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REVIEW

Mitigation and Chemistry of Indoor Air Pollutants in Urban and Rural Environments of India: A Review of Contemporary Advances

Samridhi Dwivedi[1,*], Ayushi Tewari[1], Srishti Dwivedi[1], Saima Arif[1], Tahmeena Khan[2] and Alfred J. Lawrence[1,*]

[1]Department of Chemistry, Isabella Thoburn College, Lucknow-226007, India
[2]Department of Chemistry, Integral University, Lucknow-226026, India

*Corresponding authors: E-mail: samridhi.dwivedi94@gmail.com; alfred_lawrence@yahoo.com

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Globally people devote approximately 90% of their time indoors either in their house or office or institution, *etc*. Together with the dispersion of outdoor air pollutants, toxins are produced in indoor atmosphere owing to various actions such as heating, cooking, cooling and emissions from building materials. Hence, the indoor air quality (IAQ) influences human well-being and efficiency. Even though indoor air quality (IAQ) research has been done from various outlooks, there is still an absence of inclusive assessment of peer reviewed IAQ studies, which precisely covers the IAQ in rural and urban environment helping to recognize the sources and consequences in both the environment, respectively. Therefore, this review article of scientific studies offers a broad spectrum of pollutants identified in both rural and urban indoor environments in context to India, highlighting the technical interventions, modelling techniques and remedies such as HEPA filters, carbon filters, bioremediation etc. in course of improving IAQ. This review also elucidates the chemistry of pollutants along with general chemical reactions between pollutants. Thus, this review paper holds the potential to help building professionals and researchers in the field for regulating indoor air quality and generate healthy and sustainable indoor environment.

Keywords: Indoor air pollution, Health outcomes, Technical interventions, Dosimetry.

INTRODUCTION

Indoor air quality (IAQ) depicts the air quality prevailing within and throughout the buildings and constructions, particularly relating the health and comfort of building dwellers. Revelation to indoor air pollutants (IAPs) has emerged as one of the main sources of health hazards in developing countries. According to a report released on 30th June 2021 by the Government of India Ministry of New and Renewable Energy, around 32% of the entire primary energy usage in the country is still derived from biomass and above 70% of the country's population still relies over it for its energy requirements [1]. Owing to the alarming health bearings accompanying IAPs exposure, the World Health Organization (WHO) assigned this as one among the four utmost serious global ecological problems in developing countries. The main indoor pollutants recognized are SO_x, NO_x, VOCs, CO_2, CO, *etc*. Long-term subjection to these pollutants (IAPs) can instigate serious health consequences. Along with physical health problems such as cardiovascular diseases, asthma, Endothelial dysfunction, allergies, respiratory problems. *etc*. Indoor air pollutants (IAPs) also harm cognitive abilities, which may lead to sinking of human assets, condensed earnings, and declined social well-being. Although sufficient assessment of theses pollutants has been done so far, yet, the section of regulating and modelling of pollutant has not much travelled [2,3]. The blooming of novel technology becomes the utmost promising frontiers for the improvement of air quality. Catalytic converters to zero or low emitting user products, there are number of methods for the prevention of indoor air pollution. In the same row air pollution models portray their ability to evaluate the comparative importance of significant procedures. Air pollution models quantify the inevitable association linking emissions and concentrations, together with the results in regard to past and future circumstances and therefore the fortitude of the efficacy of reduction strategies [4,5].

This review article thus emphasises on the main indoor pollutants, their chemistry, health consequences along with technical interventions which will help the researchers in the field for modulation of IAQ. According to report released by Ministry of Statistics and Programme Implementation UN, on 23rd August 2021, approximately 65% of India's population resides in rural areas till the year 2020. Hence, this work discusses the principal pollutants prevailing in urban as well as rural environment separately. The scope of the article remains confined to Indian context while still extending the discussions accomplished around the globe with the intent of assessing the Indian IAQ matters in context of a comprehensive research.

Charaterstics of houses in rural and urban enviornments: The indoor sub-structure of rural and urban environment in India varies to a great extent. The differences in the cooking fuels, ventilation, the area inside the house governs the overall quality of indoor air. Although the pollutants remain somewhat same yet the sources from which they originate varies and it highly governs the percentage and chemistry of pollutants and human well-being living in that environment [6]. The characteristics of typical rural and urban Indian houses have been depicted in Table-1.

Inhabitants: According to a report released in August 2021 by Ministry of Statistics and Programme implementation UN around 65% of India's population lives in rural area and 53 and 35% in urban areas. Therefore, the economic status and lifestyle both govern the quality of indoor air discretely in each area.

1. Air quality in rural areas has always been ignored so far. It is a general belief that rural areas are devoid of air pollutants. The situation is quite the reverse; the quality of air in rural areas all around the world and predominantly in developing countries encompass some very deadly pollutants *viz*. CO, SO_2, NO_2, O_3, *etc*. in more quantity as compared to their urban counterpart. Rural areas endure both outdoor air pollution as well as indoor air pollution. People are exposed to pollutants more in indoor environment than outdoor. The exposure to such indoor pollutants contributes towards acute respiratory infection in the young children, adverse pregnancy consequences for pregnant women, cancer, cardiovascular disorders, *etc*. [7]. Among all the occupants residing, the most vulnerable ones are children and pregnant women.

