RESEARCH PAPER

SLR Layout on Health Effects of Indoor Air Pollution in Urban Cities: A Systematic Review of Measures and Methods to Mitigate Air Pollution

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ABSTRACT
Indoor air pollution is one of the growing concerns in urban and rural areas. The exposure to different pollutants arising from construction material along with outdoor pollutants pose serious risk to maternal health and subsequent child birth. The main aim of this study is to systematically review the various indoor air pollutants and their effects with strategies that could be implemented to improve IAQ. The methods for identifying the studies were based on Preferred Reporting Items for Systematic reviews and Meta-analysis (PRISMA) guidelines. Medline/Pubmed and Science Direct databases were used for searching relevant articles. A final of 32 studies were analyzed for the work. Various search strings were used for identification of references from databases. Eligibility criteria were used for finalizing the references. Various studies identified that there is a definitive effect of indoor air pollution on maternal health and child health. The main disorders associated include asthma, COPD, respiratory tract infection and lung cancer. There were several factors that contributed to indoor air pollution such as the nature of construction material, cleaning habits, smoking and cooking. Meteorological conditions influenced both outdoor and indoor pollution. Bioremediation methods, interventions based on alternate cook stoves, regulatory aspects in construction were mainly considered based on literature selected. IAQ is a chief parameter for assessment and implementation of safety practices to protect individuals from chronic diseases. Though, in developed countries regulatory measures are being proposed they still need approval so that such measures can be implemented in LMIC. Thus, it is essential to have policy frameworks and their implementation to control indoor air pollution.

Keywords: Indoor air quality (IAQ), Air pollution, Volatile organic compounds (VOC), Low and Middle Income countries (LMIC), Household air pollution (HAP)

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1. INTRODUCTION/BACKGROUND

Air pollution is one the major problems faced by the world in the 21st Century. The presence of harmful substances in the atmosphere in excess quantities results in damage to health, environment and climate. As per WHO millions of premature deaths are caused by air pollution across the globe. There are two main types of air pollution which include indoor and outdoor pollution.[1] Outdoor air pollution is caused by a variety of factors which include industrial emissions, emission from power plants, agricultural activities and burning of fossil fuels. The main components of outdoor pollution include Particulate matter (PM2.5 & PM1), Carbon monoxide, ozone, lead and heavy metals such as lead. Outdoor air pollution has detrimental effects on human health with both shorter and longer impacts. The World Health Organization has stated that exposure to fine particulate matter (PM2.5) increases the risk of heart diseases, stroke, chronic obstructive pulmonary disease (COPD), and lung cancer. Especially vulnerable groups include children, elderly people, pregnant women, and people with pre-existing respiratory and heart conditions. Pollution has both economic and social impacts. The increase in pollution results in increased health care expenses along with loss of productivity for employees and continued absence from schools.[2]

Indoor air pollution involves the chemical, physical, and biological contamination of the indoor air, which occurs inside buildings such as homes, schools, and offices. The main sources of In developing countries Indoor air pollution include Household Cooking and Heating, building materials and furnishings, household products

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and biological contaminants. Poor ventilation and humid conditions promote the growth of these biological contaminants. Indoor air pollution leads to severe health conditions which include respiratory diseases including asthma and Chronic obstructive pulmonary disease (COPD). Indoor air pollution results in lung cancer, adverse pregnancy outcomes, eye, and skin irritation.[3]

The main aim of this study is to systematically review the various indoor air pollutants and their effects with strategies that could be implemented to improve IAQ

2. RESEARCH QUESTIONS

1. What is the nature of indoor air pollution in various urban cities?
2. What are the contributory factors for indoor air pollution and the nature of effect they have on individuals?
3. What are the established guidelines for IAQ and its maintenance worldwide and in India?
4. What are the various methods for long term monitoring of indoor and outdoor pollutants?
5. Is there any difference between outdoor/indoor pollutants due to environmental and meteorological conditions?
6. What mitigatory measures can be suggested to reduce indoor air pollution?
7. What are the best intervention practices that can be adopted to reduce indoor air pollution?

