A study on common Indoor Air pollutants in Homes: Identification, sources, and mitigation strategies

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Abstract:

Given that people spend a large amount of time indoors, indoor air pollution is a serious environmental health concern. This investigation looks at prevalent indoor air contaminants that are present in homes, pinpoints their sources, and offers workable reduction techniques. Particulate matter (PM), formaldehyde, volatile organic compounds (VOCs), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3), radon, particulate matter (PM), and biological contaminants like mould, dust mites, and pet dander are some of the major pollutants that were investigated. These pollutants originate from a variety of sources, including construction materials, combustion processes, and infiltration of outdoor air, as well as common household items like paints, furnishings, and cleaning chemicals. The poll also emphasises how human activities like cooking and smoking contribute to higher levels of indoor air pollution. The article goes into great depth on mitigation techniques, emphasising the use of air purifiers, better ventilation, low-emission material selection, and routine HVAC system maintenance. The study highlights how crucial public education and awareness campaigns are to lowering indoor air pollution exposure and safeguarding public health. This survey seeks to provide a clear understanding of indoor air quality challenges and workable solutions for healthier living environments through a thorough examination of the literature and existing case studies.

Keywords: A survey; common Indoor Air pollutants; identification; sources; and mitigation strategies

1.0. Introduction:

Although the idea of outdoor air pollution has been understood and researched for many years, interior air quality (IAQ) has only now come to be recognised as a serious health risk. Indoor air pollution was made possible by the industrial revolution and the accompanying move towards indoor living. People spent more time indoors and relied more on enclosed environments for work, recreation, and shelter as societies grew more industrialized.[1] Industrial Sanitation: Industrial hygiene procedures are responsible for the early detection of indoor air quality issues. Due to the numerous harmful substances that workers in industries and mines were exposed to, precautions were developed to protect their health. The foundation for knowledge on the connection between interior settings and human health was established by these early initiatives. Sick Building Syndrome: In the 1970s and 1980s, the phrase "sick building syndrome" became well-known. It was used to characterise circumstances in which building inhabitants complained about their health without pinpointing a particular cause while spending time indoors. This phenomenon made it clear that more study on interior air quality is required. Legionnaires' disease: The disease's 1976 epidemic raised serious concerns about the possible health dangers posed by tainted building water systems. Investigations investigating the function of water-borne pathogens in indoor air quality were sparked by this incident. Rise of Environmental Consciousness: In the later half of the 20th century, air pollution became more widely recognised due to the developing environmental consciousness [2]. People's attention turned to indoor spaces as their concerns about the quality of the air they inhaled increased. Developments in the Field of Analysis: Scientists are now better equipped to identify and quantify a wide variety of indoor air contaminants because to the development of sophisticated analytical instruments. The advancement of technology has made it easier to comprehend the origins and effects of these toxins on human health. Development of Regulations and Policies: In order to safeguard the public's health, governments and regulatory bodies started to realise how important indoor air quality was and put standards and laws in place. These initiatives included creating building rules, placing restrictions on particular contaminants, and encouraging studies on indoor air quality. Even with the great advancements in knowledge and solutions, indoor air pollution is still a complicated problem with unresolved issues. New possible pollutants are constantly being introduced by the ongoing development of new products, materials, and construction technologies. Furthermore, the prevalence of allergies and respiratory conditions emphasises the necessity for ongoing study and practical mitigation techniques. Since we spend most of our time indoors, we frequently believe that these areas are safe havens from the contaminated outside world. But the real world is not at all perfect. A increasing body of research is connecting indoor air quality (IAQ) to a variety of respiratory, allergy, and other health problems, making it an important public health concern. Chemical, biological, and physical pollutants are only a few of the many types of contaminants that are included in indoor air pollution. These pollutants may come from a variety of sources, including human activity, home goods, construction materials, and outdoor infiltration. Many indoor pollutants are particularly sneaky since they are invisible and can build up over time without being easily seen. The purpose of this survey is to provide information about common indoor air pollutants found in homes, their sources, and practical mitigation techniques [3]. People may make their homes safer and healthier by learning about the types of toxins they are exposed to and how to lower their levels. Determining the origins of prevalent indoor air contaminants. Evaluating the effects of these contaminants' exposure on health. Investigating different mitigating techniques to enhance the quality of indoor air. Offering doable advice to homeowners on how to improve their interior spaces. By addressing these goals, the survey hopes to advance knowledge about indoor air pollution and encourage people to take preventative measures to safeguard their health and wellbeing.[4]

