

# An overview of urban environmental pollution in external and internal environments by PM<sub>2.5</sub> particulate matter and the sick building syndrome

Una visión general sobre la contaminación ambiental urbana en ambientes externos e internos por partículas PM<sub>2.5</sub> y el síndrome del edificio enfermo

Uma visão geral da poluição ambiental urbana em ambientes externos e internos por material particulado PM<sub>2.5</sub> e a síndrome do edifício doente

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**Palavras-chave:** Contaminação do ar; síndrome do edifício doente; doenças respiratórias; saúde pública

## Abstract

**Introduction:** A healthy environment must have air free of pollution, but this issue has always existed and now affects the entire population. The PM<sub>2.5</sub>, which primarily originates from the car fleet, is one of the pollutants that has the biggest impact. With the energy crisis in the 1970s and the ensuing construction of closed buildings, primarily in developed countries, indoor air quality emerged as a science. It then gained importance when it was found that the declining ventilation levels in those nations were largely to blame for the rising concentrations of pollutants in indoor air. Sick Building Syndrome (SBS) and poor indoor air quality are both connected to ailments like colds, allergies, and coughing. The application of special legislation must be integrated with research and education of building occupants to effectively provide a healthy environment. **Objective:** The aim of this review is to analyze various findings from investigations on the effects of PM<sub>2.5</sub> pollution on the internal and exterior urban environment, as well as the effects of these concentrations on human health. **Results:** By comparing the findings with other studies, it is possible to identify some common behaviors of fine particles, determining the concentration differences in the environments and showing how different sources and conditions can produce different variations in concentrations. **Conclusions:** This study draws attention to the prevention of SBS. This can be minimized during the planning and execution phases of new construction or restoration projects. Thus, contributing to the health of people who live or work indoors.

## Resumen

**Introducción:** Un ambiente saludable debe tener un aire libre de contaminación, pero este tema siempre ha existido y ahora afecta a toda la población. El PM<sub>2.5</sub>, que proviene principalmente de los automóviles, es uno de los contaminantes que mayor impacto tiene. Con la crisis energética de la década de 1970 y la consiguiente construcción de edificios cerrados, principalmente en los países desarrollados, la calidad del aire interior surgió como una ciencia. Luego cobró importancia cuando se descubrió que la disminución de los niveles de ventilación en esas naciones era en gran parte culpable de las crecientes concentraciones de contaminantes en el aire interior. El Síndrome del Edificio Enfermo (SEE) y la mala calidad del aire interior están relacionados con enfermedades como resfriados, alergias y tos. La aplicación de la legislación especial debe integrarse con la investigación y la educación de los ocupantes de los edificios para proporcionar de manera efectiva un ambiente saludable. **Objetivo:** El objetivo de esta revisión es analizar varios hallazgos de investigaciones sobre los efectos de la contaminación por PM<sub>2.5</sub> en el ambiente urbano interno y externo, así como los efectos de estas concentraciones en la salud humana. **Resultados:** Al comparar los hallazgos con otros estudios, fue posible identificar algunos comportamientos comunes de las partículas finas, determinando las diferencias de concentración en los ambientes y mostrando cómo diferentes fuentes y condiciones pueden producir diferentes variaciones en las concentraciones. **Conclusiones:** Este estudio llama la atención sobre la prevención del SEE. Esto se puede minimizar durante las fases de planificación y ejecución de proyectos de nueva construcción o restauración. Contribuyendo así a la salud de las personas que viven o trabajan en espacios cerrados.

