Plant Archives Vol. 23, No. 2, 2023 pp. 269-275 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2023.v23.no2.045

A COMPREHENSIVE REVIEW OF INDOOR AIR POLLUTANTS: SOURCES, EFFECTS, AND MITIGATION STRATEGIES

Sashi Yadav[1], Narender Kumar[2], Vishesh Kumar[2], Vidyasagar Jha[2] and Sunil Kumar Chhikara[1]*
[1]Maharshi Dayanand University, Rohtak-124001, Haryana, India
[2]Ministry of Environment, Forest and Climate Change, New Delhi, Delhi-110003, India
*Corresponding author
(Date of Receiving : 05-06-2023; Date of Acceptance : 09-09-2023)

ABSTRACT

Air pollution is a global issue with far reaching consequences for human health, ecosystems, and the planet's climate. This review paper provides a comprehensive analysis of various indoor air pollutants, their sources, impacts, and the strategies employed to mitigate their adverse effects. By exploring the origins and characteristics of different indoor air pollutants, including primary and secondary pollutants, this paper focus on the diverse emissions resulting from anthropogenic activities, vehicular emissions, industrial processes, and natural sources. The subsequent examination of the health effects on humans, ranging from respiratory diseases to cardiovascular complications and even neurological disorders, underscores the urgent need for effective mitigation strategies. To address these challenges, this paper critically evaluates an array of mitigation approaches. It discusses the role of regulatory policies, technological innovations, building planning initiatives, and public awareness campaigns in reducing air pollutant emissions.

***Keywords* :** Indoor, Pollutants; Health effects; Mitigation; Pollution

Introduction

Indoor air quality (IAQ) is a critical determinant of human health and well-being, considering that individuals spend a significant portion of their lives indoors. While many people believe that indoor spaces are free from external pollution, this is frequently not the case. Numerous forms of indoor air pollution offer serious health hazards and require our immediate attention. Indoor environmental elements have a substantial positive impact on human welfare since most people spend 90% of their time indoors, primarily at home or at work (Leech *et al*., 2002). According to the World Health Organization, indoor air pollution causes 3.8 million deaths annually. Indoor air pollution (IAP) caused by different activities such as cooking, smoking, using electronics, using consumer products, or emission from building materials inside of homes or buildings. Buildings can contain dangerous contaminants such as biological pollutants, particulate matter, volatile organic compounds, carbon monoxide, and others (Kumar and Imam, 2013). Over the past ten years, research on air quality regulation has begun to shift from outdoor to indoor settings due to the changes in lifestyle brought on by increasing urbanization (Ekmekcioglu and Keskin, 2007). It has been suggested that poor indoor air quality (IAQ) can harm human health by contributing to illnesses that are linked to buildings (Hromadka *et al*., 2017). A wide variety of disorders can be brought on by both short and long term IAP exposure (Koivisto *et al*., 2019). Therefore, the use of monitoring systems is crucial to the management of indoor air quality.

IAP typically consists of a complicated mixture of gaseous and particle materials. Depending on the sources, emission rates, and ventilation settings, IAP compositions vary considerably (Hamanaka and Mutlu, 2018) Therefore, identifying the sources of air pollution is crucial for efficient IAQ control. Additionally, it is thought crucial to develop monitoring systems for determining indoor pollutant concentrations as well as important methods for enhancing and controlling IAQ.

The present study emphasizes the sources, causes, and its health effects of the IAP in this paper. It also identifies and discusses health issue and building-associated illness related to an IAQ decrease. Finally, it present the most recent and trending strategies for the mitigation of pollutant concentrations and better IAQ. Innovative materials-based sensors, intelligent monitoring systems, and smart houses are anticipated to be some of the promising approaches for monitoring and controlling IAQ in the future.

Indoor Air Quality (IAQ) and Indoor Air Pollution (IAP)

According to the EPA, indoor and outdoor air quality (IAQ) refers to how well a building's occupants are able to breathe and how well it influences their health. The term "indoor air pollution," on the other hand, refers to the presence of pollutants like particulate matter (PM), volatile organic compounds (VOCs), physical chemicals, and biological factors, inorganic compounds, that are all present in non-industrial building at higher concentrations and can all have a negative impact on human health. To protect individuals from these contaminants, IAQ has been developed as a study area (Argunhan and Avci, 2018). The main elements taken into account while assessing IAQ are pollutant concentrations, ambient variables (temperature, airflow, and relative humidity), light, and noise.