2.0. Literature Review:

Because more people are spending more time indoors, indoor air quality (IAQ) has become a serious health concern. The different facets of indoor air pollution, such as the identification of pollutants, their sources, and potential mitigation techniques, have been extensively studied in a large body of research. To help guide the next sections of this study, the purpose of this literature review is to summarise the most important discoveries from previous studies. Studies have reliably identified multiple principal classifications of indoor air contaminants [5]: Organic Volatile Compounds (VOCs): At normal temperature, these chemical molecules easily evaporate. Paints, solvents, adhesives, cleaning supplies, and building materials are examples of common suppliers. Research has connected VOC exposure to headaches, respiratory irritation, and other health problems. Tiny particles suspended in the air are known as particulate matter, or PM. They can be categorised according to size, with PM2.5 (particles smaller than 2.5 micrometres) being especially dangerous because of its capacity to enter the lungs deeply. Building materials, outside air infiltration, and combustion processes (such as cooking and smoking) are some of the sources. [6] Biological pollutants encompass mould, viruses, bacteria, and allergies. They can come from a number of things, including water damage, humidity, dogs, and poor ventilation. Additional contaminants: Radon, formaldehyde, and carbon monoxide are additional toxins to be concerned about. These drugs may have serious negative effects on health, such as cancer, neurological diseases, and respiratory issues. Numerous sources of indoor air pollution have been found via research, including: Construction supplies and furniture: volatile organic compounds (VOCs) release from paints, carpets, adhesives, and furniture. Sources of combustion: wood-burning stoves, gas stoves, fireplaces and tobacco smoke. VOCs can be released into the air by the chemicals used in cleaning and personal care products. Outdoor air infiltration: Ventilation systems and open windows are two ways that pollutants from the outside can infiltrate indoor spaces.[7] Activities of the occupants: Indoor air pollution can be caused by cooking, taking a shower, and pet dander. The literature outlines a number of tactics for lowering indoor air pollution, such as: Ventilation: Pollutants can be diluted and removed with the aid of proper ventilation. Source control is the process of locating, removing, or minimising sources of pollution. Air cleaning: Eliminating impurities from the air by the use of air filters and purification devices. Maintenance: Heating, ventilation, and air conditioning (HVAC) systems require routine cleaning and upkeep. Controlling moisture: Keeping moisture from building up to stop the growth of mould. Even while our understanding of indoor air pollution has advanced significantly, there are still a number of study gaps. The following areas require more investigation: the effects of prolonged exposure to low levels of indoor pollution on health .[8] Provide more economical and efficient mitigation techniques for people with low incomes. Examine how new technology can enhance indoor air quality .Scientists and decision-makers can create more comprehensive and successful public health protection plans by addressing these research gaps.[9]

3.0. Methodology:

In order to thoroughly investigate prevalent indoor air contaminants in houses, their sources, and potential mitigation techniques, this study will use a descriptive research approach. In order to find trends and patterns, a detailed examination of the body of current research will be combined with data analysis. For this survey, the main sources of data will be [10]: scholarly works: Using pertinent databases (e.g., PubMed, Google Scholar, JSTOR), a thorough search of peer-reviewed articles, research papers, and books focussing on indoor air quality, pollutants, sources, and mitigation measures will be carried out. Governmental documents and directives: The authoritative information on indoor air quality norms and recommendations will be sourced from reports and guidelines provided by regulatory bodies, environmental agencies, and health organisations.[11] Publications and standards for the industry: To identify possible pollutant sources and mitigation strategies, industry-specific documents and standards pertaining to building materials, household items, and ventilation systems will be analysed. To identify prevalent indoor air contaminants, their main sources, and efficient mitigation techniques, collected data will be rigorously analysed. [12] We'll use the following analytical techniques: Content analysis: To find important themes, patterns, and new trends around indoor air pollution, qualitative data from literature will be examined. Comparative analysis: To have a thorough grasp of the subject, many research and reports will be compared to find findings that are similar and different. Synthesis: To create a thorough overview of indoor air contaminants, their sources, and mitigation techniques, key information from multiple sources will be incorporated. The focus on home indoor air pollution may not fully represent the intricacies of indoor air quality in other settings (e.g., businesses, schools), hence it is crucial to highlight potential limitations of this study.[13] Furthermore, relying solely on previously published research may fail to take mitigation techniques or newly developing pollutants into consideration. Recognising the dynamic nature of indoor air pollution, the survey will make an effort to incorporate the most current and pertinent studies in order to solve these limitations. By using this methodology, the survey hopes to give readers a thorough and educational picture of indoor air pollutants in homes, enabling them to make decisions about enhancing indoor air quality that are well-informed.[14]

4.0. Result and Discussion:

Table 1: Common Indoor Air Pollutants

Pollutant	**Description**	**Health Effects**
Particulate Matter (PM2.5 and PM10)	Tiny particles or droplets in the air	Respiratory issues, cardiovascular diseases
Carbon Monoxide (CO)	Colorless, odorless gas produced by burning carbon-based fuels	Headaches, dizziness, impaired vision
Formaldehyde	Colorless gas with a strong odor	Irritation of the eyes, nose, throat; cancer
Volatile Organic Compounds (VOCs)	Organic chemicals that easily vaporize	Eye, nose, and throat irritation; headaches
Nitrogen Dioxide (NO2)	Reddish-brown gas with a sharp odor	Respiratory problems, lung damage

Pollutant	Description	Health Effects
Sulfur Dioxide (SO2)	Colorless gas with a pungent smell	Respiratory problems, eye irritation
Ozone (O3)	Reactive gas composed of three oxygen atoms	Respiratory issues, reduced lung function
Radon	Radioactive gas from soil and building materials	Lung cancer

Particulate matter, or PM2.5 and PM10, are microscopic particles or droplets that are suspended in the atmosphere. PM2.5 has a diameter of no more than 2.5 micrometres, while PM10 has a diameter of no more than 10 micrometres. Health Effects: Breathing in particulate matter can cause serious respiratory conditions such bronchitis, asthma, and other lung illnesses. Extended exposure can worsen pre-existing medical disorders and raise the risk of cardiovascular diseases.[15]

The colourless and odourless gas known as carbon monoxide (CO) is created when carbon-based fuels like wood, natural gas, and gasoline are burned. Health Effects: Headaches, light-headedness, and blurred vision can be brought on by CO exposure. Because CO can stop oxygen from entering the bloodstream, it can be deadly at high concentrations because it can cause tissue damage and even death.[16]

Formaldehyde is a colourless gas that is frequently present in household goods and building materials. It has a strong, unpleasant odour. Health Effects: Exposure to formaldehyde can cause irritation to the throat, nose, and eyes, which can cause coughing and other pain. An higher risk of cancer, specifically nasopharyngeal carcinoma, is associated with prolonged exposure.[17]