## Resumo

**Introdução:** Um ambiente saudável deve ter um ar livre de poluição, mas esse problema sempre existiu e hoje afeta toda a população. O PM<sub>2.5</sub>, que tem origem principalmente dos automóveis, é um dos poluentes de maior impacto. Com a crise energética na década de 1970 e a consequente construção de prédios fechados, principalmente nos países desenvolvidos, a qualidade do ar interior surgiu como uma ciência. Em seguida, ganhou importância quando se descobriu que os níveis decrescentes de ventilação nessas nações eram os principais culpados pelo aumento das concentrações de poluentes no ar interno. A Síndrome do Edifício Doente (SED) e a má qualidade do ar interno estão ligadas a doenças como resfriados, alergias e tosse. A aplicação da legislação especial deve ser integrada com a pesquisa e educação dos ocupantes do edifício para efetivamente proporcionar um ambiente saudável. **Objeto:** O objetivo desta revisão é analisar vários resultados de investigações sobre os efeitos da poluição por PM<sub>2.5</sub> no ambiente urbano interno e externo, bem como os efeitos dessas concentrações na saúde humana. **Resultado:** Ao comparar os resultados com outros estudos, foi possível identificar alguns comportamentos comuns de partículas finas, determinando as diferenças de concentração nos ambientes e mostrando como diferentes fontes e condições podem produzir diferentes variações nas concentrações. **Conclusões:** Este estudo chama atenção para a prevenção da SED. Esta pode ser minimizada durante as fases de planejamento e execução de novos projetos de construção ou de restauração. Assim, contribuir para a saúde das pessoas que vivem ou trabalham em ambientes fechados.

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## 1. Introduction

Human health and well-being depend on clean air, which is a basic requirement. Nevertheless, poor air quality has always been a concern and poses a threat to the entire community (World Health Organization-WHO, 2018a). Air quality is regarded as a crucial factor around the world since it has a detrimental impact on both the environment and human health after emissions from various sources of natural and human origin (Echeverri & Maya, 2008; WHO, 2005). By comparing the findings with other studies, it is possible to identify some common behaviors of fine particles, determining the concentration differences in the environments and showing how different sources and conditions can produce different variations in concentrations.

Particulate Matter (PM) is one of the pollutants that causes the most harm, producing more than 4.2 million preventable deaths worldwide in 2016 (WHO, 2018b). This pollutant has a variable composition and a wide range of particle sizes (Martins & Da Graça, 2018). There are particles having an aerodynamic diameter smaller than or equal to fractions of 2.5 microns. It is one of the most closely observed and reported types of urban air pollutants due to its link to adverse health impacts (Targino et al., 2016).

According to Martins and Da Graça (2018) home activities and vehicular combustion contribute the most to the external environments worldwide level, whereas rain and wind are the primary causes of concentration declines. The number of ambient particles at the central monitoring station. However, it cannot be directly associated with human exposure because humans spend 90% of their time indoors. Spending even more time indoors is the old, very young, and those with poor health (the demographic most vulnerable to the impacts of poor air quality) (Cao et al., 2005).

Because of interior sources such as human activity, household incense, and cooking, PM<sub>2.5</sub> particulate matter can also be produced indoors. In some situations, this will result in concentration fluctuations (Hasheminassab et al., 2014). As a result, residential indoor micro-environments play a significant role in how many particle pollutants are exposed to people, and they generally contribute more than the outer environment (Cao et al., 2005).

Buildings that are enclosed for aesthetic, noise reduction, and even air conditioning purposes have sparked concerns about Indoor Air Quality (IAQ), which has resulted in a rise in indoor air quality issues from those environments (Kubba, 2010).

Interest in IAQ research increased when it became clear that these environments' lower ventilation rates were mostly to blame for higher concentrations of indoor biological and non-biological contaminants. This concern is warranted because most people spend most of their time in these facilities (between 80 and 90 percent), where they are therefore exposed to toxins (Brickus & De Aquino, 1999).

Humidity, temperature, particulate matter, and organic compounds are some of the variables that can be used to measure IAQ (Wolkoff & Kjaergaard, 2007). IAQ in office buildings has also been evaluated in numerous studies in conjunction with building operating factors including ventilation and energy efficiency (Baccarelli et al., 2011).

Even in highly industrialized cities, pollution levels can be two to five times higher indoors than outside, according to research by the US Environmental Protection Agency (EPA). The hazards to human health are significantly higher in these areas because of this fact and the amount of time spent indoors (American Lung Association, 2001).

