = 140.3 $PM_{2.5}$ = 82 PM_{10} = 127	(Madureira et al., 2015)
PM_{10} (µg/m^3)	**PM10 = 88.06 ± 54.47**	(Kim et al., 2010)
$PM_{2.5}$ (µg/m^3) **PM_{10} (µg/m^3)**	$PM_{2.5}$ = 56.00 ± 62.58 PM_{10} = 62.00 ± 67.87	(Yen et al., 2020)
TVOCs (µg/m^3) **$PM_{2.5}$ (µg/m^3)** **PM_{10} (µg/m^3)**	Autumn $PM_{2.5}$: S1 = 383; S2 = 373; S3 = 261; S4 = 310 PM_{10}: S1 = 439; S2 = 456; S3 = 325; S4 = 424 TVOCs: S1 = 152; S2 = 42; S3 = 47; S4 = - Winter $PM_{2.5}$: S1 = 945; S2 = 937; S3 = 868; S4 = 958 PM_{10}: S1 = 1110; S2 = 1090; S3 = 976; S4 = 1185 TVOCs: S1 = 382; S2 = 229; S3 = 454; S4 = 323	(Cai et al., 2015)
VOCs (µg/m^3) **$PM_{2.5}$ (µg/m^3)** **PM_{10} (µg/m^3)**	VOCs = 48.67±11.3 $PM_{2.5}$ = 43.58±12.9 PM_{10} = 70.63±19.8	(Jovanović et al., 2014)
$PM_{2.5}$ (µg/m^3) **PM_{10} (µg/m^3)**	Occupied: $PM_{2.5}$ A = 149; B = 190; C = 175; D = 199 (morning) PM_{10} A = 138; B = 143; C = 177; D = 205 (afternoon) Unoccupied: $PM_{2.5}$ A = 59; B = 49; C = 93; D = 172 (morning) PM_{10} A = 45; B = 41; C = 99; D = 156 (afternoon)	(Peng et al., 2017)
$PM_{2.5}$ (µg/m^3) **PM_{10} (µg/m^3)**	Daytime: $PM_{2.5}$ = 95; PM_{10} = 140 Night-time: $PM_{2.5}$ = 69; PM_{10} = 71	(Madureira et al., 2012)
$PM_{2.5}$ (µg/m^3) **PM_{10} (µg/m^3)**	$PM_{2.5}$ = 46.9 PM_{10} = 397.2	(Mohammadyan et al., 2017)
TVOCs (mg/m^3)	Spring School A: TVOCs: indoor I = 0.10 ± 0.03; indoor II = - School B: TVOCs: indoor I = 0.30 ± 0.33; indoor II = - School C: TVOCs: indoor I = 0.10 ± 0.10; indoor II = - Autumn	(Pegas et al., 2011b)

	School A: TVOCs: indoor I = 1.00 ± 0.20; indoor II = 0.70 ± 0.90 School B: TVOCs: indoor I = 0.90 ± 0.20; indoor II = 0.90 ± 0.10 School C: TVOCs: indoor I = 1.50 ± 0.10; indoor II = 0.50 ± 0.30 Winter School A: TVOCs: indoor I = -; indoor II = - School B: TVOCs: indoor I = -; indoor II = - School C: TVOCs: indoor I = -; indoor II = -	
$PM_{2.5}$ (µg/m^3) PM_{10} (µg/m^3)	**PM2.5 = 102.55 ± 63.32** **PM10 = 166.02 ± 93.86**	[60(Chen et al., 2018)
$PM_{2.5}$ (µg/m^3) PM_{10} (µg/m^3)	Urban: PM2.5 = 50.72±10.65 PM10 = 87.04±16.35 Rural: PM2.5 = 28.36±4.41 PM10 = 56.76±6.7	(Jalaludin, 2014)