Volatile organic compounds, or VOCs for short, are a broad class of organic compounds that readily evaporate at room temperature and are present in a variety of consumer items, paints, and cleaning supplies. Short-term exposure to volatile organic compounds (VOCs) may result in headaches, dizziness, and irritation of the throat, nose, and eyes. Extended exposure can cause more serious health issues, including as abnormalities of the central nervous system and damage to the liver and kidneys.[18]

Nitrogen Dioxide (NO2): Characteristics: Typically created by combustion, vehicles, and industrial activities, NO2 is a reddish-brown gas with a harsh, stinging odour. Impact on Health: Breathing in NO2 can lead to respiratory issues as coughing, wheezing, and dyspnoea. Prolonged exposure can cause severe lung damage and decreased lung function.[19]

Sulphur Dioxide (SO2): Production of this colourless, strong-smelling petrol results from the burning of fossil fuels and several industrial processes .Health Effects: Shortness of breath, coughing, and throat discomfort can all be brought on by SO2. It can also cause eye discomfort and exacerbate pre-existing respiratory disorders like asthma.

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Ozone (O_3): Characteristics: Ozone is a gas that is reactive and is made up of three oxygen atoms. It is created naturally in the stratosphere and at ground level when contaminants react chemically. Health Effects: Respiratory problems, such as coughing, sore throats, and decreased lung function, can be brought on by ozone exposure. It may also make lung conditions like asthma worse.

Radon is a radioactive gas that is naturally produced when uranium decays in soil and building materials. Health Effects: Among non-smokers in particular, radon is a major cause of lung cancer. Lung cancer risk is elevated by prolonged exposure to high radon levels.

Because indoor air pollution contains a variety of contaminants, there are serious health hazards. The effects on health might vary from minor irritants to serious, sometimes fatal illnesses. To effectively minimise indoor air pollution and safeguard public health, it is imperative to comprehend the sources and effects of these contaminants.

Countermeasures: Increasing ventilation can aid in the removal and dilution of indoor contaminants. HEPA-filtered air purifiers can help cut down on some volatile organic compounds (VOCs) and particle matter. Source Control: You may lessen the number of pollutants like CO and NO_2 in the air by using less products that release dangerous chemicals and making sure combustion appliances are maintained properly

Regulatory Actions: Indoor air quality standards can be established and enforced by governments and health organisations. Campaigns for public awareness can inform the public on the causes, risks, and recommended practices for lowering indoor air pollution exposure. We can greatly enhance indoor air quality and lower the health risks related to these common contaminants by addressing indoor air pollution with these actions. [20]

Table 2: Sources of Indoor Air Pollutants

Pollutant	**Common Sources**
Particulate Matter (PM2.5 and PM10)	Cooking, smoking, burning candles, dust
Carbon Monoxide (CO)	Unvented gas stoves, heaters, car exhaust
Formaldehyde	Building materials, furniture, household products
Volatile Organic Compounds (VOCs)	Paints, varnishes, cleaning products
Nitrogen Dioxide (NO_2)	Gas stoves, heaters, tobacco smoke
Sulfur Dioxide (SO_2)	Burning fossil fuels, industrial processes
Ozone (O_3)	Outdoor air, some electrical devices
Radon	Soil, building materials, water

PM2.5 and PM10 Particulate Matter: Dust, cooking, smoking, and candle burning Because particulate matter can reach the bloodstream and delve deep into the lungs, it offers serious health hazards, particularly at PM2.5 and PM10 levels. The main indoor activities that produce these particles include cooking, smoking, and candle burning. Indoor PM levels are also influenced by dust deposition. To minimise exposure, it's imperative to make sure there is enough ventilation, utilise exhaust fans when cooking, and refrain from smoking indoors.
CO (carbon monoxide): Car exhaust, heaters and unvented gas stoves: At high concentrations, carbon monoxide, an odourless and colourless gas, can be fatal. It is created when fuels burn too slowly. The main indoor sources are unvented gas heaters and stoves, while adjacent garages can allow automobile exhaust into houses. Risks can be reduced by installing CO detectors and making sure there is enough ventilation. To avoid CO accumulation, heating equipment must receive routine maintenance. [21]
Formaldehyde: furnishings, building supplies and domestic goods A prevalent volatile organic compound (VOC) in furniture, building supplies, and household goods like cleaners and adhesives is formaldehyde. Prolonged exposure to formaldehyde has been connected to certain malignancies and can lead to respiratory problems. Reducing indoor formaldehyde levels can be achieved by using air purifiers, opting for low-emission items, and making sure there is adequate ventilation.
Organic compounds that are volatile (VOCs): Paints, varnishes, and sanitising agents Paints, varnishes, and cleaning supplies are among the solids and liquids that release volatile organic compounds (VOCs) as gases. Prolonged exposure to elevated VOC levels can result in migraines, vertigo, and other long-term health consequences. Lowering indoor VOC concentrations can be achieved by using less harsh cleaning chemicals, choosing low-VOC or VOC-free products, and keeping enough ventilation. [22]
Gas burners, heaters, and tobacco smoke all produce nitrogen dioxide (NO2). A dangerous gas that can aggravate the respiratory system and impair lung function is nitrogen dioxide. Indoor sources include cigarette smoke and gas heaters and stoves. There are several ways to drastically lower NO2 levels in households, including banning indoor smoking, using electric appliances, and properly venting kitchens.
Burning fossil fuels and other industrial operations release sulphur dioxide (SO2). The primary sources of sulphur dioxide are the combustion of fossil fuels and some industrial operations. Even while it is less common indoors, it can still enter through external openings, particularly in locations close to industrial facilities. Indoor SO2 pollution can be reduced by using air purifiers with sulphur dioxide filters and making sure that dwellings are properly sealed.[23]
Ozone (O3): Air outside, some electrical equipment at ground level, ozone is hazardous even if it is useful in the high atmosphere. It can infiltrate houses through external openings, especially in cities with high amounts of outside ozone. Ozone can also be produced by some electrical equipment, such as laser printers and photocopiers. Maintaining safer indoor air quality can be achieved by minimising the use of such devices indoors and by utilising air purifiers built to minimise ozone.
Radon in soil, construction materials, and water radioactive gases like radon can enter into homes through the foundation and building components. Among people who do not smoke, it is the main cause of lung cancer. Indoor radon levels can be lowered by conducting radon

tests on homes and implementing radon mitigation techniques, such as soil suction. Other efficient solutions include making sure there is enough ventilation and caulking wall and floor cracks. [24]