2. Increasing urbanization, flourishing industrialization, and related anthropogenic activities are the chief reasons that cause emission and poor air quality [8]. Over 80% of the population residing in urban areas is exposed to emissions and pollutants that exceed the standards set by WHO . Conferring to a report by interdisciplinary journal Lancet Planetary Health, air pollution was considered to cause over 1.7 million premature deaths in India in 2019. Since people devote more than 90% of their time indoor, which has been increased further due to COVID-19 lockdown, they are more introduced to indoor air pollutants, which is almost 5 times more as compared to outdoor. Children being the most vulnerable in the row experience and exhibit certain respiratory and cardiovascular disorders attributable to these pollutants.

The reason being that infants and young children possess a greater surface area per body weight as well as they grow promptly. As a result, they possess greater resting metabolic rate, in addition to, oxygen consumption rate per body weight as compared to adults. Furthermore, children own narrow airways as compared to adults [8]. Consequently, exasperation triggered by air pollution will give rise to a minor retaliation in adult and potentially substantial interference in the airways of a child.

Chemistry of pollutants: Abbatt & Wang [9] in their review article on the atmospheric chemistry of indoor environments [9] identified a few oxidants responsible for the chemistry of the indoor air pollution. Some of the important oxidants are summarized below:

(i) **Ozone:** Ozone is generated photochemically in the outdoor troposphere but may be transported inside.

(ii) **$OH^{\bullet}$ radical:** $OH^{\bullet}$ radical is transitory and thus cannot be transferred from outdoor but it can be generated by the

TABLE-1
CHARACTERISTICS OF URBAN AND RURAL HOUSES IN INDIA

Characteristics	Urban house	Rural house
Ventilation	• Proper ventilation is available *via* chimneys, exhaust, windows *etc*.	• Lack of windows • Lack of electrical ventilation appliances *e.g.*, chimneys, exhaust
Supply of electricity	• Temperature control devices such as heaters and air conditioners are available • Use of solar panels is not prevalent	• No temperature conditioning devices • Indoor use of solar panels as energy source is widely seen
Waste burning	• Waste collecting facilities are available • Less open waste burning	• Waste burns openly, sometimes using fuels like kerosene.
Greenery	• Lack of flora	• Abundant flora available
Ambient air	• Lack of greenery allows for lower air quality	• Good air quality due to abundant greenery
Building materials	• Paints and varnishes release volatile organic compounds	• Huts are usually made up of mud doesn't require any paints or varnishes
Cooking medium	• Liquified petroleum gas (LPG) & piped natural gas (PNG) are used as cooking medium.	• Wood and fuels like Kerosene are used as cooking medium, releasing CO & CO_2
Infiltration	• Outdoor air containing, Particulate matter, Pathogens, VOCs, Odours & Emissions	• Outdoor air contains lessen air pollutants as compared to urban
Number of rooms	• Proper division into rooms like- kitchen, bathroom, garage *etc*. • Fumes & CO from attached garage	• Common room with no separate kitchen. Toiletries are either built away from house or use public toilet.

ozonolysis of alkenes which might initiate the formation of $^{\bullet}OH$ radical in the dark.

(iii) **$NO_3^{\bullet}$ radical:** $NO_3^{\bullet}$ is the product of the reaction between NO_2 and O_3.

(iv) **Hydrogen peroxide and chlorine cleaning agents:** In places like hospitals, chlorine bleach is used as an antimicrobial cleaning agent. This solution may release a number of chlorinated species such as HOCl, Cl_2, $ClNO_2$, NCl_3, NH_2Cl, $NHCl_2$ and $CHCl_3$.HOCl and Cl_2 can disintegrate photolytically to give $^{\bullet}OH$ and $^{\bullet}Cl$ radicals, which are reactive in nature.

A wide range of pollutants are responsible for worsened indoor air quality both in urban and rural environment. Fig. 1 depicts these pollutants and the general chemical reactions between the pollutants. Soot, which is made up of elemental carbon (EC) and organic carbon (OC) makes up a huge portion of the total amount of atmospheric aerosol mass. The elemental carbon is a graphite-like microcrystalline structure and absorbs light strongly [10]. The organic carbon content is made up of hydrocarbons, PAHs and partially oxidized organic matter that might condense to form soot particles [10].

Formaldehyde (HCHO) can photochemically degrade in presence of hydroxyl radical ($^{\bullet}OH$) [11] and O_3 also degrades HCHO as shown below:

$$\begin{aligned}
HCHO + {}^{\cdot}OH &\longrightarrow {}^{\cdot}CHO + H_2O \\
{}^{\cdot}CHO + OH &\longrightarrow HCOOH \\
{}^{\cdot}CHO + O_2^{-} &\longrightarrow HCO_3^{-} \\
HCO_3^{-} &\longrightarrow HCOOOH \\
HCOOOH &\longrightarrow HCOOH \\
HCHO + 3O_3 &\longrightarrow CO_2 + H_2O + 3O_2
\end{aligned}$$