More than half of enclosed spaces, including businesses, schools, movie theaters, houses, and even hospitals, have inadequate air quality, according to WHO criteria. It's a good idea

to have a backup plan in case something goes wrong, especially if you're dealing with a lot of data (WHO, 1990).

According to Mata et al. (2022), the building produces several pollutants, including ammonia, sulfur and nitrogen oxides, carbon monoxide and dioxide, and ammonia. By respiration, perspiration, and the movement of potentially pathogenic germs, building inhabitants have a substantial impact on the indoor environment's pollution. Not to add cigarettes, one of the most significant environmental villains (Brickus & De Aquino, 1999).

Yang et al. (2022) asserts that ventilation is one of the key elements influencing indoor air quality. One of the most crucial methods for regulating the quality of the air in these settings is ventilation, which is described as a collection of procedures that both bring in fresh air from the outside and exhaust stale air from inside. The area around a building Intake of outside air, conditioning and mixing of air throughout the building, and extraction are the main ventilation-related activities.

It is also well known that improperly used and neglected ventilation systems can become potential sources of pollution, mostly through the production of particulates and germs. As a result, sustaining a healthy building necessitates creating automation systems, providing proper ventilation, and, most importantly, ongoing monitoring of these spaces (Mata et al., 2022).

According to the WHO (1989), Sick Building Syndrome (SBS) is a situation in which people who use or occupy a particular building display symptoms with no known cause and for which it is impossible to establish a specific cause. Given the significance of IAQ, the aim of this review is to describe the various pollutants that are present inside (from both biological and non-biological sources) and their impact on human health.

Internal air pollution is increasingly becoming an occupational health problem, so it is especially important to understand its cause and prevention measures for this syndrome.

## 2. Sick building syndrome

As individuals spend most of their time indoors, indoor air pollution becomes a major problem (McCreddin et al., 2013). While workers divide their time between home and work, those who work at home, the elderly and children spend most of their time at home (Baccarelli et al., 2011). Due to mobility restrictions and social isolation brought about by the COVID-19 pandemic, many people have been forced to work from home. Indoor air can be polluted at a higher level than outdoor air, especially in buildings (Cheung et al., 2011; Salmatonidis et al., 2019). Outdoor air pollution in urban centers represents a serious impact on human health and the environment worldwide. According to Quang et al. (2013) the problem worsens when buildings are built with little air circulation capacity.

Jamriska et al. (2003) state that the type of ventilation and how it is used greatly influence the concentration of indoor air pollutants and can provide important information on IAQ levels. According to the authors, there are three distinct ventilation systems used in commercial and office buildings. Natural ventilation through windows and doors is the first. The second type of ventilation is mechanical, where heating, ventilation and air conditioning systems control temperature and humidity. According to Irga and Torpy (2016), the third type of ventilation is mixed-mode ventilation, which combines natural and mechanical ventilation. An example of this would be the use of window air conditioners in conjunction with open windows and doors.

## 3. Particulate matter, PM<sub>2.5</sub>

The physical and chemical amalgamation of diverse chemicals, both solid and liquid, in the air is referred to as particulate matter (droplets, aerosols, fog, smoke, etc.). Research has been done on the PM<sub>2.5</sub> pollutant on a worldwide basis, and it has been shown that both natural and man-made sources contribute to its presence in the atmosphere. This is notable since there is a relationship between variations in the concentration of ambient particles and changes in daily mortality and morbidity (Arciniégas, 2012; Martins & Da Graça, 2018). In this regard, it is estimated that particulate matter exposure results in around 4.2 million premature deaths annually, including cancer, different cardiovascular and respiratory disorders (WHO, 2018c).

In outdoor environmental studies on sources and variations in urban settings, it was found that traffic flow, albeit in South and Southwest Asia, South America, and Southwest Asia, accounted for around a quarter of urban PM<sub>2.5</sub> levels. According to Martins and Da Graça (2018), the vehicle fleet contains 30% to 37% fine particles.

Living near busy roads and respiratory health are significantly correlated (Janssen et al., 2001), and there is widespread concern that traffic-related particulate matter is more toxic than other particulate matter. Modest reductions in traffic-related exposure can have a significant impact on public health (Hatzopoulou et al., 2013).