Because there are so many different sources of pollutants in homes and workplaces, indoor air pollution is a serious health risk. Implementing initiatives to lower pollution levels and lessen related health concerns can be made easier by having a better understanding of the common sources of these contaminants. Important actions to improve indoor air quality include making sure there is adequate ventilation, utilising low-emission products, maintaining appliances on a regular basis, and refraining from indoor smoking. Furthermore, radon testing, air purifier use, and awareness of the quality of the outside air can all help create a healthier home atmosphere.

Table 3: Health Effects of Indoor Air Pollutants

Pollutant	**Short-Term Effects**	**Long-Term Effects**
Particulate Matter (PM2.5 and PM10)	Irritation of eyes, nose, throat	Chronic respiratory diseases, heart disease
Carbon Monoxide (CO)	Fatigue, chest pain, impaired vision	Long-term exposure can be fatal
Formaldehyde	Watery eyes, burning sensations	Nasal and throat cancer
Volatile Organic Compounds (VOCs)	Headaches, dizziness, nausea	Liver and kidney damage, cancer
Nitrogen Dioxide (NO2)	Coughing, wheezing	Reduced lung function, chronic bronchitis
Sulfur Dioxide (SO2)	Eye irritation, coughing	Aggravation of existing heart diseases
Ozone (O3)	Chest pain, shortness of breath	Decreased lung function, respiratory diseases
Radon	No immediate symptoms	Lung cancer

Indoor air pollutants can have a wide range of health effects, both in the short term and long term. This table outlines some of the key pollutants, their immediate effects, and the potential for serious health consequences with prolonged exposure.

Short-Term Effects of Particulate Matter (PM2.5 and PM10) Particles have the ability to enter the respiratory system and irritate the eyes, nose, and throat, resulting in pain and inflammation. Effects throughout time: Chronic respiratory conditions like emphysema and chronic bronchitis can result from prolonged exposure. Heart disease: Cardiovascular illnesses are exacerbated by fine particles that enter the bloodstream [25]. Impact of Carbon Monoxide (CO) in the Short Term: Weariness, soreness in the chest, and blurred vision are caused by CO's stronger binding to haemoglobin than oxygen, which lowers the body's supply of oxygen and results in these symptoms. Long-Term Repercussions: Death: Severe hypoxia brought on by prolonged CO exposure can be lethal. Formaldehyde: Immediate Symptoms: Burning feelings, watery eyes: This irritant can impact mucous membranes, causing pain. Long-Term Effects: Cancer of the nose and throat: Prolonged exposure to formaldehyde causes cancer, which is especially common in the respiratory system.

Short-Term Effects: Headaches, nausea, dizziness: Because of their toxicity, volatile organic compounds (VOCs) can produce acute neurological symptoms. Long-Term Effects: Cancer, liver, and kidney damage: Prolonged exposure can raise the chance of developing cancer and cause serious organ damage.[26]

Nitrogen Dioxide (NO2): Long-Term Effects: Reduced lung function, chronic bronchitis: Prolonged exposure can cause severe reductions in lung function and chronic respiratory disorders. Short-Term Effects: Wheezing and coughing: NO2 is a respiratory irritant, aggravating problems like asthma. Short-term effects of sulphur dioxide (SO2) include coughing and eye irritation. SO2 can irritate the respiratory system and eyes very away. Long-Term Effects: Chronic exposure can make cardiovascular disorders worse. It can also aggravate pre-existing heart illnesses. Short-term Effects of Ozone (O3): Breathlessness and chest pain: Ozone can cause respiratory distress very away, especially in sensitive people. Long-Term Effects: Respiratory disorders and decreased lung function: Extended exposure might result in long-term respiratory disorders and decreased lung function.[27] Short-Term Impacts of Radon: Absence of acute symptoms: Radon exposure is particularly sneaky because it usually doesn't produce any symptoms right away. Long-Term Effects: Lung cancer: Because radon releases alpha particles, which can eventually harm lung tissue, it is one of the main causes of lung cancer among non-smokers. The table illustrates the substantial health hazards associated with different types of indoor air pollution. Irritation or acute symptoms are common short-term effects that, while irritating, act as warning indicators. On the other hand, the long-term consequences are more serious, encompassing cancer, chronic illnesses, and even death. This emphasises how crucial it is to keep indoor air quality high in order to safeguard long-term health. Enhancing ventilation, utilising air purifiers, cutting back on the usage of VOC-emitting goods, and routinely checking the quality of the air inside are all good mitigation techniques. Regulatory actions and public awareness campaigns are also essential for reducing exposure to these dangerous chemicals. Designing focused interventions to lower the incidence of these pollutants in indoor environments, especially in industrial settings where workers may be at increased risk, can be made easier by having a better understanding of the specific health implications.[28]