According to Peng *et al.* (2017) and Marc *et al.* (2018), three key factors-outside air quality, human activities inside buildings, and building and construction material, furniture and equipments, have a significant impact on indoor air quality (IAQ) in residential area or building. It is widely known that outside pollutant concentrations and building air tightness have a major impact on indoor air quality (IAQ) due to the likelihood of contaminants being carried from outside to inside (Poupard *et al.*, 2005). Ventilation enables external pollutants to migrate from the outside to the indoor environment when concentrations of them increase. As a result, the link between outdoor air pollution and IAQ largely depends on ventilation rate in addition to the lifetimes and mixing ratios of these pollutants (Liang, 2013). According to Micallef *et al.* (1998), IAP is frequently triggered by waste gas emissions, tobacco smoke, pesticides, solvents, cleaning supplies, particulates, dust, mould, and fibers, as well as allergies. Millions of insects, such as roaches and dust mites, as well as fungi, bacteria, viruses, pollen, spores, and mould can also flourish as a result of human activities. Combustion sources and cooking activities have an impact on the emissions of particulate matter (PM), carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon monoxide (CO), into indoor air environments (Strom *et al.*, 1994; Linaker *et al.,* 1996). Ozone (O_3) and volatile compounds are also released by equipment like computers, photocopiers, printers, and other office supplies. Common building materials like poly (vinyl chloride) PVC floor covering, lacquer, paint, linoleum, parquet, rubber carpet, adhesive, sealant, acetophenone, 2-ethylhexanol, ketones, glycols, toluene, styrene, texanol, siloxane, and formaldehyde can release toxic compounds. In addition to headaches, eye irritation, dizziness, and fatigue, exposure to these substances has been linked to a number of health issues, including minor to acute respiratory illnesses like cold, cough, and bronchitis, cardiovascular diseases, as well as lifelong illness such as chronic asthma, even in families without the history of these condition (Guak *et al.*, 2021; Manuel *et al.*, 2021). When children breathe in significant amounts of chemical pollutants from the environment, their development can be hindered, and their immunological and respiratory systems can suffer (WHO, 2018). The development and operation of the lungs can be harmed by excessive indoor air pollution, which also increases the risk of metabolic illnesses in human physiology. Additionally, it prevents children from developing their cognitive abilities and maturing their brains. According to Lee *et al.* (2020) and Jafta *et al.* (2017), a child's IQ is significantly impacted by their IAQ. According to a study, children exposed to contaminated air while still in the womb may experience a four-point decline in IQ by the time they are five years old (Perera *et al.*, 2019).

Major Pollutants in Indoor Air Environment: Sources, effects and their mitigation

Volatile organic compounds (VOCs)

Chemicals including paints, cleaning chemicals, glues, building materials, and even some furniture all release VOCs as gases into the air. More serious long-term health problems such as respiratory and central nervous system issues as well as short-term health impacts like eye, nose, and throat irritation are possible. It was found that the concentration of VOCs is increasing at an alarming rate in urban areas compared to rural areas due to extensive use of vehicles, industries, biomass burning, gas leakage etc and an increase in population in rural areas due to burning of biomass for cooking. An increase in VOCs emission affects human health and climate change. Natural sources such as biogenic sources constitute higher VOCs emission worldwide. Most of the studies have reported that the VOCs concentration was found to be higher in the winter season in indoor environments as compared to outdoor environments. Most people spend their maximum time in indoor climatic conditions, and they have possible cancer risk and other health effects (Yadav *et al.*, 2022a). Biogenic and anthropogenic VOC emission leads to the occurrence of different photochemical reactions and results in tropospheric ozone formation. Ozone formation was observed to be higher in urban areas due to a higher concentration of oxides of nitrogen (NO_x) than in rural areas. Atmospheric ozone formation requires photolysis of NO_2 at < 424nm wavelength. VOCs act as a precursor for ozone production through OH radical initiated oxidation and consequent reaction with NOx in the presence of sunlight and led to the production of other secondary oxidant pollutants. The primary source of the emission of NO_x is vehicles and industries.