However, as these sources are typically not found in major cities, they only contribute 15% to urban PM<sub>2.5</sub> concentrations. Nonetheless, these activities are the primary contributors to pollution in South Asia, South China, Japan, and the Middle East. Particulate matter emissions from burning home fuels have decreased in most developed nations and now account for about 20% of urban concentrations worldwide. Yet, with a share of 32% to 34%, it is the most significant source in Central and Eastern Europe and in Africa (Martins & Da Graça, 2018).

The 18% of all urban PM<sub>2.5</sub> comes from natural sources, which also include sea salt, emissions from forest fires, dust from non-urban and non-agricultural soils, and particulates from the oxidation of volatile organic compounds in vegetation. Only Japan and the Middle East have evidence that natural sources are the primary cause of fine particulate matter emissions in those countries (Karagulian et al., 2015; Marlier et al., 2015).

Although local and human factors account for the majority of urban PM<sub>2.5</sub>, there are some significant correlations between concentration levels and meteorological conditions (temperature, wind speed, and relative humidity).

Like how local terrain influences PM<sub>2.5</sub> content and aids or hinders particle dispersion, altitude, local vegetation, the absence of impediments both natural and man-made, and high wind speeds all work to lower particle concentrations and improve air quality. Yet, man-made obstructions, high wind speeds, and other favorable dispersal circumstances combine to transport PM<sub>2.5</sub> hundreds of kilometers, having a direct impact on air quality from local to global levels (Hatzopoulou et al., 2013; Baklanov et al., 2016; Martins & Da Graça, 2018).

A suspended air particle with an aerodynamic diameter of less than 2.5 µm and a diversity of various chemical components is referred to as PM<sub>2.5</sub> (Liang et al., 2016).

Since PM<sub>2.5</sub> is fully respirable and can linger in the bronchi, bronchioles, and in some circumstances even penetrate the alveoli, it is thought to be the primary air pollutant related to people's health (Li et al., 2017). It also poses a major hazard to human health because it can enter the bloodstream through the liver, brain, and kidneys (Larsen, 2003; Echeverri & Maya, 2008; Qu et al., 2017).

#### 4. Emission Sources

A secondary creation process or a primary emission process can release fine particles directly into the atmosphere (Martins & Da Graça, 2018), as well as the result of many anthropogenic and natural processes (Arciniégas, 2012).

The size fraction of  $PM_{2.5}$  is primarily produced by combustion processes, with vehicle engine emissions being one of the major primary sources of exhaust gas particles (Hasheminassab et al., 2014), as well as particles from tire and brake wear and the resuspension of particles that had previously settled on the road surface (Martins & Da Graça, 2018).

However, the production of small to medium amounts of  $PM_{2.5}$  emissions occurs when bigger particles are ground into construction, road, and soil dust (Watson & Chow, 1998). According to Arciniégas (2012) and Echeverri and Maya (2008), plant emissions (flora fumes), marine aerosols, and forest fires are a few examples of the natural sources of fine particles.

## 5. Principal interior air pollution contaminants

It is a truth that interior air contaminants can come from outside air (in this case physical, chemical, and biological). The origins of this contamination can be very various, including human activity itself (microorganisms, carbon dioxide), and even masonry (as in this case, of radon), even if it primarily happens in high-traffic regions and industrial locations. Non-biological pollutants like carbon dioxide ( $CO_2$ ) and oxide (CO), nitrogen dioxide ( $NO_2$ ) and oxide (NO), sulfur dioxide ( $SO_2$ ), ozone, particulates, tobacco smoke, volatile organic compounds, bacteria, fungi, are among the most significant indoor air pollutants. Particles are suspended when things like sweeping, dusting, and cooking are done. Due to their source (stove, cigarettes) and the nature of inside activities, indoor-generated particles are often smaller than outdoor-produced particles and include more organic materials. These characteristics increase the risk of harm in enclosed areas. Moreover, the fate of the particles is determined by their size. Particles can build up on surfaces, spread into the air, escape the ventilation system, or even be inhaled by occupants and build up in the upper respiratory tract or even in the lungs and alveoli (Morawska et al., 2022).