Among the parameters of quality of indoor air, concentrations of PM in many schools have been found to be very high. The highest concentration of PM_{10} (1,185 µg/m^3) was observed in Wuhan, China (Cai et al., 2015), and the lowest PM_{10} (0.11 ± 0.03 µg/m^3) level was observed during the spring/summer season in Coimbra, Portugal (Ferreira and Cardoso, 2014). While for the concentration of $PM_{2.5}$, the highest level (199 µg/m^3) was observed during the occupied period in the morning time in Tai'an, China (Peng et al., 2017) and the lowest $PM_{2.5}$ (0.08 ± 0.04 µg/m^3) level was observed during the fall/winter season in Coimbra, Portugal (Ferreira and Cardoso, 2014). The IAQ levels in the primary school buildings in various parts of the world exhibit a broad spectrum, influenced by various factor such as seasonal variations, site characteristics, occupant activities, types of the ventilation system, outdoor pollution levels, and building characteristics. These factors contribute to the diverse range of indoor air pollutant sources discussed in the preceding section. Thus, when considering factors of both indoor and outdoor sources, it is important to take account of the student exposures to pollutants at primary school. Their form, distance from the school, and also their intensity and frequency of emissions also play a significant role in the outdoor sources of indoor air pollutants. A previous research study found that all the schools studied possessed sufficient high levels of indoor air qualities such as CO_2, TVOCs, and total particulate matter (TPM) to cause health or comfort problems (Behzadi and Fadeyi, 2012).

3.2.2. Comparison of Particulate Matters Mean Values with Existing Standards and Guidelines

Table 6 provides a synthesis of the requirements and recommendations set forth by international agencies as well as those specific to Malaysia, pertaining to contaminants encounters indoors, within the framework of this report.

Table 6. PM & TVOCs standards and guidelines.

Pollutants	NAAQS/USEPA (NAAQS, 1990)	WHO guidelines (Organization, 2006)	ICP-IAQ/Malaysia (Safety and Health, 2010)
$PM_{2.5}$	35 µg/m^3 (24 h) 12 µg/m^3 (Annual, Primary) 15 µg/m^3 (Annual, Secondary)	25 µg/m^3 (24 h) 10 µg/m^3 (Annual)	0.15 µg/m^3
PM_{10}	150 µg/m^3 (24 h)	50 µg/m^3 (24 h) 20 µg/m^3 (Annual)	
TVOC	-	-	3 ppm

The issues of human exposure to indoor air pollutants have grabbed greater recognition on its importance which urged neither national nor international organizations around the world proposed IAQ standards and guidelines focused to improve the quality of indoor air in the enclosed environment. The international air quality guidelines (AQGs) for IAQ standards suggested by WHO is mostly used in many countries in assessing for IAQ. However, as there is heterogeneity between countries in different regions and approaches, thus the government before adopting the AQGs explicitly as legally based criteria, countries should specifically consider their local circumstances. The WHO AQGs specified the applicable recommended values for PM, Ozone (O_3), nitrogen dioxide (NO_2), and sulphur dioxide (SO_2) in all non-occupational environments which include households, schools and vehicles (Organization, 2006).

The National Ambient Air Quality Standards (NAAQS) required by the amended Clean Air Act in 1990 were developed by the USEPA are applicable for both outdoor and indoor air quality. In this standard, two types of national environmental air quality standards are listed, including the protection of "sensitive" populations such as asthmatics, infants, and even the elderly against public health, while the secondary standards are the protection against decreased visibility and harm to livestock, crops, etc. that specialize in public welfare protection (NAAQS, 1990).

The Industry Code of Practice on Indoor Air Quality 2010 in Malaysia (ICP-IAQ/Malaysia), which acts as a guide to improving the IAQ target of providing health protection to employees and occupants from poor indoor air quality, has been defined by a set minimum standard for selected IAQ parameters to avoid discomfort and negative health effect in an indoor or enclosed environment served by a Air conditioning and mechanical ventilation (ACMV) (Safety and Health, 2010). The relation between the mean $PM_{2.5}$ and PM_{10} concentrations and the standard recommendations is shown in Figures 2 and 3, respectively.