Rostami *et al.* (2021) studied BTEX levels in photocopy and printing shops in Iran and the concentration of BTEX was influenced by printing, copying machines and ventilation systems. BTEX concentration was found to be 93.6, 150.6, 34.3 and 29.5µg/m, respectively. Lifetime cancer risk in photocopy and printing shops caused by benzene, and ethylbenzene were 44.4 x10^{-6} and 153.3 x10^{-6} with laser print and 23.4x10^{-6}, 54.2x10^{-6} with an inkjet printer, which was higher than the permissible limit prescribed by USEPA (US Environmental Protection Agency) and WHO (World Health Organization). Ari *et al.* (2020) observed the concentration of BTEX at 6.57, 31.3, 1.19 and 1.08µg/m^3 in a restaurant in Turkey. VOCs pollutants emitted from the kitchen and restaurant were influenced by the following factors such as ventilation, temperature, material type and fuel type. Lifetime cancer risk varied from 3.4x10^{-8} to 1.1 x10^{-5}, which causes possible cancer risk to people working in a restaurant. Cooking emissions and cooking fumes cause cancer risk and affect the indoor air quality of restaurants (Dai *et al.*, 2018).

Some VOCs are released by typical building supplies. Some wooden-based products, such as plywood or fiberboard, are frequently made using resins and varnishes that contain formaldehyde and other VOCs. VOCs (BTEX) are used as additives or solvents in paints, binders, plastics, and other building products. Use of low-emitting materials, such as improved paints (phenol resins instead of urea resins, polyurethane coatings, etc.), solid wood, or used furniture can help reduce some of these emissions (Environmental Protection Agency, 1995). By effectively sealing and storing these liquid components and minimizing storage periods to prevent leakages and emissions, VOC emissions from paints, adhesives, cleaning products, and fuels can be largely mitigated (US Environmental Protection Agency, 1995).

Particulate matter

(PM) is a term used to describe tiny airborne particles that can come from a variety of sources, including cooking, candle burning, smoking, and even outdoor air pollution that seep indoors. Smaller particles ($PM_{2.5}$) can get deeper into the lungs and even reach the bloodstream whereas larger particles (PM_{10}) can irritate the respiratory system. Due to its effects on a child's developing brain, it has reportedly been one of the pollutants that have been the subject of the most investigation (Jelili *et al.*, 2020).

Climate, interior location, specific source types, and modulating factors can all have a substantial impact on source profiles (chemical composition and size distribution) of indoor PM. For instance, the amount and type of external pollution, the concentration of oxidants, cooking methods, food ingredients, cooking oil composition, relative humidity, cooking temperature, and fuel type all have a significant impact on cooking emissions. However, secondary PM production activities, which involve interactions with gas-phase precursors released both indoors and outdoors, can also produce particles. For instance, O_3-initiated reactions (boosted by photo-oxidation), resulting from outdoor infiltration or from indoor ozonizers, with chemicals emitted from consumer goods, building materials, and cleaning products, can generate secondary particles indoors (Bergmans *et al.,* 2022).

The composition and source types of the PM affect its toxicity in different way. In a study conducted by Chitra and Nagendra, (2018) in a naturally ventilated school in Chennai, it was discovered that the 24-hour average concentrations of suspended particulate matter (SPM), PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ were 168.64 g/m^3, 135.88 g/m^3, 42.95 g/m^3, and 25.89 g/m^3, respectively. Singh et al., (2017) assessed the indoor air quality in a few Delhi-NCR schools and found that average $PM_{2.5}$ concentrations in both naturally and air-conditioned school buildings were significantly higher than those recommended by National Ambient Air Quality Standards, India (Mishra *et al.*, 2020).

An effective ventilation plan is essential to reducing the particulate matter concentration. This was supported by a study by Lee *et al.* (2020), which found that the concentration of particulate matter was significantly reduced in nursery facilities that used effective hygiene practices. Noting that indoor activities and controlled ventilation might help achieve better indoor air quality, it is important to note that indoor air pollutants over the set threshold were typically recorded during the occupancy duration.

By causing oxidative stress and the production of reactive oxygen species, PM causes respiratory epithelial inflammation and hypersensitivity, which can impair lung function. Chronic long-term exposure can result in remodeling, scarring, and fibrosis of the lung tissue, which can cause asthma, bronchitis, chronic obstructive pulmonary disease (COPD), and even lung cancer. In addition to causing inflammation, particulate matter also alters blood coagulation and raises the risk of death when exposure exceeds the threshold level. A key environmental risk factor for lung cancer and cardiovascular disease death is prolonged exposure to fine particle air pollution brought on by combustion (Girma and Kebede, 2019; Andersson *et al.*, 2020; Yadav *et al.*, 2022b).