Nitrogen oxides (commonly called as NO_x) include NO, NO_2 and other oxides of nitrogen. NO_x can react with volatile organic compounds (VOCs) in the presence of light and heat, and form ozone. NO_2 can photolyze in radiation of wavelength (λ) less than 420 nm forming $^{\bullet}O$ radical and nitric oxide. This $^{\bullet}O$ radical forms ozone by combining with dioxygen. The ozone further reacts with NO to form NO_2 and O_2.

$$NOx + VOCs + h\nu \xrightarrow{\text{heat}} O_3$$

$$\begin{aligned}
NO_2 + h\nu &\xrightarrow{<420\text{ nm}} NO + O^{\cdot} \\
{}^{\cdot}O + O_2 &\longrightarrow O_3 \\
O_3 + NO &\longrightarrow NO_2 + O_2 \\
NO_2 + {}^{\cdot}OH &\longrightarrow HONO_2
\end{aligned}$$

When radiations of $\lambda < 320$ nm are available, ozone can decompose into dioxygen and oxygen radicals, which react with water vapours to form hydroxyl radicals [12]. These hydroxyl radicals can degrade HCHO as shown before. Ground level ozone is formed when methane gas reacts with oxygen producing formaldehyde along with ozone. This is one of the reactions occurring in a greenhouse, otherwise called greenhouse reaction.

$$\begin{aligned}
O_3 + h\nu &\xrightarrow{<320\text{ nm}} {}^{\bullet}O_2 + O_2 \\
{}^{\bullet}O + H_2O &\longrightarrow 2{}^{\bullet}OH \\
CH_4 + 4O_2 &\longrightarrow HCHO + H_2O + 2O_3
\end{aligned}$$

It is now a common knowledge that human haemoglobin has more affinity for CO than for O_2. Thus, a high concentration of CO might lead to what is called "CO poisoning". According to what is referred to as "cooperativity effect", the addition of first CO molecule facilitates the addition of other CO molecules.

$$Hb(O_2)_4 \longrightarrow Hb(O_2)_3(CO) \xrightarrow{+\,3CO} Hb(CO)_4$$

HONO is formed by the reaction of nitrogen dioxide with water surface.

$$2NO_2 + H_2O \xrightarrow{\text{Surface}} HONO + HNO_3$$

Pitts *et al.* [13] employed differential optical absorption spectrophotometry (DOAS) thus establishing that NO_2, which was injected into a mobile home formed HONO. HONO was formed as NO_2 decayed along with small amounts of NO, according to laboratory studies [14]. It was observed that there was a delayed release of HONO, which suggests that it was adsorbed in part on the surfaces and was released later in gas

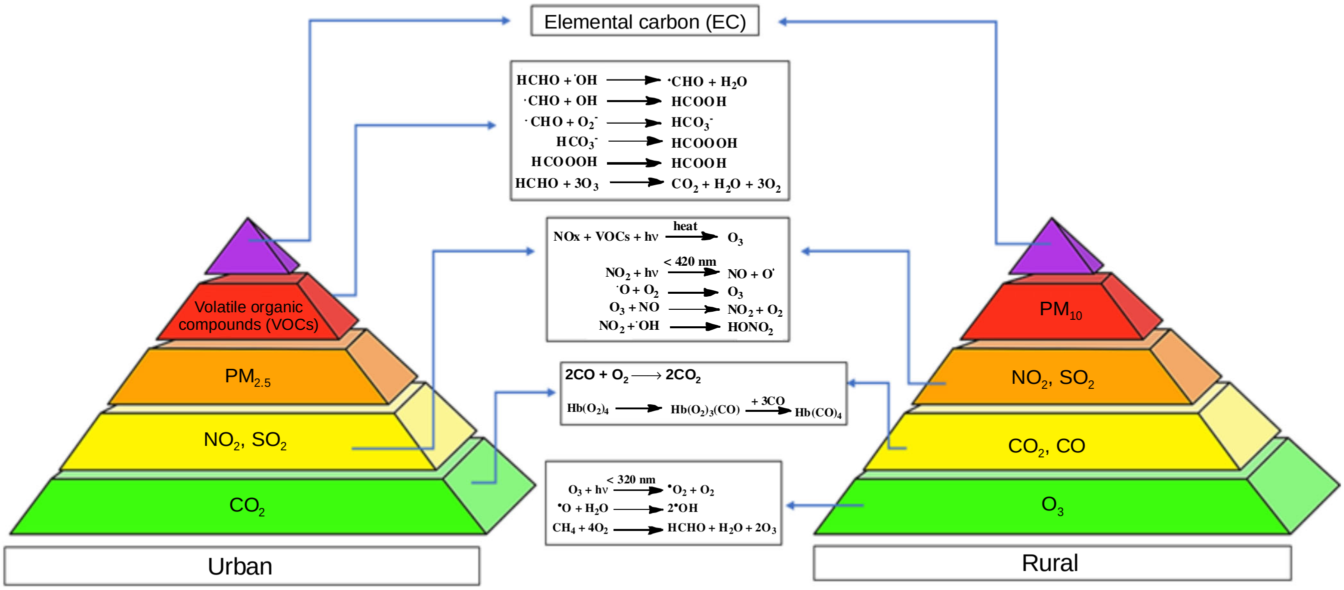


Fig. 1. Various pollutants and the general chemical interactions in urban and rural environment

phase [15]. Weschler *et al.* [16] concluded that dissolved HONO in a surface film of water is oxidized to nitrate by ozone since it was observed that the indoor HONO concentrations did not increase under high concentrations of indoor ozone [16].