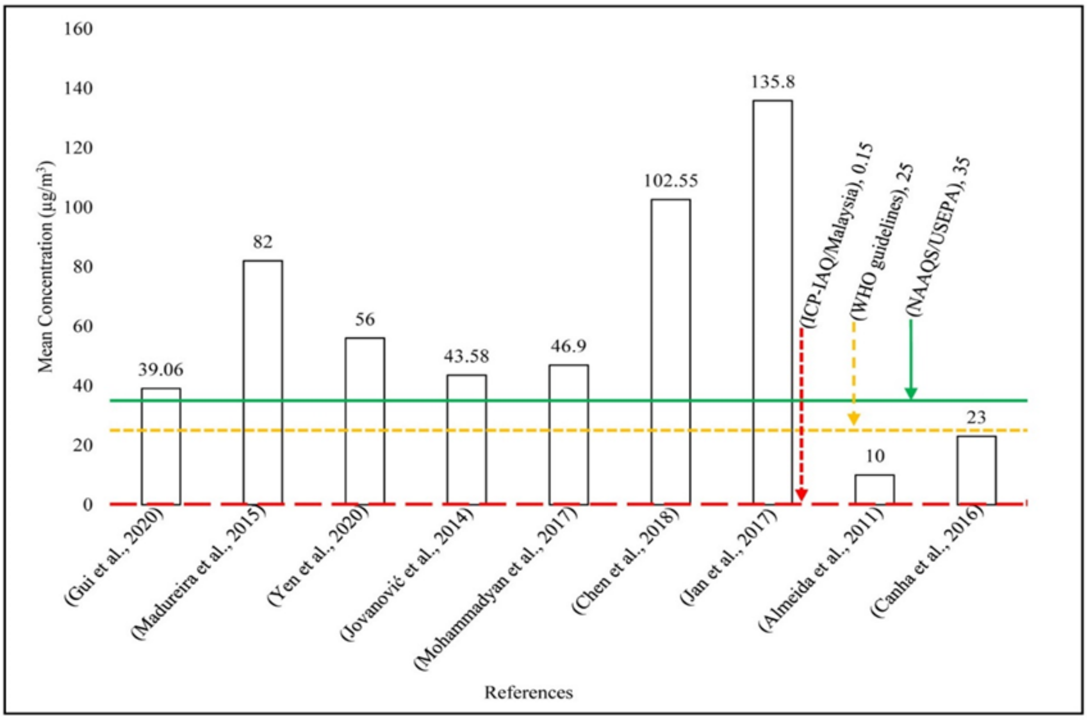

Figure 2. Mean concentration of $PM_{2.5}$ reported across different studies compared against NAAQS/USEPA, WHO, and ICP-IAQ/Malaysia standards.