Numerous indoor air pollutants, such as PM, BTEX, NO_x, or CO, are released in homes during combustion operations like cooking and heating. Indoor pollution is prevented from building up through increased ventilation rates and the lowering of these combustion emissions from stoves, boilers or fireplaces. Buildings' combustion equipment needs to be periodically inspected and maintained to avoid breakdowns and the release of dangerous pollutants into the air inside. Although biomass is becoming more and more popular in industrialized countries due to its increased sustainability, highly polluting fuels like kerosene or biomass must be replaced at home with cleaner fuels like electricity or natural gas (Gonzalez–Martin *et al.*, 2021).

Carbon monoxide

CO is an odorless, colorless gas that is created when fossil fuels like gas, oil, or coal are burned. Poorly vented stoves and fireplaces, faulty gas equipment and CO buildup are all risks that can result in fatally high quantities of CO.

A hazardous indoor air pollutant that mostly results from incomplete combustion is carbon monoxide (CO). When there is not enough air for combustion, household appliances like gas water heaters, furnaces and stoves emit carbon monoxide (CO). Smoking indoors and vehicle exhaust from linked garages both have a large impact. CO can be trapped within when vents and chimneys are blocked, making it difficult for combustion byproducts to escape.

CO causes serious health hazards, when breathed and it binds to hemoglobin more readily. Headaches, nausea, dizziness, and fatigue are brought on by even low-level exposure. Prolonged or high-level exposure can be life-threatening, leading to unconsciousness and death. Chronic exposure to low levels may cause cardiovascular difficulties, cognitive decline, and neurological abnormalities.

The greenhouse gases that are closely linked to climate change and global warming are impacted by carbon monoxide. The temperature of the soil and water should rise as a result, and severe weather or storms may develop. However, it has been observed to result in increased plant growth in laboratory and field trials (Emberson *et al.*, 2018; Manisalidis *et al.*, 2020).

For people safety and wellbeing, carbon monoxide (CO) as an indoor air contaminant must be minimized. To prevent CO exposure, it is crucial to put effective solutions into practice. Fresh air is ensured to dilute CO concentrations in spaces with potential CO sources, such as kitchens and garages, by proper ventilation. The hazards related to CO can be considerably decreased by performing routine maintenance on fuel-burning appliances, installing carbon monoxide detectors, and enforcing a strict no-smoking indoors rule. Further reducing CO emissions can be accomplished by keeping chimneys and flues clean, employing vent less heaters, or using electric substitutes. The prevention of CO-related events depends heavily on occupant education and awareness, including the value of ventilation and emergency action procedures. We can make indoor spaces free from the threats of carbon monoxide by combining these precautions and being watchful, giving everyone a safer and healthier place to live.

Nitrogen Oxide

Fossil fuel burning is primarily responsible for indoor nitrogen dioxide (NO_2). This happens in homes when gas is used for heating and cooking, as well as when people smoke inside. These activities cause the indoor environment to become NO_2 rich. Additionally, interior NO_2 levels can be increased by external sources such car exhaust entering through improperly sealed apertures. In comparison to gas cooking without pilots, nitrogen oxides (NO_x) and NO_2 levels were greater in homes with hob pilot burners. Self-reported use of kitchen exhaust fans was linked to lower NO_x and NO_2 exposure in residences in California, USA, where inhabitants cooked with gas for at least 4 hours per day (Mullen *et al.*, 2016).

Indoor NO_2 exposure can have negative health effects, especially on the respiratory system. For those who already have respiratory disorders like asthma, it can cause irritations like coughing, wheezing, and shortness of breath, which can be particularly uncomfortable. It is crucial to address indoor NO_2 since sustained exposure to high NO_2 levels can aggravate these symptoms and increase the risk of respiratory infections. Children, elderly people, and asthmatics are especially vulnerable to the negative effects of NO_2 exposure. Edoema, or the fluid filling of the intercellular gaps, is one of the indirect effects. Eye and nasal irritation, as well as pulmonary discomfort, are frequently reported at dosages of 15 to 25 ppm. Nitric acid vapour and related particles are produced when NOx combines with ammonia, moisture, and other substances, further harming human health (Rajoria *et al.*, 2023).