Research objectives

1. Evaluation of the extent of indoor pollution and its effects in Urban cities
2. To understand the IAQ and its monitoring by established guidelines World wide and in India
3. To evaluate the various contributing factors for Indoor pollution and understanding the effects of the same in Urban cities.
4. Long-term monitoring of gaseous and particulate matter databases at adjacent indoor and outdoor sampling locations
5. To assess the differences in indoor/outdoor pollutants concentrations caused by changes in environment and meteorological conditions
6. To suggest appropriate measures and interventions for reducing the indoor air pollution

3. METHODS

a. Inclusion criteria

1. Studies related to indoor air pollution/ IAQ world wide, in India with specific reference to Tamilnadu/ Madurai.
2. Studies published between 2020-2026
3. Studies concerning guidelines for IAQ and measures to mitigate Indoor air pollution

b. Exclusion criteria

1. Studies not published in English
2. Studies published before 2015
3. Studies which are related to general air pollution
4. General Studies which solely focus on air pollution and its health effect

c. Search strategy

1. Indoor air pollution and its effects world wide
2. Indoor air pollution and its effects in India
3. IAQ guidelines in India and Worldwide
4. Indoor air pollution and contributory factors
5. Indoor air pollution and frameworks for mitigation
6. Indoor air pollution and measures for reduction
7. Indoor air pollutants and environmental and meteorological conditions

d. Study selection

Step 1

Using the search strings mentioned above all the three databases were searched for relevant references. The summary of the number of references found in the first step is summarized in the table given below.

Table 1. Description of Search String

Search string	Pubmed	Science Direct
Indoor air pollution and its effects world wide	324	18835
Indoor air pollution and its effects in India	495	11943
IAQ guidelines in India and Worldwide	1	511
Indoor air pollution and contributory factors	10	240
Indoor air pollution and frameworks for mitigation	33	10979
Indoor air pollutants and environmental and meteorological conditions	144	9940

Thus, a total of 53455 references were identified for the study in the first step. Science Direct has a lot more references which are found to be non-specific. Of the 53455 references identified the studies before 2015 and duplicates were removed. This resulted in removal of 12087 references resulting in 41368 studies to be considered for step II.

Step II
Of the total of 41368 a total of 32216 were eliminated as there were non specific references. Thus a total of 9152 were considered for step III.

Step III
Of the 9152 references non relevant based on exclusion criteria consideration resulted in removal of 7500 references. Thus, only 1652 were considered for the final step.

Step IV
Of the 1652 references based on inclusion criteria and suitability a final of 32 references were considered for review.

e. Study selection
Relevant studies were selected by utilizing a search strategy in two distinct steps. First articles were screened using keywords related to the study. Important information related to the topic was extracted in the first step. The available titles and abstracts were identified and analyzed to justify the inclusion of studies in the present in the paper. The second step involved the analysis of the full-text articles appropriately by independently reviewing them. PubMed and Science Direct were used for retrieving the full texts of the papers. The articles were independently screened by three reviewers. After study selection, a consensus was reached before the inclusion of the studies in this review. Any conflicts were resolved through discussion and common consensus among reviewers.

f. Quality assessment
The selected articles were independently reviewed by two reviewers. The reviewers assessed whether the included articles matched the inclusion criteria. Each of the selected articles was analyzed in detail for the quality of the work and the database from where they were collected. Based on assessment done a final list of articles for the study was obtained. The final articles that were considered for study were indexed in Pubmed. The Mixed methods assessment tool (MMAT) was used for the quality assessment of the papers. MMAT methods were proposed for qualitative and quantitative studies. However, this method is not applicable for the assessment of the review papers and theoretical papers.

4. RESULTS

4.1. Indoor air pollution and factors contributing

Effects of indoor air pollution
Aithal et al.[4] performed a systematic review to analyse the effect of household air pollution on lungs of children. The review showed interesting facts about the effects of solid fuel burning for cooking and the way it affects the lungs of children. The use of coal as a fuel for cooking was associated with lower growth rate of lung functional index (FEV1) when compared to control groups who were not exposed to coal. Similarly the functional volume (FVC) growth when monitored over 4 years showed a distinct difference. In children exposed to coal based fuel for cooking the growth was lower when compared to controls. Surprisingly there were no changes in FEV1/FVC in children exposed to coal based indoor air pollution. Thus, the study showed a reduction in lung flow rate and volume in children exposed to pollutants.