Table 4: Mitigation Strategies for Indoor Air Pollutants

Pollutant	**Mitigation Strategies**
Particulate Matter (PM2.5 and PM10)	Use air purifiers, regular cleaning, avoid smoking indoors
Carbon Monoxide (CO)	Install CO detectors, ensure proper ventilation
Formaldehyde	Use low-formaldehyde products, improve ventilation
Volatile Organic Compounds (VOCs)	Use products with low VOCs, proper ventilation
Nitrogen Dioxide (NO2)	Ensure proper ventilation, avoid smoking indoors
Sulfur Dioxide (SO2)	Avoid using fossil fuels indoors, ensure proper ventilation
Ozone (O3)	Use air purifiers, limit use of ozone-generating devices
Radon	Test homes for radon, seal cracks in floors and walls

Particulate Matter (PM2.5 and PM10): These tiny particles can cause respiratory and cardiovascular problems by deeply penetrating the lungs. Strategies for Mitigation: Employ air purifiers: PM2.5 and PM10 particles can be efficiently captured by high-efficiency particulate air (HEPA) filters, which lowers their concentration indoors. Frequent Cleaning: Particulate matter build-up can be minimised by dusting and cleaning with HEPA-filter vacuums. Steer clear of indoor smoking: Since tobacco smoke contributes significantly to indoor particulate matter, outlawing indoor smoking can significantly reduce PM levels.[29]

2. Carbon Monoxide (CO): Lacking colour and odour, carbon monoxide is a gas that can be fatal in high doses because it prevents oxygen from entering the blood. Strategies for Mitigation: Install CO detectors: These devices can warn residents of potentially hazardous carbon monoxide concentrations, enabling prompt ventilation and evacuation. Make Sure There Is Enough Ventilation: CO build-up can be avoided by ensuring there is enough ventilation, particularly in spaces with combustion appliances.

3. Formaldehyde: A volatile organic compound (VOC), formaldehyde can irritate the skin, nose, eyes, and throat. Prolonged exposure can also result in respiratory problems and cancer. Strategies for Mitigation: Low-emitting materials, furniture, and home goods help lower formaldehyde concentrations inside. Boost Ventilation: More ventilation aids in the removal and dilution of formaldehyde from indoor air.[30]

4. Volatile Organic Compounds (VOCs): VOCs can have a variety of negative health consequences and are released by a wide range of items, such as paints, cleaning agents, and building materials. Mitigation Strategies: Use Low-VOC items: You can cut down on the emissions of these compounds by selecting items that are labelled as low- or no-VOC.

Ensuring proper ventilation helps disperse volatile organic compounds (VOCs) and lowers their concentration inside.
5. Nitrogen Dioxide (NO2): This combustion by product can make respiratory conditions like asthma worse. Mitigation Strategies: Make Sure It's Ventilated Properly: In spaces where there are combustion sources, like kitchens, proper ventilation helps lower NO2 levels. Steer Clear of Smoking Indoors: Since tobacco smoke is a major source of NO2, banning smoking indoors will help reduce exposure.
6. Sulphur Dioxide (SO2): This gas, which is mostly produced when fossil fuels are burned, can lead to respiratory disorders as well as other health concerns. Mitigation Strategies: Steer clear of using fossil fuels indoors. You can reduce the amount of SO2 produced indoors by using alternative energy sources for cooking and heating. Make Sure Your Ventilation Is Correct: Ventilation can aid in removing and dispersing SO2 from indoor air.
7. Ozone (O3): At ground level, ozone is a dangerous pollutant that can lead to various health concerns, including respiratory disorders. Strategies for Mitigation: Employ air purifiers: Activated carbon filters in air purifiers can lower the amount of ozone produced inside. Restrict the Use of Ozone-Generating Equipment: Refrain from utilising ozone-generating air purifiers and other ozone-releasing appliances indoors. 8. Radon: This radioactive gas can enter buildings from the ground and has been connected to lung cancer. Strategies for Mitigation: Test Houses for Radon: Elevated radon levels can be detected with routine testing. Seal Wall and Floor Cracks: Radon infiltration can be decreased by sealing access sites.
By putting these mitigation techniques into practice, indoor air quality can be greatly improved and the health risks posed by different pollutants can be decreased. The particular context, which includes the building's ventilation system, the existence of pollution sources, and the general indoor environment, has a major impact on how effective these tactics are. Air Purifiers and Ventilation: While adequate ventilation is essential for dilution of gases such as CO, NO2, and VOCs, air purifiers are especially efficient in eliminating particulate matter and ozone. Source Control: A key strategy for enhancing interior air quality is to remove or minimise sources of indoor pollutants, such as using less high-VOC items and fossil fuels. Awareness and Maintenance: To guarantee that the mitigation measures continue to be effective over time, HVAC systems should undergo routine maintenance in addition to sporadic testing of the air quality. It is also possible to encourage actions that lead to a better interior environment by teaching residents about the origins and dangers of indoor pollution. In order to minimise indoor air pollution and protect occupant health, a combination of source control, air cleaning, and ventilation that is customised to the particular interior environment and pollutant types would be most effective.[31]

Table 5: Measurement Methods for Indoor Air Pollutants

Pollutant	**Measurement Method**
Particulate Matter (PM2.5 and PM10)	Air quality monitors with PM sensors

Pollutant	**Measurement Method**
Carbon Monoxide (CO)	CO detectors, portable CO monitors
Formaldehyde	Formaldehyde detectors, air sampling methods
Volatile Organic Compounds (VOCs)	VOC detectors, air sampling methods
Nitrogen Dioxide (NO2)	NO2 sensors, passive sampling methods
Sulfur Dioxide (SO2)	SO2 monitors, air sampling methods
Ozone (O3)	Ozone monitors, UV absorption methods
Radon	Radon test kits, continuous radon monitors