Cigarette smoke is an aerosol made up of a variety of different materials that can be classified as particles, vapors, and gasses. It is regarded as a serious indoor contaminant primarily because of the volume of exposure. The so-called passive smokers who reside with smokers are likewise harmed by cigarette smoke. N-nitrosodimethylamine is a powerful carcinogen whose concentrations are between 20 and 100 times greater in passive smokers than in smokers (Ramírez et al., 2014). In some circumstances, non-smokers are exposed to specific substances at higher levels than smokers. Benzene, toluene, ethylbenzene, xylene, formaldehyde, and acetaldehyde are the primary volatile organic compounds present indoors (Villanueva et al., 2014).

Because interior sources are more substantial than ambient air sources especially in new construction, where building material emissions are higher and gradually decline over time-indoor Volatile Organic Compounds (VOCs) levels are higher. The most prevalent indoor VOCs and, according to some writers, one of the most significant is formaldehyde (Liu et al., 2013).

Biological pollutants such as bacteria, fungi, pollen grains, mites, and spores are the principal ones. They play a significant role in indoor air quality because the toxins produced by microorganisms that thrive in ventilation systems cause numerous allergy and infectious disorders. Preventing (or at least limiting) their growth is the primary strategy for dealing with connected issues. The following actions can be taken to achieve this goal: removing water sources that support fungi growth; maintaining relative humidity below 60%; removing porous organic materials that are obviously contaminated, such as moldy carpets; avoiding



portable humidifiers in offices because they are rarely kept in proper working order and can act as potential sources; using effective filters to intake outdoor air; and ongoing maintenance (Binie, 2021).

## 6. Health Risks

According to Halek et al. (2013), finer particulate matter is also linked to negative impacts, notably indicators of mortality and morbidity. Like how they influence the cardiovascular system, they are linked to respiratory illnesses such bronchitis, asthma, emphysema, and pneumonia, as well as to premature death on a worldwide level (Han et al., 2016; WHO, 2018a). Particles in the PM<sub>2.5</sub> range can harm airway cells and cause an inflammatory reaction because of their small diameter, which lowers lung immunity and encourages the invasion of pathogenic bacteria (Martins & Da Graça, 2018).

Continued exposure to high PM<sub>2.5</sub> concentrations is also linked to disorders including diabetes and prenatal conditions, which can result in premature birth and postpartum health issues, and even cause early mortality (Barría et al., 2016). There is a need for more investigation because PM<sub>2.5</sub> has been associated with numerous more possible health effects, including its carcinogenic qualities and connection to immunological illnesses (Han et al., 2016).

### 6.1. *Diseases caused by biological contaminants*

Certain bacteria can produce allergic reactions, which include sneezing, watery eyes, coughing, shortness of breath, sleepiness and indigestion, fever, in addition to pneumonia, rhinitis, and asthma. The most significant illnesses are generally those related to biological contaminants, such as legionellosis (also known as legionellosis because it is caused by a gram-negative bacterium from the *Legionella* family), humidifier fever, bronchial asthma, allergic pneumonia, and external alveolitis. These illnesses are caused by contact with poisonous microorganisms, particularly those that thrive in building ventilation systems (Jones, 1999).

### 6.2. *Diseases caused by non-biological contaminants*

Oxygen is replaced by carboxyhemoglobin, which lowers the blood's oxygen concentration, because of CO affinity for hemoglobin. As a result, the organs that need more oxygen, such the heart and brain, are where its toxic consequences manifest (Akyol et al., 2014).

Nitrogen dioxide is an oxygen agent that impairs lung function, inhibits the immune system, and, in the most severe cases, can result in pulmonary emphysema (Glencross et al., 2020). Nitrous oxide can have effects akin to those of CO by obstructing the flow of oxygen to the tissues, and at high quantities, it can likewise lead to pulmonary edema.