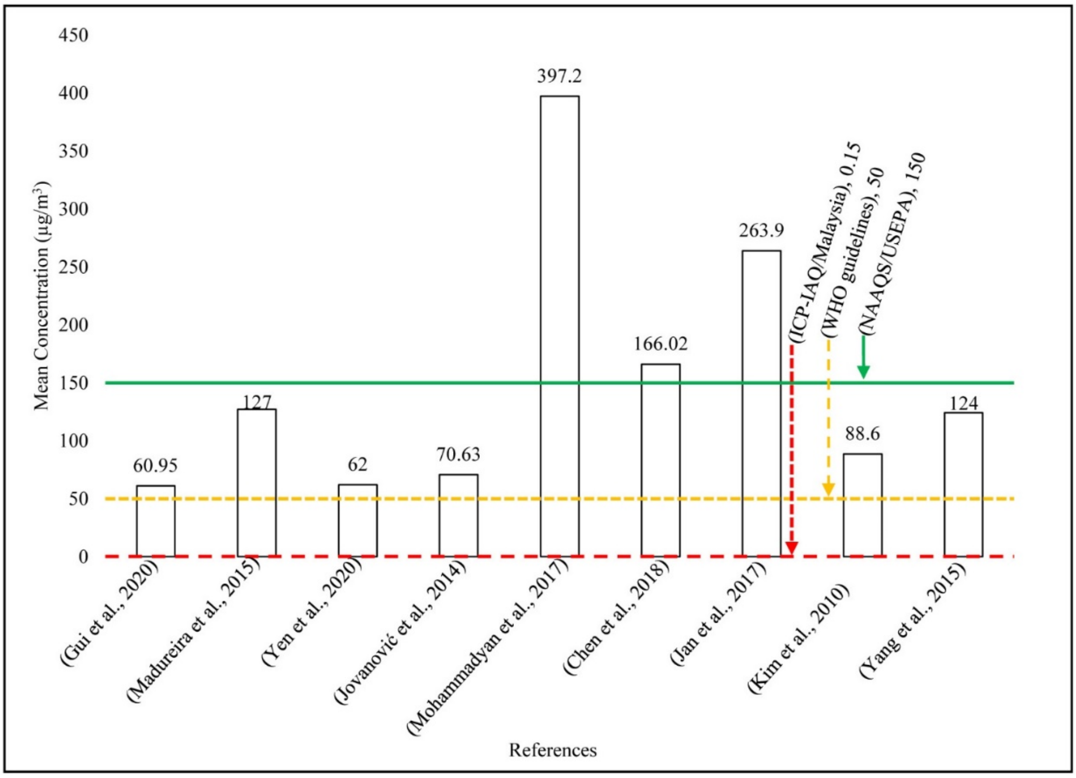

Figure 3. Mean concentration of PM_{10} reported across different studies compared against NAAQS/USEPA, WHO, and ICP-IAQ/Malaysia standards.

The three horizontal lines represent the recommended limit values by the NAAQS/USEPA of 35 µg/m^3 (green continuous line), WHO guidelines of 25 µg/m^3 (yellow dotted line), and ICP-IAQ/Malaysia of 0.15 µg/m^3 (red dotted line). From the Figure 2, it can be seen that the mean value of $PM_{2.5}$ from all of the nine research studies far exceeded at least 66 times than the limit value set by ICP-IAQ/Malaysia. While when compared to another limit value set by NAAQS/USEPA, and WHO guidelines, the mean values of $PM_{2.5}$ from all research papers exceeded the limit except for the research by Almeida et al. (2011) and Canha et al. (2016) with the mean value of 10 µg/m^3 and 23 µg/m^3 respectively. The primary contributors to this phenomenon was reported based on the previous discussions.

Figure 3 shows the mean concentration of PM_{10} of different references in primary schools. The three horizontal lines represent the recommended limit values by the NAAQS/USEPA of 150 µg/m^3 (green continuous line), WHO guidelines of 50 µg/m^3 (yellow dotted line), and ICP-IAQ/Malaysia of 0.15 µg/m^3 (red dotted line). It has been denoted that the mean value of PM_{10} from all of the nine research studies far exceeded at least 406 times the limit value set by ICP-IAQ/Malaysia and 1.2 times than the limit value set by WHO guidelines. From the previous study, the finding showed that in most of the studied schools, the measured average indoor PM_{10} concentrations goes beyond 4 times the limit set by WHO guidelines (Dorizas et al., 2013). In contrast, when compared to another limit value set by NAAQS/USEPA, the mean values of PM_{10} from all research papers did not exceed the limit except for the researches by Mohammadyan et al. (2017), Chen et al. (2018), and Jan et al.(2017) with the mean value recorded at 166.02 µg/m^3, 263.9 µg/m^3, and 397.2 µg/m^3 respectively.

3.2.3. Health symptoms of PM & TVOCs on the health of school students

A total of 12 previous studies have centered on the relationship between IAQ and the health of primary school students. The health symptoms found in the students after the exposure to the indoor air pollutants in these studies were summarized in Table 7. The majority of research has focused on investigating the impact of particulate matter (PM) on students' well-being. However, the study conducted by Sofuoglu et al. (2011) diverged from this trend, concentrating on health risks associated with volatile organic compounds (VOCs). Similarly, the study by Annesi et al. (2012) shifted the focus to examining the effects of PM2.5 and VOCs specifically on health issues such as asthma and rhinitis.

Table 7. Impact of PM & TVOCs on the health of primary school students.