Meta-analysis was performed to evaluate the effect of indoor air pollutants on the health of individuals. Analysis of a total of 267 articles showed that people exposed to indoor air pollutants were at high risk for asthma, COPD and acute respiratory infections. Children under 5 were susceptible to cancer, TB and COPD. Gas cooking or heating was associated with asthma. The IAQ had a severe effect on pregnant mothers as well. Infants who were born to mothers exposed to indoor pollutants were on average 149g lighter than their control counterparts. All-cause mortality was significantly higher in infants exposed to indoor pollutants.[5]

HAP measurement is always challenging. In most of the cases the measurements are done based on the VOC, particular matters and gaseous compounds. Though HAP is correlated with COPD most of the studies where correlation is done are dependent on the use of solid fuel for cooking. The socio-economic conditions are the major variable that controls the HAP and COPD relationship. Poverty is one of the main factors in Low and Middle income countries (LMIC). Poverty is responsible for many of the health factors and hence the role of poverty in COPD needs to be checked before HAP and COPD correlation are directly taken up. Although HAP and COPD are inter related, poverty as one of the moderating variables needs to be checked since it plays a major role in morbidity and mortality.[6]

Pillarisetti et al.[7] performed a RCT to evaluate the role of indoor air pollution and correlation with blood pressure in an pollution-intervention network trial. 368 adult women with an average age of 52 years were considered for the study. The women were from Rwanda, Peru, Guatemala and India. The women used liquid petroleum based gas cook stoves for a period of 18 months. Exposure to PM2.5, black carbon (BC), and carbon monoxide (CO) and correlation with blood pressure was evaluated. The study found that the exposure to the pollutants increase the systolic and diastolic pressure by 2mmHg. A positive association was found between exposure to PM2.5 and increase in blood pressure by 1.6mmHg. The results were significant in short term exposure only and long term exposure showed no differences between control and exposed groups.

Indoor air pollution in South Asian countries has serious effects. Of the several South Asian countries only five of them have published results related to effects of indoor air pollution on health of individuals. Solid fuel burning was the main source of indoor air pollution. Women and children were mainly affected by this. In most cases the effects were visible on lungs and eyes. Coughing, sneezing, and breathing difficulties were most common symptoms seen in the women. COPD was most common in kids and women along with respiratory tract infections.

Thus, appropriate interventions are needed to control the situation.[8]

Simkovich et al.[9] performed a review of existing literature to correlate the HAP and prevalence of disorders. The study found that HAP exposure is associated with respiratory diseases, head and neck cancer and lung cancer. Tobacco smoke exposure is another significant factor as well.

Benzene is a known carcinogen. The levels of benzene indoor and outdoor and their estimation is a vital factor for policy makers to develop appropriate interventions. Of the 193 countries in the United Nations only 53 countries have ambient levels of benzene. Estimation of benzene is typically done by gas chromatography and mass spectrometry. The highest concentrations of benzene were found in Asian countries which recorded 3.5 times the higher values than the expected. European and North American countries had lower values than the normal indices.[10]

Meta-analysis done on HPA and COPD in Asian countries mainly Nepal, India, and Pakistan showed significant results. The use of kerosene and biomass for cooking were the main sources for pollution. The study observed that women were more prone to COPD than men. Poverty was one of the main reasons for COPD in the subjects.[11]

An RCT was conducted in Honduras to evaluate the concentration of PM2.5 and Black carbon levels. 230 households of rural Honduras were considered wherein traditional cooking using solid fuel was done. Six measurements were done for over a period of three years. The study found 37% variation in PM2.5 over the three year period. 47% variation was seen in Black carbon over the same time frame. The main factors that were to be considered included stove type, placement of stove in kitchen, seasonal variations, the availability of electricity and presence of kerosene.[12]

The Household Air Pollution Intervention Network (HAPIN) trial was performed in rural Tamilnadu to understand the role of HAP and its effects on pregnant women. All women were between 9-20 weeks of gestation. The study found that systolic and diastolic pressure were higher in women exposed to higher HAP levels. CO was mainly correlatable with increased diastolic blood pressure. PM2.5 had lower effect on DBP than CO.[13]