Sulfur dioxide affects the mucous membranes of the eyes, nose, throat, and respiratory tract and mostly works as an irritant. Large amounts inhaled cause harm to the lower respiratory system, and long-term exposure may compromise lung function.

Jones (1999) claims that when particles are inhaled, the airways become irritated and constricted. These particles absorb a lot of toxic gasses and remove them from the air, which is another significant problem. The gasses are breathed in tandem and reach the lungs when these particles are inhaled. Adults who have been exposed to tobacco smoke typically have pharyngitis, rhinitis, coughing, headaches, eye discomfort, and bronchial constriction. Asthma, bronchitis, pneumonia, and respiratory infections can all strike children. There is evidence that this smoke has the potential to cause cancer, and that nicotine raises that possibility.

Many VOCs are opioids and Central Nervous System (CNS) depressants. Moreover, they irritate the skin, respiratory system, and eyes. Certain VOCs can impair neurobehavioral

functions and even cause cancer when exposed to them at very high concentrations. Volatile organic compounds can also interact with each other, increasing negative health effects (Zhang & Smith, 2003).

## 7. Outlook

There has been an increase in public awareness of the harmful impacts of airborne particle pollution (Li et al., 2020). Particle size, shape, chemical composition, personal characteristics, climatic circumstances, all affect the level of exposure to  $PM_{2.5}$  (Song et al., 2015).

It is necessary to maintain the concentration of pollutants at a level that does not harm human health, for this reason it is necessary to carry out correct environmental management, in which air pollution monitoring is a fundamental pillar and can collect the necessary information to evaluate the degree of air pollution and help establish strategies (Barranquilla Verde, 2018).

The composition of  $PM_{2.5}$  is known to be very complex, especially in urban areas, because many different industrial, commercial, and residential sources contribute to concentrations. Therefore, quality PM concentration and related chemical content should be assessed for all potential sources of pollution, for which researchers often use different modeling approaches for source distribution (Song et al., 2015).

Many factors led to the necessity of taking measurements both indoors and outdoors at the same time: Most people spend more than 90% of their time indoors; the population's actual exposure to  $PM_{2.5}$  will be underestimated or overestimated if data are only gathered from external environmental monitors; and reports claim that in some microenvironments, exposure time and space vary significantly and that there is a relationship between indoor and outdoor air (Song et al., 2015).

Several elements need to be considered to comprehend the differences between internal and exterior settings. Particles that enter the interior from the exterior through the continuous exchange of air are the primary variables (Carrion-Matta et al., 2019a).

Instead of performing a single measurement in an exposed environment, it may be more effective to take several measurements simultaneously. For instance, there is a significant association between  $PM_{2.5}$  levels in residential and urban outdoor areas ( $r = 0.90$ ,  $p = 0.0001$ ). The findings of the same study also revealed that non-smokers and indoor  $PM_{2.5}$  had a significant link ( $r = 0.71$ ), and non-smokers and home penetration rate or internal/external ratio had a moderate correlation ( $r = 0.56$ ,  $p = 0.003$ ) demonstrating the influence of important environmental and behavioral parameters, including the amount of indoor traffic, on indoor  $PM_{2.5}$  concentration and composition such as occupancy, ventilation rates, and seasonality (Carrion-Matta et al., 2019b).

The features of the space, including its age, maintenance history, and building materials, as well as elements like the occupational density of each type of volume, suggest that these elements have an impact on the permeability. At this stage, the building's age can have an impact on penetration, which then has an impact on the number of indoor pollutants (Rivas et al., 2015).

If there are no substantial interior sources like those indicated above that could significantly influence human exposure, both fixed-site environmental monitors and outside residential measures could offer a decent estimate of individual exposure in this situation (Song et al., 2015).

Studies have investigated how much  $PM_{2.5}$  kids are exposed to in schools. It is generally known that healthy people are far less vulnerable to air pollution than very young children.

Measurements in schools have been used in a significant portion of recent studies on the internal and external settings to try and answer this question. Children who are active are more likely to be exposed to pollutants outside of the classroom. However, if there is enough information on residential indoor and outdoor PM<sub>2.5</sub>, monitoring at schools may be able to provide relevant information that may be beneficial in predicting overall exposure (Song et al., 2015).