The common indoor air pollution assessment techniques are listed in Table 5, each of which may identify different pollutants with differing degrees of practicality and precision. Below is a thorough explanation and analysis of each technique:
1. Particulate Matter (PM2.5 and PM10): Air quality monitors equipped with PM sensors are used for measurement. These monitors assess airborne particle matter using gravimetric or optical methods. Particle concentration is determined via optical sensors using laser light scattering, and gravimetric methods, which collect particles on filters for analysis afterwards. Both PM2.5 and PM10 are important markers of respiratory health hazards, but because PM2.5 can enter the bloodstream and lungs deeply, it should be taken especially seriously.[32]

2. Carbon Monoxide (CO): CO detectors and portable CO monitors are the methods of measurement CO detectors measure the amount of CO in the air using either metal oxide or electrochemical sensors. Portable monitors are helpful for determining the dangers associated with short-term exposure and can offer real-time data. Precise measurement is essential since elevated CO levels can cause fatalities as well as major health problems like headaches and vertigo.
3. Formaldehyde: Air sampling techniques and formaldehyde detectors are the methods of measurement. Colorimetric or electrochemical sensors are commonly used in formaldehyde detectors to gauge gas concentration. Using canisters or filters, air samples are collected and subsequently subjected to laboratory analysis as part of air sampling techniques. A frequent indoor contaminant that has been connected to cancer and can irritate the respiratory system is formaldehyde.[33]

4. Volatile Organic Compounds (VOCs): Air sampling techniques and VOC detectors are the measurement methods To monitor VOC levels, VOC detectors use metal oxide sensors or photoionization detectors (PIDs). Using an air sampler, samples are gathered and placed in canisters or sorbent tubes for analysis in the lab. VOCs are a broad category of chemicals that

can have short-term health consequences like headaches and respiratory troubles as well as long-term effects like cancer.

5. Nitrogen Dioxide (NO2): Passive sampling techniques and NO2 sensors are used for measurement Gas concentrations are frequently measured with NO2 sensors using electrochemical or chemiluminescence methods. Using diffusion tubes, passive sampling includes collecting NO2 throughout time for analysis at a later time. One of the main pollutants from combustion sources is NO2, which can worsen respiratory disorders and cause smog to form.[34]
6. Sulphur Dioxide (SO2): Air sampling techniques and SO2 monitors are used for measurement Typically, SO2 monitors utilise electrochemical or fluorescence sensors to measure the amount of sulphur dioxide present. Using air sampling techniques, SO2 is collected for laboratory analysis in filters or sampling tubes. In addition to causing respiratory issues, SO2 can lead to the development of acid rain.

7. Ozone (O3): UV absorption techniques and ozone sensors are used for measurement. Ozone monitors frequently assess ozone concentrations using chemiluminescence or UV absorption methods. The amount of UV light absorbed by ozone in the air is measured using UV absorption techniques. Ground level ozone can aggravate respiratory ailments and make illnesses like asthma worse.

8. Radon: Continuous radon monitors and radon test kits are the methods of measurement. Radon test kits are used to evaluate radon levels over a predetermined length of time. They can be passive, like charcoal canisters, or active, like alpha track detectors. Real-time data on radon levels is provided via continuous radon monitors. Long-term exposure to the radioactive gas radon can cause lung cancer.[35]

Every measurement technique is made to tackle particular problems related to pollution detection and quantification. Electronic sensors and detectors work best for real-time monitoring and quick reactions. Laboratory analysis and air sampling techniques offer extensive insights into pollution concentrations and fluctuations for more thorough analysis over longer periods of time. Combining these techniques can provide a more comprehensive view of indoor air quality, making it easier to locate pollution sources and evaluate health hazards.

Table 6: Average Concentrations of Indoor Air Pollutants (Example Data)

Pollutant	**Average Concentration (Residential)**	**Average Concentration (Industrial)**
Particulate Matter (PM2.5)	10-50 µg/m³	50-150 µg/m³
Carbon Monoxide (CO)	0.5-5 ppm	5-20 ppm

Pollutant	**Average Concentration (Residential)**	**Average Concentration (Industrial)**
Formaldehyde	0.01-0.05 ppm	0.05-0.1 ppm
Volatile Organic Compounds (VOCs)	50-500 µg/m³	500-2000 µg/m³
Nitrogen Dioxide (NO2)	0.01-0.05 ppm	0.05-0.2 ppm
Sulfur Dioxide (SO2)	0.01-0.05 ppm	0.05-0.1 ppm
Ozone (O3)	0.02-0.05 ppm	0.05-0.1 ppm
Radon	1-4 pCi/L	4-20 pCi/L

The average concentrations of different indoor air contaminants in residential and commercial settings are shown in the table you have supplied. Here is how these values are understood and discussed: PM2.5, or particulate matter: Household: 10–50 µg/m³Business: 50–150 µg/m³ Because fine particles are released during processes including manufacturing, construction, and processing, industrial areas usually have higher PM2.5 concentrations. High concentrations in industrial environments can be harmful to health, increasing the risk of cardiovascular and respiratory disorders.

Residential Levels of Carbon Monoxide (CO): 0.5–5 ppm Commercial: 5–20 ppm Industrial settings have greater CO levels, most likely as a result of machinery use and combustion processes. Headaches, light-headedness, and decreased cognitive performance can result from high CO concentrations. Exposure to high quantities over an extended period of time may be fatal [36].

Formaldehyde: 0.01–0.05 ppm, residential Business: 0.05–0.1 ppm Since formaldehyde is utilised in a variety of industrial processes and products, its levels are often greater in these environments. Prolonged exposure has been connected to cancer and can cause respiratory problems.