Weschler *et al.* [16,17] also suggested the indoor formation of NO_3 and its secondary forming nitric acid.

$$O_3 + NO_2 \rightarrow NO_3 + O_2$$

$$NO_3 + NO_2 \rightleftharpoons N_2O_5$$

$$N_2O_5 + H_2O \xrightarrow{\text{Surface}} 2HNO_3$$

$$NO_3 + RH \rightarrow HNO_3 + R$$

Carpet exposed to ozone in an enclosed space generated formaldehyde, benzaldehyde, benzoic acid, acetophenone, the products one would expect from the reaction of styrene (emitted from the latex adhesive which is used to bind the back to the carpet) and ozone [18]. Latex paint exposed to ozone led to the production of formaldehyde, acetaldehyde and acetone in some cases [19]. Reiss *et al.* [19] proposed that these were the result of the reaction of ozone with the remaining double bonds that were not entirely reacted in the course of the procedure in which the CH_2=CHR was polymerized to form the latex paint. Indoor formic acid concentrations increase with the indoor ozone concentration and relative humidity [20].

The reaction scheme shown in Fig. 2 depicts the transformation of NO_x and sulphur oxides and their interactions with other pollutants. In daytime, NO_x converts into nitric acid, meanwhile when it is dark, NO_x can exist in the form of dinitrogen pentoxide, which convert into HNO_3. This will exist as nitrate ions in the environment and might undergo further reactions. Furthermore, a multiphase reaction occurs when sulphite ion converts into bisulphite and further into solvated sulphur dioxide. This SO_2 can exist as sulphuric acid or as sulphate ions, whereas ammonia exists as ammonium ions. The O_3 and H_2O_2 might act as oxidants and can oxidize the multiphase reaction products thus forming sulphate ions too (Fig. 2). Thus, the indoor environment becomes a pool of ions and particulate matter, consequently facilitates the mixing of these pollutants, which might or might not become more hazardous to human health.

Surface chemistry of indoor air pollutants/multiphase reaction of ozone as an indoor pollutant: Due to high deposition rate, availability and low mixing ratios in the interior surfaces, the surface absorption of ozone is easier [21]. Interior materials like carpets, clothing items, edible oils, skin oil substituents, building materials [22], filters and vents [23], *etc.* were used to study the ozone absorption [24]. During reactive absorption the yield of carbonyls particularly aldehyde formed was high [25]. Carbonyl emissions occur in high amount during ozone mixing used in indoor disinfection [26]. Over the time, indoor surfaces also loss reactivity and become less reactive to ozone like air ducts, carpets, building material like ceiling [27], painted drywalls, kitchen rooftop, *etc.* [28]. Some studies suggest that due to the constant addition of edible oils to such surfaces, skin oils and flakes, essential oils and detergents, surfaces become more reactive. To check the above two scen-arios, work has been done to evaluate the usefulness of various surfaces [29].

Prime reasons for high ozone deposition rates are the oxygen molecule formation on the solid inorganic surfaces such as mineral dust [30] thus making surface inactive with high ozone exposure with time but some degree of reactivity regenerates over time. This mechanism is the chemical rationale behind commercial products that catalytically remove ozone from indoor air, using ceramic surfaces and metal oxides. Ozone's electrophilic nature also makes it reactive with unsaturated carbon-carbon bonds found in variety of molecules that