Multiple strategies can be used to reduce indoor NO_2 levels. In places where combustion takes place, like the kitchen, adequate ventilation is essential. Open windows and exhaust fans aid in spreading NO_2 concentrations. The effective operation and reduced NO_2 emissions of fuel-burning equipment are guaranteed by routine maintenance. As an alternative, thinking about electric appliances can completely reduce NO_2 emissions while in operation. NO_2 exposure can be decreased by restricting indoor smoking or placing it in well-ventilated settings. Infiltration of external NO_2 can be stopped by caulking cracks around windows and doors. A better indoor environment can be achieved by monitoring indoor air quality and encouraging public transport to reduce outdoor NO_2 sources.

Biological Contaminants

Animal dander, dust mites, mould spores, and pollen are examples of biological contaminants. Mould can grow as a result of inadequate ventilation, high humidity, and wetness, which can aggravate allergies and create respiratory issues. The sources of biological pollutants in indoor air are numerous. Skin cells, hair, and dander shed by people and animals, which can become airborne particles; contribute to the problem (Tran *et al.*, 2020). Mould and bacteria may be present in indoor plants and potted soil. If ventilation and HVAC systems are not properly maintained, impurities can build up, and pollen, viruses, and germs from the outside can enter the building through doors, windows, or vents.

The health and indoor air quality can be significantly impacted by these biological pollutants. Exposure to allergenic particles like pollen or pet dander frequently causes respiratory problems, aggravating allergies and asthma. Infectious diseases can be brought on by airborne viruses and bacteria, especially in crowded or poorly ventilated areas. Pet dander and pollen can cause allergic reactions, such as sneezing and skin rashes. Long-term contact with indoor mould can irritate the skin and eyes, tiredness, and cause respiratory problems.

Biological contamination mitigation requires a diverse strategy. Dust, dander, and mould can be reduced with routine cleaning and upkeep. Mould cannot thrive in environments with humidity levels below 50%, and contaminants can be removed by using air purifiers and sufficient ventilation. Reduced pet-related allergies can be achieved through careful pet grooming and cleanliness practices. Maintaining HVAC systems, caulking cracks, and taking careful care of indoor plants to avoid soil mould growth are all crucial. By often washing your hands, you can reduce the spread of viruses within. These techniques can improve interior settings by lowering the negative effects of biological pollutants on air quality and human health.

Radon

Radon, a naturally occurring radioactive gas, can seep into buildings from the ground. Prolonged radon exposure can increase the chance of developing lung cancer. The World Health Organization (WHO) describes radon as an inert gas that is constantly present in both indoor and outdoor air and is released during the decay of uranium (238U) (WHO, 2009). Exposure to radon carries significant health risks for those exposed, as it is the second-leading cause of lung cancer, the main cause of cancer-related fatalities globally. Radioactive contamination, whether of natural or human origin, poses a major risk to the environment and public health (WHO, 2009). Normal causes include human activity or the use of radioactivity or ionizing radiation for medicinal or diagnostic purpose. Radon makes up a large portion of all naturally occurring radioactive compounds that can have an immediate effect on people and the environment because it is the major sources of radiation to which population are exposed. Second only to smoking as a primary cause of lung cancer, radon is a silent indoor air contaminant. Long-term exposure to high radon levels can raise the risk of lung cancer, especially among smokers. When inhaled, radon decay products, also known as radon daughters or radon progeny, can adhere to airborne dust and aerosols and lodge in the lungs where they can produce damaging radiation. As is the case in many parts of the United States, artificial radiation can occasionally dominate natural radiation, magnifying the effects of natural radiation on populations exposed to it (Ruano and Wakeford, 2020). Because of this, it is also anticipated that exposure to radon will have more profound and long-lasting impacts on human health than exposure to radiation from other sources. This is due to the fact that this radiation can occasionally be greater and more hazardous to both human and the environment, especially in rare instances resulting from manmade events, such as accidents (WHO, 2009).

The use of insulation materials, like specialized paint and screen that prevent the passage of radon from the ground to indoor spaces can be required during renovation of already-existing buildings as well as during the construction phase of new buildings. When practical, air boxes can even be built between the ground and the floors or walls. The construction of routines for opening doors and windows to produce air circulation circuits, in lieu of constant monitoring, may be used to perform manual ventilation processes for spaces (Nunes *et al.*, 2022). This is due to the fact that actions taken to improve the ventilation of indoor spaces involve installing air-renewal systems, which may or may not be linked to sophisticated systems for ongoing monitoring of air quality indicators.