Dwivedi et al.[14] studied the concentration of indoor particulate matter and associated PAH during winter. The study was conducted in Lucknow in both indoor and outdoor sites. Six distinct PM's were analysed which included PM> 2.5, PM2.5, PM1.0-2.5, PM0.50-1.0, PM0.25-0.50 and PM<0.25. Three distinct areas namely residential, commercial and industrial were checked for the concentrations of the various PM's. Households in industrial areas had the highest PM2.5 followed by households in residential areas. In industrial belt households there was a significant amount of PAH along with PM. Surprisingly the values of PAH along with PAM was found to be equally high in households of residential areas. Higher levels indoors could be due to cooking, smoking and incense burning. High levels outdoors were mainly contributed by vehicular and industrial effluents. Thus, the study highlighted the fact that there are high levels of these pollutants which is making them hazardous for health. The government needs to set specific standards to control such levels of these air pollutants.

A correlation between household air pollution (HAP) and incidence of cardiovascular diseases was performed by meta analysis. The study showed interesting observations. A total of 466,498 cases within six papers were subjected to meta analysis. The random effect model showed that people exposed to HAP generated by coal or other solid fuel had a 13% likelihood of death by cardiovascular diseases. Five studies were assessed for impact of HAP on stroke and cerebrovascular incidents. The random effects model showed that there is around 12% risk of cerebrovascular accidents post exposure to HAP. However, analysis did not find any significant correlation for HAP and myocardial infarction or association with ischemic heart disease. However, people exposed to HAP were 2.3 times more susceptible for heart failure and 1.3 times more susceptible to hypertension when compared to non-exposed cases. HAP had no effect on preeclampsia or carotid intimal myocardial thickness.[15]

Factors affecting indoor air pollution

Meteorological conditions play a significant role in the extent of indoor air pollution. A study done on the role of meteorological factors governing the accumulation of PM2.5 and PM1 in a Polish resort showed interesting results. The daily average concentrations for PM10, PM2.5, and PM1 fractions were 50, 42 and 23 µg/m3 indoors. The daily averages reached highest values depending on the outdoor concentrations. The outdoor concentrations were affected by an influx of pollutants from North Africa. Wind speed and direction played a prominent role in controlling the overall pollutant concentration. High concentrations of these pollutants in winter was associated with the aforementioned factors. However, in summer the higher concentrations were associated with use of chimney or gravity ventilation.[16]

Weather and climate changes have a significant impact on the IAQ. During the rainy season the presence of continuous wet conditions results in indoor dampness and high rates of fungal spore dissemination. This in turn can be toxic and produce systemic allergy in residents. The growth of mold is another distinct feature during rainy seasons which heavily influences the indoor air quality. Air pollution from burning mosquito repellents generates toxic chemicals that need to be checked and controlled. Outdoor pollen concentrations change with seasons which in turn influences their accumulation indoors. Thus, allergic reactions need to be checked and interventions to be placed appropriately to prevent deterioration of health of residents.[17]

There are multiple sources of indoor air pollution that affect its quality. Household behaviours and practices are one amongst them. Smoking, solid fuel combustion, cooking and heating and cleaning are some of the routine practices that affect the IAQ. A second significant feature is the housing characteristics. Ventilation, dampness, allergens from household pests, residential crowding, and proximity to busy traffic areas all contribute to significant enhancement in deterioration of IAQ. The use of air cleaners, gas stove replacement, wooden stove replacements, remediation of dampness and humidity and smoking cessation all play a role in effective control of the IAQ.[18]

The impact of ventilation and indoor air quality was studied in Swiss primary schools. 24 schools in Fribourg, Switzerland, were selected for study. One lower and upper floor of each school was used for assessment. Relative monitoring of CO2, Temperature, relative humidity and PM were evaluated. The study observed that the levels of CO2, VOC and PM2.5 was in general low. The use of mechanical ventilation further reduced the values. The various pollutants were found to be lowest in summer. VOC were ubiquitously seen in the classrooms. Thus, the study highlighted the effective usage of management strategies for controlling the indoor air quality.[19]