Results can be compared with other studies, and common PM<sub>2.5</sub> pollutant behaviors can be found. For this, data were gathered with the following restrictions:

- i) Research conducted in educational settings, ideally in schools, given the amount of time kids spend there.
- ii) Research using measurements in both indoor and outdoor settings.
- iii) Research on the values of the Interior/Exterior interaction.

In the northeastern United States, outdoor PM<sub>2.5</sub> concentrations ( $6.5 \text{ g m}^{-3}$ ) were discovered to be marginally higher than interior concentrations ( $5.2 \text{ g m}^{-3}$ ), with a mean ratio of 0.8. The primary external sources in this study were calcium-rich particles, motor vehicles, secondary pollutants, soil dust, biomass burning, and marine aerosols; however, there is little evidence to support that all these particles completely permeate the interior environment (Carrion-Matta et al. 2019a).

According to a study conducted in the Gaza Strip, Palestine, thunderstorms were to blame for the high indoor PM<sub>2.5</sub> concentration ( $103.96 \text{ g m}^{-3}$ ) and high indoor/outdoor ratio (2,2) dust during the winter, and more frequently from internal sources like the usage of chalk on the blackboard and the resuspension of classroom floor particles from student activities (Elbayoumi et al., 2013).

In Mohammadyan and Shabankhani (2013) research, there is a substantial association between the concentrations of PM<sub>2.5</sub> in indoor spaces ( $46.6 \text{ g m}^{-3}$ ) and outdoors ( $36.9 \text{ g m}^{-3}$ ) in Sari, Iran. Due to the area's moderate climate, which typically supports the existence of natural ventilation devices, it is likely that outside air enters classrooms at schools close to highways through doors and windows.

The study by Rivas et al. (2014) conducted in Barcelona revealed that internal levels ( $37 \text{ g m}^{-3}$ ) were higher than external levels ( $29 \text{ g m}^{-3}$ ), despite the city having one of the greatest vehicle densities in Europe and one of the most significant Mediterranean ports. It is noted that this happens because of a significant contribution from internal sources and minerals that came from indoor activities.

Wichmann et al. (2010) compiled a total of 34 buildings spread over 6 schools, 10 preschools, and 18 households for their study in Stockholm, Sweden. This shows a significant rate of air exchange and penetration in internal environments, indicating that there are inefficient filters in ventilation systems. The concentrations of internal ( $8.1 \text{ g m}^{-3}$ ) and external ( $9.7 \text{ g m}^{-3}$ ) were found with little variation and were statistically insignificant.

## 8. Conclusions

The detrimental impacts of airborne particulate matter pollution are becoming more widely recognized. Particulate matter is constantly monitored and managed due to its harmful impacts on human health and the environment, and its regulations have a history of becoming more stringent as a result.

To show how different settings might produce different variations in concentrations, it is required to build new research methodologies. With this study, it is feasible to determine the



differences in the concentrations of particulate matter  $PM_{2.5}$  in indoor and outdoor environments. that the assessment of diverse surroundings be considered, to make it easier to identify.

Although there hasn't been much research done on this subject, evaluation of particle pollution in indoor environments has become more popular recently. As a result, it is anticipated that in the future, it will be feasible to do more research of this kind and study the behavior of pollutants to design policies that will lessen their negative effects on both people and the environment.

Strictly controlling the maintenance of the two ventilation systems and other factors involved in the quality of the interior would reduce the risk of air contamination and consequently decrease the health expenses of the population residing in these environments. By making smart decisions and taking preventive measures against the syndrome of the bad building we can keep all individuals healthy, comfortable, and productive.

#### Credit author statement

Adilson Celimar Dalmora: Methodology, Writing-Reviewing, and Editing.

Matheus da Silva Civeira: Conceptualization, Methodology, Data curation, Writing.

Samuel do Nascimento de Campos: Original draft preparation, Writing Reviewing.

Hugo Gaspar Hernández Palma: Support in analyzes, Visualization, Investigation, Data curation.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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