Challenges

Effectively implementing mitigation methods for indoor air pollution involves a complicated collection of issues as follows:

1. First and foremost, there is a big obstacle with the cost. It can be expensive to implement several mitigation strategies, such as modernizing ventilation systems, installing air purifiers, or resolving structural problems that encourage the spread of pollutants. Individuals, homes, or organizations may be discouraged from taking proactive measures to enhance indoor air quality due to this financial burden.
2. The lack of knowledge and instruction regarding indoor air pollutants is another major issue. The potential health effects brought on by pollutants like mould, particulate matter, or volatile organic compounds are frequently underestimated. People may become complacent as a result of their lack of knowledge, failing to take appropriate precautions or realizing how urgent the situation is.
3. Particularly for older buildings or structures with architectural restrictions, accessibility and viability of mitigation solutions can be limiting concerns. In some cases, it may not be practical or financially feasible to retrofit ventilation systems or make other structural changes, leaving inhabitants vulnerable to indoor contaminants.
4. The need for maintenance presents a continual difficulty. The effectiveness of many mitigation methods depends on routine replacement or cleaning, such as filters in ventilation systems or air purifiers. The advantages of initial investments can be diminished over time if maintenance schedules are not followed, rendering these systems worthless.
5. Equity related issues are also relevant. Socioeconomic differences may make it harder for some people or groups to implement mitigation strategies. The equitable access to clean indoor air for all people is a difficult problem that calls for all encompassing solutions.

Future Directions

1. Advanced sensor based technology: Real-time monitoring of indoor air quality will be possible because to ongoing developments in sensor technology. These sensors will become more accessible, portable, and able to identify a greater variety of pollutants, such as biological contaminants, certain volatile organic compounds (VOCs), and ultrafine particles.
2. Data integration: Data integration from many sources, such as sensors, wearable technology, and building automation systems, will become more and more important in future studies. Finding patterns, trends, and connections between indoor air contaminants, health consequences, and building conditions will be made easier with the aid of advanced data analytics and machine learning approaches.
3. Policy and Regulation: The creation and revision of indoor air quality standards and regulations will receive more attention. Policymakers will be educated by research on the necessity for tougher regulations and the creation of efficient compliance and enforcement procedures.
4. Customer Behavior and Interventions: It will be important to comprehend customer behavior with reference to indoor air quality. Research will examine the effectiveness of various interventions, including air purifiers, filtration systems, and indoor plants, as well as ways to motivate people and households to adopt healthier indoor practices.
5. Cross-Disciplinary Collaboration: It will be crucial for professionals in domains like psychology, public health, engineering, and architecture to work together. Interdisciplinary study will offer comprehensive understandings of indoor air quality and wider societal effects.

Conclusion

This review study has highlighted the numerous origins, wide-ranging effects, and several mitigation tactics related to indoor air pollution. These pollutants can have a serious negative influence on human health, causing everything from respiratory issues to cognitive impairments. They come from a range of sources, including combustion, biological contaminants, and chemicals. It is clear that there is a need for complete mitigating measures, such as sufficient ventilation, air purification, and behavioral modifications.

Collaboration in research will also be important for expanding our knowledge of indoor air quality. To that purpose, interdisciplinary research amongst specialists in disciplines like environmental science, public health, architecture, engineering, and behavioral sciences should be prioritized in the future. With this strategy, indoor air quality may be examined holistically, taking into account the relationships between contaminants, building design, human behavior, and health outcomes.

We must continue to be adaptive as we advance in order to meet new difficulties, such as the discovery of emerging contaminants and the effects of climate change on interior settings. We may work towards creating healthier interior environments that enhance wellbeing and lessen the burden of indoor air pollution on people and society at large by encouraging collaboration and embracing cutting-edge technology and approaches. In this approach, collaboration and research will be at the forefront of efforts to enhance indoor air quality and guarantee a healthy future for all.

References

Andersson, E., Sällsten, G., Lohman, S., Neitzel, R. and Torén, K. (2020). Lung function and paper dust exposure among workers in a soft tissue paper mill. *International Archives of Occupational and Environmental Health*, 93(1): 105-110.

Argunhan, Z. and Avci, A.S. (2018). Statistical evaluation of indoor air quality parameters in classrooms of a university. *Adv. Merteorol.* , *2018*, 4391579.

Ari, A., Ari, P.E., Yeni soy-Karakas, S. and Gaga, E.O. (2020). Source characterization and risk assessment of occupational exposure to volatile organic compounds (VOCs) in a barbecuerestaurant. *Build. Environ*., 174: 106791.