Alonso-Blanco et al.[20] studied the role of weather, atmospheric stability and the wind speeds in indoor and outdoor pollution in the classroom of Urban primary school in Madrid. Simultaneous measurements of PM1, PM2.5, and PM10 along with ultrafine particle number concentration (PNC) and black carbon content (eBC) were assessed both indoor and outdoor. The PNC and eBC concentration were similar at different points for outdoor and these were lower indoor. The study found a strong correlation between indoor and outdoor levels. There was a time delay in indoor level accumulation and depending on the wind patterns and weather conditions. Atmospheric stability helped in increasing the indoor and outdoor pollution with these components. The days on which the school was empty the levels were found to be lower when compared to the days when the students were attending classes. The indoor levels were also increased if windows were left open. Thus, altering the variables suggested above could help in effective intervention and protecting kids from health related issues.

4.2. Assessment of Indoor air pollution

Air quality monitoring systems (AQMSs) are essential tools for evaluating atmospheric composition. AQMS, with its systematic measurement and evaluation of pollutants along with measurement of particulate matter in air, holds a significant potential for environmental sustainability. The data captured in the monitoring systems can help in drafting policies and creating public awareness. Thus, the use of robust AQMSs is vital for cities to monitor indoor and outdoor pollution. The use of the linguistic Pythagorean fuzzy Dombi ordered weighted averaging (LPFDOWA) and the language Pythagorean fuzzy Dombi ordered weighted geometric (LPFDOWG), operators could help in detecting the indoor air pollutants much accurately. The effectiveness of utilizing these operators could be helpful in overcoming the challenges in AQMS and be useful in more effective detection of indoor air pollutants.[21]

VOCs are the main indoor pollutants. WHO classified VOCs as very volatile, volatile and semi volatile. VOCs include hydrocarbons, benzene, toluene, xylene, ketones, terpenoids and organic acids. Building materials, human activities and outdoor air are chief contributors of VOC. Indoor VOC are measured post collection of air samples by active or passive sampling methods. The measuring technique depends on the nature of VOC. Change in optical parameters, conductivity, mass and voltage change have been successfully utilised for measuring VOC. Carbon black or its derivatives are most commonly used sorbents for VOC. Analytically VOC are estimated by liquid chromatography based methods in conjunction with Gas chromatography.[22]

A hybrid framework was used for testing indoor air quality (IAQ) and its impact on student health and academic performance in healthcare and laboratory environments. A comparative analysis was done of Spearman, Kendall and SHAP values for identifying PM10 with location, noise and thermal factors playing a secondary role. The analysis using the three methods showed that there is significant PM10 levels which was comparable across along with high total volatile organic compounds (TVOC) and CO2. Thus, the use of such methods could be helpful in calculating the indoor air quality and providing suggestive measures for the same.[23]

4.3. Frameworks for mitigation of indoor air pollution

Improved cook stove innovation

Adane et al.[1] performed a RCT for examining the role of improved biomass fuelled cookstove innovation and its role in preventing indoor air pollution. A total of 2031 households were enrolled for across 36 randomly selected clusters. At least one follow up was done from 1977 households. The cook stove intervention was effective in reducing the indoor particulate matter by about 343 μg/m3 when compared to traditional stove based cooking. The overall reduction was found to be 46% in the intervention arm. Thus, in conclusion this study done in Ethiopia clearly showed that such interventions can help in reducing indoor air pollution.

HAPIN trial was performed in four distinct countries to evaluate the role of LPG stove and fuel intervention and adverse outcomes in maternal women. 3195 pregnant women were considered from Guatemala, Peru, India, and Rwanda. The study found no statistically significant results for reduction in spontaneous abortions, spontaneous hemorrhage, or hypertensive disorders in intervention vs control. Thus, the intervention alone might not have an effect on the exposure and maternal outcomes.[25]

Saleh et al.[26] performed a systematic review of various RCTs that tested various interventions to reduce indoor

air pollution and enhance IAQ. 14 RCTs conducted in LMIC were considered. Out of the 14 RCT, 12 of them showed that improved cookstoves played a significant role in improving the IAQ. However, in most of the studies the use of better cookstoves could not show significant results in reduction of child pneumonia or COPD. The studies had significant heterogeneity which resulted in inconclusive results. Thus, the household interventions alone might not be sufficient to control the IAQ quality and needs a systemic evaluation.