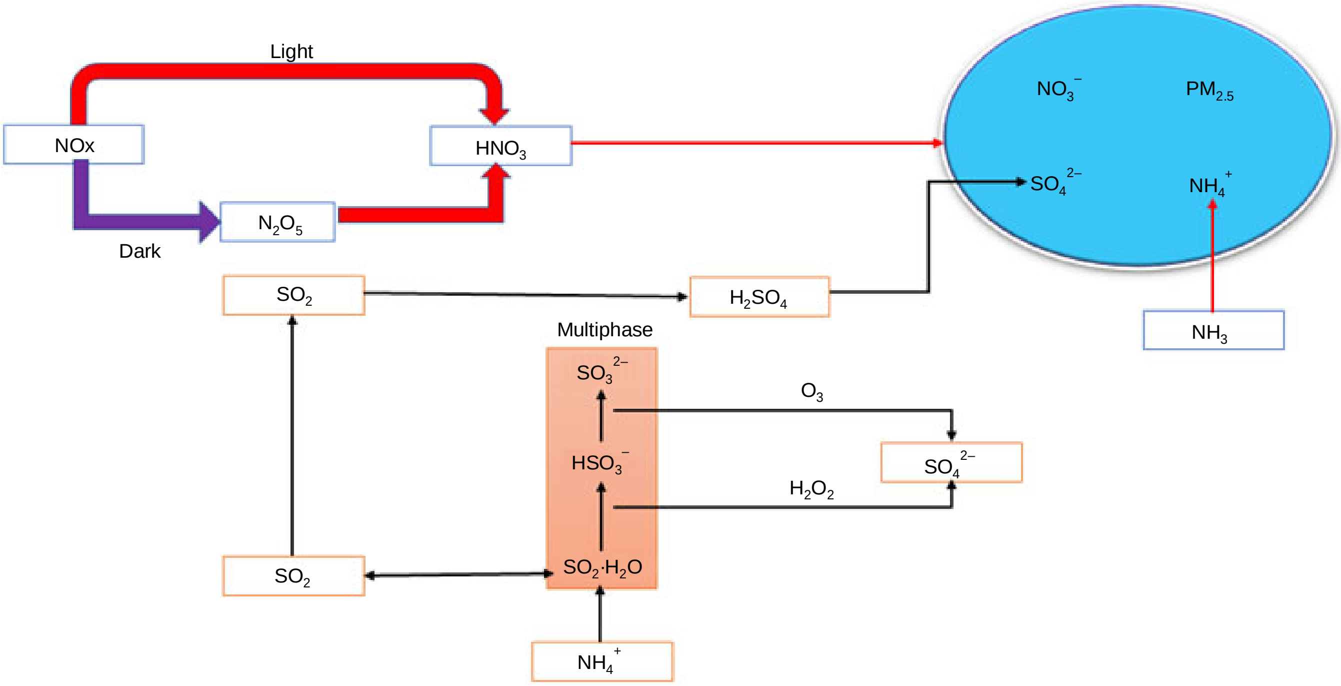


Fig. 2. Reaction scheme for transformation of NO_x and SO_x and their interactions

break down the surface reservoirs, such as components of skin oil and cooking oil (unsaturated triglycerides, cholesterol) [31-33], terpenoids [34], especially polar compounds such as terpineol [35,36].

Ozonolysis of olefins occurs through the formation of primary ozonoids, which are formed by electrons in the carbon-carbon double bond covalently bonding with an unpaired electron density to the terminal oxygen atom of ozone molecule [37]. The primary ozone then decomposes to form biradical intermediate and carbonyl [38], which is quite volatile [39-41]. The yield of the product increases at high relative humidity as compared to dry conditions. It ia also dependent on secondary ozonoids and hydroperoxy esters' concentration [42-45]. The above chain reactions have been summarized in **Scheme-I**.

Ozone with many electron rich substrates like PAHs and nicotine [46,47] reacts heterogeneously. Sources of above pollutants can be candle burning, incomplete combustion process, cooking stove operation and upto certain extent smoking. These pollutants can show both carcinogenicity and mutagenicity [48] due to low volatility to indoor surface particles [49]. A recent indoor study suggested that ozone heterogeneously functionalizes benzo[*a*]pyrene (BaP) into epoxides and epoxy diols [50]. The epoxydiol BaP product is highly carcinogenic and known to be formed biochemically in the body's cytochrome P450 enzyme complex.

Photochemistry: Ozone decomposition is very prominent in inner glass surfaces of windows. PAHs, such as perylene, are known to photodegrade when adsorbed onto silica under sunlight conditions [51]. Other surfaces that might undergo faster photochemical transformations will be very close to light fixtures, such as the backsplash of an illuminated kitchen side wall.

Photochemical degradation can occur *via* several direct mechanisms. One differently active chromophore is the carbonyl functional group. For example, there was observed to be light-enhanced release of benzaldehyde and other volatile organic compounds (VOCs) from a lacquer coated particle board, probably *via* Norrish type I reactions that involve carbon-carbon bond breakage from photo-initiators such as 2-hydroxy-2-methyl-1-phenylpropan-1-one as shown in Fig. 3 [52].

One particularly special photooxidation agent widely present indoors is rutile (TiO_2), a famous whitening agent which is added in paint [53-55]. Under actual indoor conditions with substrates of white paint on glass in a chamber, there was significant loss of gas-phase NO_2 under illumination, but only moderate to no effects were observed for degradation of a variety of VOCs [56].

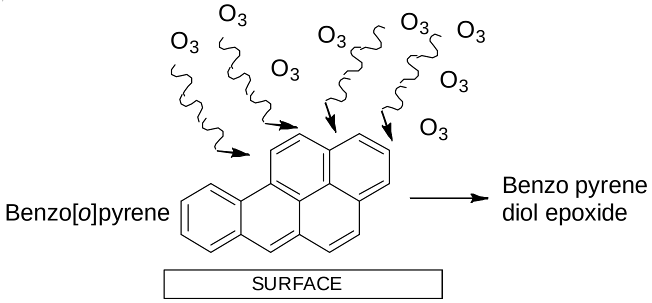


Fig. 3. Reaction of ozone with PAHs

Hydrolysis reactions: Surface reservoirs are famous for having complex organic reactions. Hydrolysis reactions are another example, where organic esters hydrolyze to form alcohols and acids (Fig. 4). This has been demonstrated by degradation of phthalate plasticizers, *e.g.* the release of 2-ethyl-1-hexanol from the hydrolysis of diethylhexylphthalate and *n*-butanol from the hydrolysis of *n*-butyl phthalate [57,58].