Bergmans, B., Cattaneo, A., Duarte, R.M., Gomes, J.F., Saraga, D., Ródenas García, M. and Mihucz, V.G. (2022). Particulate matter indoors: a strategy to sample and monitor size-selective fractions. *Applied Spectroscopy Reviews*, 57(8): 675-704.

Chithra, V.S. and Nagendra, S.M.S. (2018). Source identification of indoor particulate matter and health risk assessment in school children. https:// doi.org/ 10.1061/(ASCE)HZ.2153-5515.0000390

Dai, W., Zhong, H., Li, L., Cao, J., Huang, Y., Shen, M. and Ho, K.F. (2018). Characterization and health risk assessment of airborne pollutants in commercial restaurants in northwestern China: Under a low ventilation condition in wintertime. *Sci. Total Environ.*, 633: 308-316

Ekmekcioglu, D. and Keskin, S.S. (2007). Characterization of indoor air particulate matter in selected elementary schools in istanbul, turkey. *Indoor Built Environ.*, 16: 169–176.

Emberson, L.D., Pleijel, H., Ainsworth, E.A., den Berg, M., Ren, W. and Osborne, S. *et al*. (2018). Ozone effects on crops and consideration in crop models. *Eur J Agron.,* 100: 19–34.

Girma, F. and Kebede, Z. (2019). Dust exposure associations with lung function among ethiopian steel workers. *Annals of Global Health*, 85(1).1

Gonzalez-Martin, J., Kraakman, N.J.R., Perez, C., Lebrero, R. and Munoz, R. (2021). A state–of–the-art review on indoor air pollution and strategies for indoor air pollution control. *Chemosphere*, 262: 128376. Guak, S., Kim, K., Yang, W., Won, S., Lee, H. and Lee, K. (2021). Prediction models using outdoor environmental data for real-time PM_{10} concentrations in daycare centers, kindergartens, and elementary schools. *Build Environ,* 187:107371.

Hamanaka, R.B. and Mutlu, G.M. (2018). Particulate matter air pollution: Effects on the cardiovascular system. *Front. Endocrinol.*, 9: 680.

Hromadka, J., Korposh, S., Partridge, M.C., James, S.W., Davis, F., Crump, D. and Tatam, R.P. (2017). Multi-parameter measurements using optical fibre long period gratings for indoor air quality monitoring. *Sens. Actuat. B Chem.*, 244: 217–225.

Jafta, N., Barregard, L., Jeena, P.M. and Naidoo, R.N. (2017). Indoor air quality of low and middle income urban households in Durban. *South Africa Environ Res.,* 156: 47–56.

Jelili, M.O., Gbadegesin, A.S. and Alabi, A.T. (2020). Comparative analysis of indoor and outdoor particulate matter concentrations and air quality in Ogbomoso Nigeria. *J Heal Pollut.,* 10(28):1–16.

Koivisto, A.J., Kling, K.I., Hänninen, O., Jayjock, M., Löndahl, J., Wierzbicka, A., Fonseca, A.S., Uhrbrand, K., Boor, B.E. and Jiménez, A.S. (2019). Source specific exposure and risk assessment for indoor aerosols. *Sci. Total Environ.*, 668: 13–24.

Kumar, P. and Imam, B. (2013). Footprints of air pollution and changing environment on the sustainability of built infrastructure. *Sci. Total Environ.*, 444: 85–101.

Lee, E., Dressel, A., Bell-Calvin, J., Garacci, Z. and Steinberg, J. (2020). Assessment of indoor air quality and cleaning behaviors in urban child care facilities. *J Allergy Clin Immunol.,* 145(2): AB83.

Leech, J.A., Nelson, W.C., Burnett, R.T., Aaron, S. and Raizenne, A.M.E. (2002). It's about time: A comparison of canadian and american time–activity patterns. *J. Expo. Sci. Environ. Epidemiol.*, 12: 427–432.

Liang, J. (2013). Other toxins in the air. In *Chemical Modeling for Air Resources: Fundamentals, Applications and Corroborative Analysis*; Elsevier: Amsterdam, The Netherlands, pp. 221–237.

Linaker, C.H., Chauhan, A.J., Inskip, H., Frew, A.J., Sillence, A., Coggon, D. and Holgate, S.T. (1996). Distribution and determinants of personal exposure to nitrogen dioxide in school children. *Occup. Environ. Med.*, 53: 200–203.

Manisalidis, I., Stavropoulou, E., Stavropoulos, A. and Bezirtzoglou, E. (2020). Environmental and health impacts of air pollution: a review. *Frontiers in Public Health*, 8: 14.