Consumer behavior based intervention

Gabriel et al.[27] studied the role of consumer behaviour in electricity usage and its effect on indoor air quality. The study was a part of the NUDGE project for providing interventions based on occupant behaviour. Smartphone-based monitoring was done for evaluation of indoor air quality. A very strong correlation was not found between the increased electric usage and enhanced AQI. The opening of windows briefly was helpful in reducing the AQI irrespective of power consumption. The study observed that if participants adopt to improve the natural ventilation that could help in reducing the AQI and thus would be a beneficial strategy.

Role of Biobased approaches

Abhijit et al.[28] (2022) studied three distinct interventions to reduce the indoor air pollution in urban schools of the UK. Green screens were placed across the school fence to prevent the traffic pollution from entering the schools. The screen consisted of Ivy grown on a galvanised steel frame. In another intervention in School B, air purifiers were installed on walls of the school. The school was in close proximity to the road resulting in heavy traffic pollution. In the third case, the intervention consisted of a school street which involved closing the street for traffic. The study observed that increase in class occupancy increased the indoor pollution with PM2.5 and PM1. The PM concentration was heavily influenced by outdoor pollution. The use of any of the interventions resulted in overall reduction of the PM from outdoor to indoor. The wind direction controlled the extent of decrease of pollutants indoor, with perpendicular wind showing drastic decrease in PM levels. Thus, this study is extensively helpful in evaluating the different strategies for mitigating the air pollution levels.

Indoor air pollution and its mitigation play a significant role in improving the health of residents. The use of bioactive coatings for reducing indoor air pollution is a prominent strategy. Bioactive coating-based bioreactor was tested for reducing concentration of different VOC at different empty bed residence times and inlet VOC concentrations. The performance of the bioreactor was evaluated with respect to conventional biofilm-based bioreactor. The coated bioreactor showed significant reduction of different VOC with abatement of 50% for hexane, 80% for toluene and 70% for pinene at EBRTs of 112–56 s and inlet concentrations of 9–15 mg m^{-3}. When VOC concentrations and EBRT were reduced, there was significant improvement in removal of VOCs, showing that at low concentrations there is limited mass transfer and bioavailability. Thus, the study showed that bioactive coating could be used successfully in reducing inhouse VOC concentrations.[29]

Phytoremediation-based approach was another method that was tested for reducing the overall concentration of indoor air pollutants. The use of inexpensive indoor plants helps in a sustainable environment and also provides safety from VOC. Potted plants or plants on walls can help in overall improving the IAQ. Various plant species have been used and the removal of VOC depends on the nature of the plant being used. *Zamioculcas zamiifolia* was found to be very effective in removing xylene. Areca palm shows an efficiency of 90% in removing the VOC. *Dieffenbachia maculata* and *Spathiphyllum wallisii* were effective in removing toluene and 2-ethylhexanol. Ornamental plants such as *Hemigraphis alternata* and *Asparagus densiflorus* were found to be effective in reducing the VOC concentration. Several of the green wall plants have been effective in removing the VOC at high concentration as well. Thus, phytoremediation approaches are promising alternatives for removal of VOC and improving IAQ.[30]

Appropriate intervention for IAQ improvement is the need of hour. Ag and its nanoparticles have found extensive application in antibacterial and antimicrobial coating systems. The use of nanofibre technology gained importance as it has large surface area and is effective in purification. Silver nanoparticle fabricated nanofiber membranes have been used for several applications. These membranes have been used extensively for removal of microbes and reduce their concentration in air. However, more research is needed to evaluate the recycling efficiency of these materials and their ultimate advantage in using.[31]