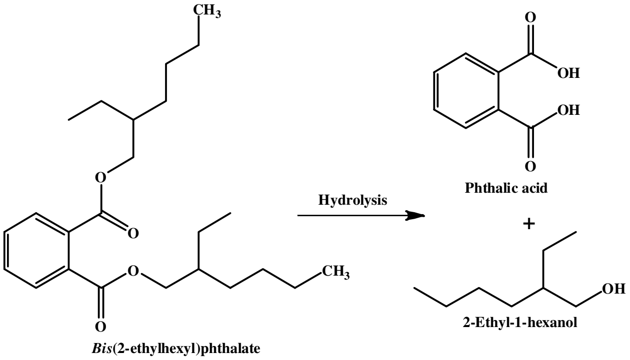
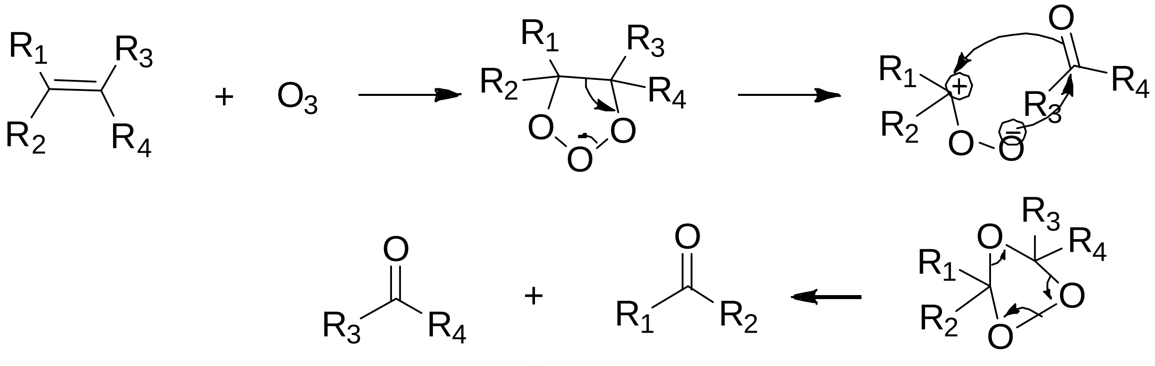


Fig. 4. Organic esters hydrolyze to form alcohols

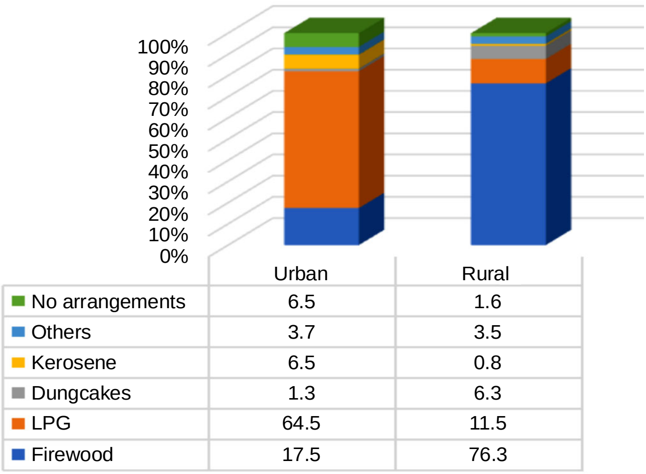
Hydrolysis rate depends on the furnishings and building materials and relative humidity/water content of the substrate [59,60] usually, under basic conditions ester hydrolysis is faster, as may prevail with the concrete substrates. For example, polyvinyl chloride (PVC) floor coverings contain phthalate and adipate plasticizers that can hydrolyze to form mini alcohols, significantly if the floor materials are laid on a concrete (*i.e.* alkaline) substrate, which is not fully dried. Another example of hydrolysis reactions are those that occur with urea



Scheme-I

formaldehyde resins and glues used in various processed wood products, such as particle and fibre boards [61,62]. These substances instantaneously release formaldehyde with high emission rate at higher relative humidity [63].

Sources and consequences: Although pollutants are same in urban and rural environment, yet their percentage and sources vary. It is reported that nearly 80% of the people in rural India depend on biomass fuel to accomplish their domestic necessities [64]. The assessed figure of individuals using harmful fuel in rural and urban areas in India has been shown in Fig. 5.



	Urban	Rural
🟩 No arrangements	6.5	1.6
🟦 Others	3.7	3.5
🟨 Kerosene	6.5	0.8
⬜ Dungcakes	1.3	6.3
🟧 LPG	64.5	11.5
🟦 Firewood	17.5	76.3

Fig. 5. Percentage of household by primary source of energy used for cooking

The major Indoor air pollutants, their principal sources and related health consequences in urban and rural areas are given in Tables 2 and 3, respectively.

Methodology: The review is based on the peer-reviewed journals from notable databases such as Science direct, Wiley databases, PubMed, SCOPUS and Web of science. Only, last ten years published articles to assess the progress in the field of indoor air quality. Some journal articles were also reviewed from other databases. The search was accomplished using combinations of keywords, *e.g*. IAQ, residential building, major pollutants, commercial building, disease related, modelling techniques of air pollutants.

Discussion

Technical interventions: The blooming of the modern technology is the most encouraging frontiers for the improvement of air quality. As the result of technological advancements, six innovations are discussed which vigorously hampering air pollutants from damaging the environment and well-being (Table-4).