IAQ Parameters	Health Symptoms	Articles/References
VOCs	Carcinogenic risk.	(Sofuoglu et al., 2011)
$PM_{2.5}$, PM_{10}	Respiratory health risk (wheeze and cough) during non-heating period.	(Zhang et al., 2019)
$PM_{2.5}$, PM_{10}	Asthma, allergic rhinitis, atopic dermatitis.	(Lee et al., 2015)
$PM_{2.5}$, PM_{10}	Prevalence of respiratory conditions (cold, running nose, cough, fever, and eye irritation).	(Jan et al., 2017)
$PM_{2.5}$, PM_{10}	Poorer performance of children in executive function (working memory, inhibitory control, behavioral regulation, and metacognition).	(Gui et al., 2020)
$PM_{2.5}$, PM_{10}, TVOCs	Children asthma, active wheezing, reduced FEV1 reflect reduced lung growth (FEV1, forced expiratory volume in one second).	(Branco et al., 2020)
$PM_{2.5}$, PM_{10}	Adverse impact on school children's lung function.	(Yen et al., 2020)
VOCs, $PM_{2.5}$, PM_{10}	Outbreaks of sneezing, loss of focus, allergic rhinitis, cough, wheezing, and asthma.	(Ferreira and Cardoso, 2014)
TVOCs, $PM_{2.5}$, PM_{10}	Self-reported respiratory symptoms and asthma-like symptoms.	(Madureira et al., 2015)
$PM_{2.5}$, VOCs (Formaldehyde, Acetaldehyde, Acrolein)	Occurrence of clinical symptoms of rhinitis and asthma.	(Annesi-Maesano et al., 2012)
$PM_{2.5}$, PM_{10}	Adverse impact on children's lung function.	(Chen et al., 2018)
$PM_{2.5}$, PM_{10}	Vital risk of getting acute respiratory illnesses and respiratory symptoms.	(Jalaludin, 2014)

Among all reported health risks or health symptoms in these studies, respiratory-related health risk or health problems were the most reported issues. Jan et al. (2017) reported that the prevalence of respiratory problems such as cold, running nose, cough, fever, and eye irritation in children has become the primary cause of child absenteeism in an assessment of children's exposure to particulate matter and gaseous species for schools in Pune, India. Poor IAQ will also lead to an adverse impact on the school children's lung function (Yen et al., 2020, Chen et al., 2018) that associated with exposure to air pollution in the short term (Chen et al., 2018) in which the reduction in forced expiratory volume in one second (FEV1) reflect reduced lung growth of the students (Branco et al., 2020). Interestingly, the finding from Chen et al. (2018) showed that girls posed stronger short-term adverse impact on air pollution compared to the boys.

Acute respiratory illnesses and respiratory symptoms were at high risk if continuous exposure of children to indoor air pollutants for a longer period take place (Jalaludin, 2014). Poor IAQ also possessed a vital risk of getting asthma-like symptoms (Madureira et al., 2015) and respiratory health risks such as wheeze and cough during the non-heating periods (Zhang et al., 2019). Previous research found that the high levels of PM_{10} were the factor that leads to beyond acceptable health quotient limit of 1 which was proposed by USEPA and resulted in a potentially high health risk faced by the school children (Madureira et al., 2016). Another study also indicated that $PM_{2.5}$ is the cause of concern for toxicity in the lungs and as well as airways (Jalaludin, 2014).

From the previous studies, it was found that asthma is one of the health symptoms that being reported to adversely affected the health of students in primary schools (Branco et al., 2020, Ferreira and Cardoso, 2014, Lee et al., 2015, Annesi-Maesano et al., 2012) which followed by rhinitis whether in terms of allergic (Ferreira and Cardoso, 2014, Lee et al., 2015) or prevalence of clinical manifestation (Annesi-Maesano et al., 2012). A study also found that high PM_{10} levels resulted in health symptoms of allergic rhinitis and conjunctivitis in the elementary schools (Kim et al., 2010). Despite the health symptom of atopic dermatitis being reported (Lee et al., 2015), other health symptoms such as sneezing attacks, lack of concentration, cough, and rales/wheezing were also reported in the study (Ferreira and Cardoso, 2014). Branco et al. (2020) stated in their study which focus on the effect of indoor air contamination in nursery and primary schools on childhood asthma found that active wheezing is one of the health symptoms when the students being exposed to indoor air pollution of $PM_{2.5}$, PM_{10}, and VOCs.