Volatile Organic Compounds (VOCs): 50–500 µg/m³ are residential levels. Sector: 500–2000 µg/m³ Industrial settings have significantly greater VOC concentrations because of the emissions from paints, solvents, and other chemicals. High volatile organic compound (VOC) levels might cause long-term health problems and respiratory issues. Nitrogen Dioxide (NO2): 0.01–0.05 parts per million Business: 0.05–0.2 ppm Industrial environments have higher NO2 levels, frequently as a result of combustion operations. Long-term exposure raises the risk of respiratory infections and damages the lungs [37]. Sulphur Dioxide (SO2): 0.01–0.05 parts per million Business: 0.05–0.1 ppm When fossil fuels are used in industrial settings, SO2 levels are usually greater. While long-term exposure can result in more serious health problems, short-term exposure can induce respiratory

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problems. Ozone (O3): 0.02–0.05 parts per million Business: 0.05–0.1 ppm There is a small increase in ozone in industrial settings. Ozone can aggravate asthma symptoms by irritating the respiratory system. Extended exposure may cause more severe respiratory issues. Residential Radon: 1-4 pCi/ LIndustrial: pCi/LR 4–20Adon concentrations are higher in industrial environments, possibly as a result of the local geology or particular industrial processes. Lung cancer risk increases with prolonged exposure to radon, a recognised carcinogen.[38]

In conclusion, compared to residential settings, industrial workplaces often contain greater quantities of indoor air pollutants. This is caused by a number of things, such as the usage of chemicals, combustion processes, and industrial machinery. Because of the potential health risks associated with these elevated pollutant levels for workers, industrial environments must include efficient ventilation and pollution control strategies. It is essential to limit exposure to these pollutants in order to safeguard the health of employees and maintain a secure workplace.[39]

Table 7: Indoor Air Quality Standards

Pollutant	**WHO Guidelines**	**EPA Standards**
Particulate Matter (PM2.5)	10 µg/m³ (annual), 25 µg/m³ (24-hour)	12 µg/m³ (annual)
Carbon Monoxide (CO)	9 ppm (8-hour), 35 ppm (1-hour)	9 ppm (8-hour), 35 ppm (1-hour)
Formaldehyde	0.08 ppm (30-minute)	0.1 ppm (short-term)
Volatile Organic Compounds (VOCs)	No specific guideline	0.5 mg/m³ (24-hour)
Nitrogen Dioxide (NO2)	0.02 ppm (annual), 0.1 ppm (1-hour)	0.053 ppm (annual)
Sulfur Dioxide (SO2)	0.02 ppm (24-hour)	0.075 ppm (1-hour)
Ozone (O3)	0.05 ppm (8-hour)	0.07 ppm (8-hour)
Radon	2.7 pCi/L	4 pCi/L

The World Health Organization's (WHO) and the Environmental Protection Agency's (EPA) criteria for indoor air quality in Table 7. The following explains these requirements and

provides an interpretation:
The WHO recommends 10 μg/m³ for annual averages of particulate matter (PM2.5) and 25 μg/m³ for 24-hour averages. EPA Guidelines: 12 μg/m³ (average per year) The yearly PM2.5 standard set by the WHO is marginally more stringent than the EPAs. The 24-hour restriction set by the WHO is likewise stricter. This discrepancy is a reflection of the two organisations' differing approaches to caution and public health priorities.[40] WHO Guidelines and EPA Standards for Carbon Monoxide (CO): 8 ppm (8-hour average), 35 ppm (1-hour average) The fact that both organisations have the same CO limits shows that there is agreement on the acceptable threshold for this pollutant's exposure. WHO Guidelines for formaldehyde: 0.08 ppm (30-minute average)0.1 ppm (short-term average) is the EPA standard. The formaldehyde guidelines set by the WHO are stricter than those by the EPA. This implies that the WHO either takes a more cautious stance in preserving public health or believes formaldehyde to be more dangerous.
WHO Guidelines for Volatile Organic Compounds (VOCs): Not a set of rules 0.5 mg/m³ (24-hour average) EPA standard in wide range of substances that are categorised as VOCs and the challenge of establishing a unified standard may be the reasons behind the absence of WHO guidelines on VOCs. Although it might be viewed as less thorough, the EPA standard offers a precise limit.[41]
WHO Guidelines for Nitrogen Dioxide (NO2): 0.02 ppm (annual average), 0.1 ppm (one-hour average)0.053 ppm (year average) is the EPA standard. In comparison to EPA limits, WHO guidelines are more stringent for both annual and short-term exposures. This shows that the WHO is taking a more circumspect stance. WHO Guidelines for Sulphur Dioxide (SO2): 0.02 ppm (average over 24 hours)0.075 ppm is the EPA standard (one-hour average). The EPA sets a greater short-term exposure level, and the WHO has a stricter 24-hour average norm. This demonstrates how long-term and short-term exposure limitations differ in their emphasis. WHO Guidelines for Ozone (O3): 0.05 ppm (8-hour average) EPA Standards: 8-hour average of 0.07 ppm. The WHO's ozone guideline is lower, suggesting a more cautious approach. The allowed concentration varies, but the same exposure duration is the emphasis of both criteria.
WHO Guidelines for Radon: 2.7 pCi/LEPA Requirements: 4 pCi/L The WHO has a lower criterion, which reflects their stricter radon exposure guidelines. This variation implies different degrees of concern; regarding radon levels, the WHO advises being extra cautious.[42] The divergences in risk assessment and public health methodologies between EPA and WHO standards are evident. Whereas EPA rules might strike a compromise between pragmatic concerns and public health protection, WHO guidelines are typically more stringent and probably strive for a higher degree of caution. Comprehending these distinctions can aid in harmonising regional laws with international standards and guaranteeing optimal indoor air quality.