Modelling: Air quality modelling helps in the formation of air pollution control policies and strategies. Air quality models portray the outward observable effects. Therefore, a number of models exist which work according to specific requirements. Some examples of the widely used air quality models are given in Table-5.

Remediation: Particulate matters (PMs), ground-level ozone (O_3), sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and volatile

TABLE-2
MAJOR URBAN INDOOR AIR POLLUTANTS

Pollutants	Principal sources	Heath consequences	Ref.
Elemental carbon	Partial incineration of fossil fuel and biomass	Struggle in breathing, tiredness, sweating, increase in heart rate and blood pressure, coma, convulsions, asphyxia *etc*.	[65,66]
VOCs	Burning kerosene, wood, cleaning agents, use of paints, hair spray, fragrance, tobacco smoke, building materials	Lung irritation, Damage to kidney, liver, Central nervous system.	[66]
$PM_{2.5}$	Fresh & aged aerosol, traffic exhaust, mineral dust/construction works, oppressive heating processes.	Aggravation of Asthma, Wheezing, Respiratory corruptions, Chronic bronchitis and COPD.	[66]
NO_2	Welding, tobacco smoke, kerosene heaters, gas combustion.	Swelling in tissues of upper respiratory tract, lowering oxygenation of tissues, death.	[66,67]
SO_2	Burning materials containing sulphur	Decreased fertility in men and women, Loss of smell, Bronchitis, shortness of breath, Severe corneal damage.	[68]
CO_2	Combustion activities, metabolic activity.	Inflammation, Reduced cognitive performance, Kidney and bone defects.	[69,70]

TABLE-3
MAJOR RURAL INDOOR AIR POLLUTANTS

Pollutants	Principal sources	Heath consequences	Ref.
NO	Combustion activities.	Formation of O_3, cancer, reduction in life expectancy.	[70]
NO_2	Welding, tobacco smoke, kerosene heaters, gas combustion, biological decay.	Throat and lungs irritation, coughing, shortness of breath, tiredness, nausea.	[71,72]
SO_2	Fossil fuel ignition, smelting, transformation of wood pulp to paper, incineration of by-product and formation of elemental sulphur.	Chest pains, breathing problems, decreased resistance to heart and lung diseases.	[71,72]
PM_{10}	Dust from construction sites, landfills and agriculture.	Asthma, heart diseases, chronic bronchitis, mortality, lung cancer	[71,72]
O_3	Fuel consumption and Photochemical reactions.	Airway exasperation, permanent lung damage, pneumonia and bronchitis, exacerbate asthma.	[71]
CO	Tobacco smoke, stoves, boilers, kerosene or gas heaters, fuel burning	Low birth weight, increase in perinatal deaths	[71]

TABLE-4
TECHNOLOGICAL INTERVENTIONS

Technologies	Applications	Ref.
Multi-Pollutant monitoring devices	• Although this technology does not directly reduce emissions from our atmosphere, yet it proves to be a critical part of the air pollution control system. • Multi-pollutant monitoring warrants regulatory bodies for securing conformity with emission limits regarding different pollutants and reducing cost and time corresponding to monitoring.	[73]
Catalytic converters	• For reduction of vehicular exhausts Gasoline- and Diesel-powered vehicles comprised of catalytic converters, • The device transforms dangerous air pollutants into innocuous pollutants by catalysing a redox reaction • Thus, permits a reaction converting CO to CO_2 and nitrogen oxide to nitrogen and CO_2. As CO_2 and atmospheric nitrogen are comparatively less harmful than CO and NO_2.	[73]
Scrubbers	• Eliminates air pollutants such as sulfur dioxide, chlorine, hydrogen sulfide, and hydrogen chloride. • Wet scrubbers use liquid (generally water) for absorption particles or gases from an air stream. • Whereas, dry scrubbers devices spray dry reagents in the stream, before entering the atmosphere. • Also, no distortion is observed in production process, hence, economic as well as industrial activities continue without any proportional rise in air pollutants.	[73]
CFCs and HCFCs Substitutes	• CFCs and HCFCs used in refrigerators, solvents, propellants *etc.* are replaced by HFCs (Hydrofluorocarbons) that have an ozone depletion potential (ODP) of 0 (zero).	[73]
Low emitting stoves and heaters	• Biomass stoves now are available incorporated with secondary combustions, insulated combustion chambers that burn off leftover fuel and ventilate the chemicals, which remains after burning.	[73]
VOCs free consumer products	• Crucial for regulating indoor air pollution.	[73]