Gui et al. (2020) conducted the only study on Chinese primary school children examining the impact of ambient air pollution on executive functions. They found that exposure to both $PM_{2.5}$ and PM_{10} was associated with poorer performance in working memory, inhibitory control, behavioral regulation, and metacognition. The results on odor detection, sensory discomfort, chronic toxic and cancerous results in their evaluation of indoor pollution levels and health threats of VOCs in three primary schools showed that the estimated carcinogenic risks were above an appropriate amount. Furthermore, when assessing the significant factors influencing children's health outcomes, both the levels of pollutants and the duration of exposure have been identified as key contributors (Zhang et al., 2019).

3.2.4. Forest Plot on Asthma Health Symptoms

This section studied the symptom of asthma due to poor IAQ that being reported by three prior studies. Utilizing a forest plot, this analysis facilitates a direct comparison of the findings from these studies, consolidating the quality of results in a single presentation. The result is plotted in Figure 4.

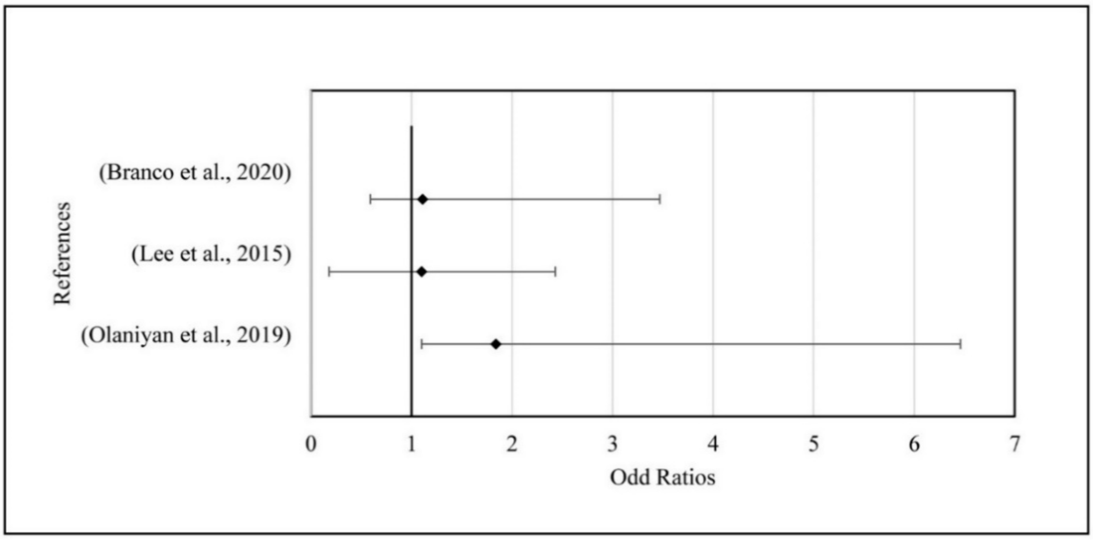

Figure 4. Forest plot of different references on asthma health symptom in primary schools.

The risk ratio (RR) is the ratio of the chance or risk of the outcome of interest in one group over the risk of all possible outcomes whereas the odd ratio (OR) is the ratio of the likelihood of an occurrence in one group to the probability of an event in another group not occurring (Ranganathan et al., 2015). Figure 4 displayed the OR forest plot generated from the meta-analysis, focusing on studies investigating the exposure and outcome of the asthma health symptom among the primary school's students.

The previous research focusing on the effect of indoor air pollution on childhood asthma in nursery and primary schools showed that the rise in PM exposure was correlated with a greater increase in the chances of asthma being diagnosed with aeroallergen sensitization (OR 1.83, 95% CI 0.90-3.73 for $PM_{2.5}$) compared to odd for those of without aeroallergen sensitization (OR 1.08, 95% CI 0.58-2.00 for $PM_{2.5}$), although the statistical for $PM_{2.5}$ inhaled dose model was not significant ($p = 0.786$) (Branco et al., 2020). However, interestingly, the results from Branco et al. (2020) concluded that there was no evidence found a vital association between indoor air pollutants with the prevalence of childhood asthma.