Risk mitigation protocols

Risk mitigation measures for IAQ are essential and protocols for the same need to be established. In one such study, the European Union has developed Construction Product Regulation set to control the total VOC emitted. A group of experts from ten European countries have developed an EU-LCI list. The construction products were tested for VOC emission based on the values decided by the list. The EU-LCI list was defined as "health-based reference concentrations for inhalation exposure used to assess emissions after 28 days from a single product during a laboratory test chamber procedure". A classification system was introduced and the extent of VOC emission was colour coded so that it is easy to screen and confirm. As of 2019, the list has been made for 152 organic compounds typically emitted by construction projects. The list is handy and suitable to evaluate the products before proceeding for construction. However, an official legal aspect is still in process.[32]

Indoor air pollution has a significant effect on maternal and child health. Indoor pollution is contributed by a variety of factors, including the building material. Hence, necessary safety regulations need to be in place so that the risk of pollution is reduced. Regulatory and legal

frameworks corresponding to IAQ need to be established thoroughly and followed such that people residing in enclosed areas do not suffer from diseases. Legal perspectives include that builders or developers consider IAQ and construct buildings which are compliant for the same. Evolution of smart building technologies thus is very important. There are significant lacunae in this area which need to be addressed. A multidisciplinary framework which involves real-time IAQ monitoring, targeted interventions and establishment of regulatory framework are needed to improve the situation.[33]

Photocatalytic oxidation

Reduction of VOC in indoor air by photocatalytic oxidation has been considered as an effective remediation method. However, photocatalytic oxidation often generates toxic byproducts. These byproducts, once released, could affect the health of individuals. Incomplete oxidation of VOC can result in the generation of a mixture of compounds that could be more toxic than the parent compound. Photocatalytic oxidation is known to generate acetaldehyde, benzene, formaldehyde and other toxic compounds. Thus, optimizing the photocatalysis and ensuring that there is no release of toxic compounds is essential for this strategy to work.[34]

Economic impact of mitigation measures

Wang et al.[35] (2024) studied the effect of cost and economic impact of air pollution control strategies. In the systematic review, a total of 104 studies were considered. Of these studies, 72 observed that the benefits of control strategies outweighed the cost of implementing the same. Source reduction and end-of-pipe treatments were the most widely used methods for reducing air pollution. Thirty-one studies showed partial or complete positive economic evidence. In summary, 70% of studies highlighted the advantage of economic benefits of implementing air pollution control strategies. However, the major issue was with policy flaws in implementation, which affected their effective optimization.

5. DISCUSSION

IAQ is a key indicator of the health of individuals residing in homes, schools and offices. The IAQ is influenced by several factors which include outdoor pollution, meteorological conditions, nature of construction, habits of residing people and interaction of the construction material with the environment. Thus, it is a complex phenomenon that results in either increase or decrease of indoor pollutants. The major indoor pollutants include aldehydes, ketones, aromatic compounds and VOC. The presence of CO, PM2.5 and PM1 is mainly associated with outdoor pollution and its interaction with the indoor environment. The indoor pollutants and their levels have a significant impact on the health of individuals, with women and children being more susceptible than men. The main effects are seen on the lungs, heart and brain. Persistent cough, respiratory tract infections, COPD and lung cancer are reported predominantly from LMIC wherein cooking is done using solid fuels. The molds and their spores from the indoor environment pose a serious threat to the lungs with allergic reactions. It is essential to monitor the various indoor pollutants by different methods.[36] Presently, gas chromatography, mass spectrometry and related methods are used, but advanced methods are needed to ensure accurate detection.[37] Several strategies have been implemented to control indoor air pollutants. Phytoremediation along with the use of LPG-based cookstoves has been proposed as one of the methods. The use of VOC-compliant construction material along with proper risk mitigation protocols in place is essential for controlling the IAQ. Thus, the present review has discussed the current literature on the same and provided a comprehensive overview of the threats and mitigation measures associated with indoor air pollution.[38]

6. CONCLUSION

The present review has identified several factors that contribute to indoor air pollution which include meteorological conditions, personal, cleaning, cooking habits and construction materials for enhanced indoor pollutants. Measures such as phytoremediation, use of silver nanofibres, risk mitigation measures and their legality have been proposed based on the literature identified. However, most of the measures are at early stages and there is a lack of implementation in LMIC. Appropriate planning and developing framework with contribution from Government and Stakeholders is essential in controlling the indoor air pollution and its effects on women and children.

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