Table 8: Recommended Actions for Homeowners

Pollutant	**Recommended Actions**

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Pollutant	**Recommended Actions**
Particulate Matter (PM2.5 and PM10)	Use high-efficiency particulate air (HEPA) filters, maintain clean living spaces
Carbon Monoxide (CO)	Install and maintain CO detectors, avoid using unvented combustion appliances
Formaldehyde	Select low-formaldehyde products, ensure good ventilation
Volatile Organic Compounds (VOCs)	Choose low-VOC products, ventilate during and after use of VOC-emitting products
Nitrogen Dioxide (NO2)	Ensure proper ventilation, regularly maintain gas appliances
Sulfur Dioxide (SO2)	Avoid using sulfur-containing fuels, ensure proper exhaust systems
Ozone (O3)	Limit use of ozone-generating air cleaners, improve indoor ventilation
Radon	Test for radon, mitigate high levels with professional help

PM2.5 and PM10 Particulate Matter: Suggested Course of Actions: Keep your living areas clean and use HEPA filters. Particulate matter has the ability to infiltrate the circulation and delve deeply into the lungs, particularly fine particles (PM2.5). The quality of indoor air is enhanced by HEPA filters' ability to effectively capture these minute particles. Frequent cleaning improves air quality by lowering dust and other particulates.[43]

Carbon Monoxide (CO): Suggested Course of Action: Place and maintain CO detectors; stay away from appliances with unvented combustion. CO is an odourless, colourless gas that, at high concentrations, can be fatal. Because CO detectors give off an early warning, homeowners may take action before the gas levels get deadly. Use alternate equipment or make sure there is adequate ventilation because unvented appliances, such as some gas heaters, can leak CO indoors.
Formaldehyde: Suggested Actions: Make sure there is adequate ventilation and choose low-formaldehyde goods. A prevalent indoor air contaminant present in certain household items and building materials is formaldehyde. Selecting goods with fewer formaldehyde emissions and keeping the ventilation system in good working order will assist lessen exposure and the health hazards it carries, like irritation and respiratory problems.
Recommendations for handling volatile organic compounds (VOCs): When using VOC-emitting goods, choose low-VOC options and make sure to ventilate both during and after usage. Several household items, such as paints and cleaning supplies, release volatile organic

compounds (VOCs). These substances may aggravate various medical conditions as well as respiratory disorders. Reduce indoor VOC concentrations by using low-VOC products and making sure there is enough ventilation.[44] Nitrogen Dioxide (NO2): Suggested Actions: Make sure your gas appliances are properly ventilated and maintained. Combustion processes, including those in gas heaters and stoves, release NO2. It might aggravate the respiratory system and aggravate other medical conditions. Maintaining appliances and providing adequate ventilation can help lower the amount of NO2 in a home.

Sulphur Dioxide (SO2): Suggested Course of Action: Keep your fuels free of sulphur and make sure your exhaust systems are working properly. Usually, burning fuels containing sulphur produces SO2. It can worsen pre-existing diseases and lead to respiratory problems. Reducing SO2 levels inside can be achieved by using cleaner fuels and having efficient exhaust systems.

Ozone (O3): Suggested Course of Action: Reduce the use of air cleaners that produce ozone and enhance interior ventilation. Ozone-generating air purifiers can raise indoor ozone levels, which can irritate the respiratory system, even if ozone itself can help with some types of air pollution. Enhancing ventilation can lessen any health effects and aid to dilute indoor ozone concentrations.

Test for radon and seek professional assistance to minimise elevated levels. Lung cancer is mostly caused by radon, a naturally occurring radioactive gas that can build up inside. To lower the danger, radon levels must be tested for, and if excessive levels are found, expert mitigation is required.[45]

A mix of prevention, monitoring, and mitigation techniques is required for the efficient management of indoor air quality. Homeowners may greatly lower their exposure to dangerous pollutants and enhance the general quality of the air within their homes by implementing these suggested activities, which will improve their health and well-being. A thorough summary of prevalent indoor air pollutants, their origins, health effects, mitigation techniques, measuring techniques, average concentrations, air quality standards, and suggested homeowner activities are given in these tables.

5.0. Conclusion:

Because people spend so much time indoors, indoor air pollution is a subtle but serious environmental health hazard. The common indoor air contaminants found in home settings, their numerous sources, and practical mitigation techniques have all been identified by this survey. Indoor air quality is challenged by a variety of major pollutants, including particulate matter (PM), formaldehyde, volatile organic compounds (VOCs), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3), radon, particulate matter (PM), and biological contaminants (such as mould, dust mites, and pet dander). They come from a variety of sources, including commonplace items like paints, furnishings, and cleaning supplies; behaviours like cooking and smoking; and structural elements like HVAC systems and building materials. Furthermore, a major factor in indoor pollution is outside air infiltration. Using mitigation techniques is essential when dealing with problems with indoor air quality. The survey highlights a number of useful actions: Increasing both mechanical and natural ventilation will improve ventilation and lower the quantities of pollutants. Using Air Purifiers: To remove pollutants and particle matter, use air purifiers equipped with HEPA filters. Choosing Low-Emission Materials: To reduce indoor pollution, utilise construction and household materials with low volatile organic compounds (VOCs). Frequent Inspection and Maintenance of HVAC Systems: Ensuring that HVAC systems receive routine inspections and maintenance to stop the build-up and spread of pollutants. It is impossible to overestimate the importance of public awareness and education in reducing indoor air pollution. Encouraging healthier living environments requires educating people on the causes of indoor pollutants, their effects on health, and doable mitigation techniques. By means of an extensive examination of extant literature and case studies, this analysis highlights the intricacy of indoor air quality concerns and furnishes a structure for tackling them. The development and promotion of novel technologies and regulations targeted at further lowering indoor air pollution should be the main emphasis of future research. We can greatly enhance indoor air quality and safeguard human health by putting the suggested techniques into practice and raising public knowledge, which will result in healthier and more sustainable living conditions.

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