Manuel, P., João, L., João, V., Ana, I. and Tiago, F. (2021). Kindergartens and nurseries in central Portugal assessments of indoor environment quality. *Int J Sustain Build Technol Urban Dev.,* 12(1): 27–43.

Marć, M., Śmiełowska, M., Namieśnik, J. and Zabiegała, B. (2018). Indoor air quality of everyday use spaces dedicated to specific purposes-A review. *Environ. Sci. Pollut. Res.*, 25: 2065–2082.

Micallef, A., Caldwell, J. and Colls, J.J. (1998). The influence of human activity on the vertical distribution of airborne particle concentration in confined environments: Preliminary results. *Indoor Air*, 8: 131–136.

Mishra, A.K., Mishra, P., Gulia, S. and Goyal, S.K. (2020). Assessment of indoor fine and ultra-fine particulate matter in a research laboratory. In *Indoor Environmental Quality: Select Proceedings of the 1st ACIEQ* (pp. 19-26). Springer Singapore.

Mullen, N.A., Li, J., Russell, M.L., Spears, M., Less, B.D., Singer, B.C. (2016) Results of the California Healthy Homes Indoor Air Quality Study of 2011–2013: Impact of natural gas appliances on air pollutant concentrations. Indoor Air, 26: 231–245

Nunes, L.J., Curado, A., Graça, L.C.D., Soares, S. and Lopes, S.I. (2022). Impacts of indoor radon on health: a comprehensive review on causes, assessment and remediation strategies. *International Journal of Environmental Research and Public Health*, 19(7): 3929.

Peng, Z., Deng, W. and Tenorio, R. (2017). Investigation of indoor air quality and the identification of influential factors at primary schools in the north of china. *Sustainability*, 9: 1180.

Perera, F., Ashrafi, A., Kinney, P. and Mills, D. (2019). Towards a fuller assessment of benefits to children's health of reducing air pollution and mitigating climate change due to fossil fuel combustion. *Environ Res.*, 172:55–72.

Poupard, O., Blondeau, P., Iordache, V. and Allard, A. (2005). Statistical analysis of parameters influencing the relationshipbetween outdoor and indoor air quality in schools. *Atmos. Environ.*, 39: 2071–2080.

Rajoria, N., Jhamaria, C., Sharma, S., Singh, N., Ameriya, T. and Gupta, A. (2023). Sources and Effects of Indoor Air Pollutants: A Review. *Ann. For. Res*, 66(1): 1035-1047.

Rostami, R., Fazlzadeh, M., Babaei-Pouya, A., Abazari, M., Rastgho, L., Ghasemi, R. and Saranjam, B. (2021). Exposure to BTEX concentration and the related health risk assessment in printing and copying centers. *Environmental Science and Pollution Research*, 28: 31195-31206.

Ruano-Ravina, A. and Wakeford, R. (2020). The increasing exposure of the global population to ionizing radiation. *Epidemiology*, 31: 155–159.

Singh, P., Arora, R. and Goyal, R. (2017). Indoor air quality assessment in selected schools of Delhi NCR, India. *Int J Appl Home Sci.,* 4(5&6): 389–394.

Ström, J., Alfredsson, L., Malmfors, T. and Selroos, O. (1994). Nitrogen dioxide: Causation and aggravation of lung diseases. *Indoor Environ.*, 3: 58–68.

Tran, V.V., Park, D. and Lee, Y.C. (2020). Indoor air pollution, related human diseases, and recent trends in the control and improvement of indoor air quality. *International journal of environmental research and public health*, 17(8): 2927.

World Health Organization (2018) Air pollution and child health: prescribing clean air. Summary. World Health Organization, Geneva (WHO/CED/PHE/18.01). Licence: CC BY-NC-SA 3.0 IGO

World Health Organization. *WHO Handbook on Indoor Radon: A Public Health Perspective*, World Health Organization: Geneva, Switzerland, 2009.

Yadav, S., Dhankhar, R. and Chhikara, S.K. (2022b). Significant Changes in Urban Air Quality during Covid-19 Pandemic Lockdown in Rohtak City, India. *Asian Journal of Chemistry*, 34(12): 3189-3196.

Yadav, S., Dhankhar, R. and Chhikara, S.K. (2022a). Volatile Organic Compounds in Ambinet Air: Potential Sources, Distribution and Impact. *Ambient Science*, 9(3): 22-28.