Another research in Seoul (Lee et al. 2015) investigating the relationship between allergic diseases and air quality in school children at elementary schools on the roadside showed that a high level of traffic was statistically insignificant in school environments ($p = 0.729$) for asthma symptom for a lifetime (OR 1.10, 95% CI 0.92-1.33) after considering traffic-related factors. A study of Olaniyan et al. (2019) reported that students with genetic tendency to develop allergic diseases or known as atopy were statistically not significant for doctor-diagnosed asthma (OR 1.84, 95% CI 0.74-4.62). Subsequently, a previous study found that one of the factors which increased the likelihood of having asthma-like symptoms is high concentrations of $PM_{2.5}$ and PM_{10} where the association for PM_{10} is stronger, while doubled of the risk of having asthma-related symptoms was found in the exposure to high levels of TVOCs concentrations (Madureira et al., 2015).

3.3. Synthesis of Key Findings and Implications

This systematic review highlights that common indoor sources of PM and TVOCs across primary and elementary schools include occupant activities, cleaning products, furniture emissions, and infiltration from outdoor traffic. Seasonal variations, types of ventilation systems, and building characteristics were found to significantly influence pollutant concentrations. Urban schools generally exhibited higher levels of particulate matter compared to rural counterparts due to greater outdoor pollution exposure, particularly from vehicular traffic and industrial emissions. In contrast, rural schools were more affected by indoor sources such as occupant activities and material degradation, despite lower outdoor pollutant levels.

Across different climates and regions, variations in indoor air quality were linked to factors such as temperature, humidity, and seasonal ventilation practices, emphasizing the need for location-specific IAQ management. Additionally, the limited standardization of IAQ measurement methodologies across studies presents a challenge for direct comparison and highlights the need for harmonized assessment protocols. These findings underline the urgent need for implementing targeted mitigation strategies tailored to the specific environmental, structural, and operational contexts of school environments to effectively safeguard student health.

4. Conclusion

This study was based on a systematic review of published articles from 2010 to 2024, using publicly available data from scientific databases including Scopus, Web of Science, PubMed, and Embase. This study highlights the critical sources of PM and TVOCs in primary school environments and their implications for student health which reinforcing the need for sustainable IAQ management. The primary sources that lead to high TVOCs concentrations in primary schools are cleaning activities, cleaning products and furnishings, and occupants' behavior and densities while the main sources of PM are the occupational activities and cleaning activities inside the classrooms, building characteristics such as degradation of paint in wall and ceiling, teaching materials used such as chalk, and outdoor which mainly from the traffic emissions. For the relationship between IAQ physical parameters and the effects on health of student, it was found that the concentration levels of indoor air pollutant played a significant role in influencing the health of school children. Most of the previous research focused on urban schools and this confirmed that urbanization could pose a high risk to the wellbeing of school children as they are exposed to air pollutants and sourced from both outdoor and indoor. Seasonal factors, site characteristics, occupant activities, types of the ventilation system, outdoor pollution levels, and building characteristics have all played roles in the effects of students' health as well. The types, distance from the school and the intensity, and frequency of emissions were associated with the outdoor sources. Therefore, the indoor and outdoor sources of PM & TVOCs should be considered. Based on previous studies, most of $PM_{2.5}$ and PM_{10} mean values greatly exceeded the recommended values set by NAAQS/USEPA, and WHO guidelines. Additionally, while temperature and humidity variations showed minimal impact on PM concentrations, high PM and TVOC levels were consistently linked to compromised lung function, increased asthma prevalence, and other respiratory issues. Future IAQ management should integrate sustainable building practices, improved ventilation, and eco-friendly solutions. Strengthening policies to mitigate indoor and outdoor pollution will be vital in creating healthier school environments and promoting environmental sustainability. To achieve these improvements, it is recommended that schools adopt sustainable building practices, install efficient air purification systems, enforce regular maintenance and cleaning protocols using low-emission products, and integrate continuous indoor air quality monitoring into school management policies. Future research should also aim to standardize IAQ assessment methods and consider seasonal variations to provide more comprehensive risk evaluations.

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