TABLE-5
MODELLING TECHNIQUES

Model name	Model type	Applications and pollutants concerned	Pros	Cons	Ref.
SLAB	Steady State plume and transient puff models.	Simulates the atmospheric dispersion of a denser-than-air release.	It is easiest to use dense gas model. The model runs quickly.	Does not include different dispersion treatments. Source emission rates cannot be calculated.	[74,75]
HG System	Four types of Models (Dispersion Model)	Assessing hazard and/or mitigation strategies.	It is best atmospheric dispersion models. It can simulate different dispersion scheme.	Can only be used be expertise of the field.	[74-76]
CAMx	3D Photochemical Grid Model	Simulates air quality over many geographic scales, modelling air quality episodes. Modelling of NOx, SOx.	Treats deposition in a more realistic manner. Includes detailed treatment of chemistry, emission and other processes.	Limited range of spatial resolution. Indirect calculation of trajectories.	[77]
CMAQ	Eulrerian Grid Model	Simulates the emission, conversion and transport of species that comprise particulate matter (PM), ozone.	Applied at both long range and short-range simulations. used for urban and regional scale.	Only one way grid listing available. Requires meteorological model to impart an input	[77,78]
CHIMERE	Eulerian deterministic Model	Accurate analysis of pollution episodes, day-to-day prediction of ozone, aerosols, and other pollutants.	State-of-the-art model. Includes aerosols, different gas phase.	Simulation period more than 24 hour. Global version not available (only for Europe)	[79,80]

organic compounds (VOCs) are all major air pollutants [81]. The $PM_{2.5}$ has been shown in epidemiological studies to increase morbidity and mortality, harm the respiratory, cardiovascular systems, and impair immunological function. Indoor pollution is caused more by human activities (cooking, smoking, and cleaning) than by outdoor sources. In general, indoor human activities have a greater impact on $PM_{2.5}$ concentration. Sulphur dioxide (SO_2) was one of the first air pollutants to be discovered as a threat to human health and ecosystems. The burning of fossil fuels has resulted in a significant increase in SO_2 levels in the atmosphere [82]. Nitrogen dioxide (NO_2), nitric oxide (NO), nitrous oxide (N_2O) and nitrogen trioxide (N_2O_3) are some of the nitrogen oxides (NO_x) found in the environment. The existence of NO and NO_2 in the lower atmosphere is inextricably connected to O_3 levels at the ground level [82].

VOCs are a diverse group of chemical molecules that include both naturally occurring and manmade chemicals. The VOCs participate in atmospheric photochemical reactions that contribute to the formation of O_3 and play a role in the formation of secondary organic aerosols, which are found in particulate matter. Also, VOCs include a wide range of organic chemicals, including formaldehyde and PAHs. Formaldehyde is recognized to be a human carcinogen, as a result of its strong reactivity with proteins and DNA. To tackle these hazardous air pollutants novel remedial measures should be adopted.

High-efficiency particulate air (HEPA) filters assist in capturing all dust particles such as lead particles, brominates, and fire-retardant compounds (polybrominated diphenyl ethers, PBDEs). The best results come from using HEPA filters with a vacuum. They are usually referred to as air purifiers and can catch a considerable number of biological and chemical allergens, making them quite useful for the allergic people [83]. *Chlorophytum comosum*, the well-known spider plant is an excellent air purifier. This plant helps filter out hazardous benzene, trichloroethylene and formaldehyde pollutants by removing about 90% of the possibly cancer-causing chemical formaldehyde from the air [84]. In air, SO_2 can be photochemically or catalytically oxidized to sulphur trioxide (SO_3) and sulphate (SO_4^{2-}). Lastly, SO_3 rapidly transforms to sulfuric acid (H_2SO_4) in the presence of water, resulting in the acid rain.

$$2SO_2 + O_2 \xrightarrow{h\nu} 2SO_3$$

$$SO_2 + O_2 + 2e^- \xrightarrow{h\nu} SO_4^{2-}$$

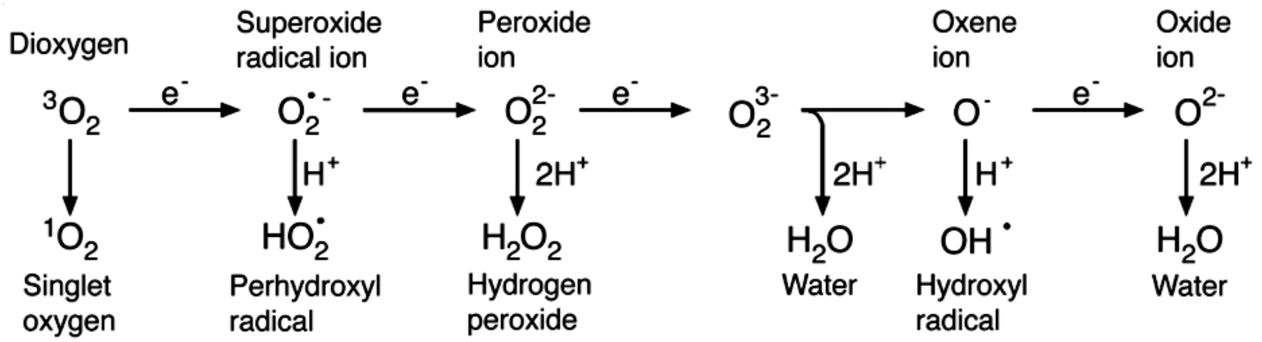
$$SO_3 + H_2O \longrightarrow \underset{\text{(acid rain)}}{H_2SO_4}$$

Sulfate-reducing bacteria, fungi and plants convert SO_4^{2-} to organic sulfhydryl groups (R-SH) during sulphur assimilation. The USEPA solely controls NO_2 since it is the most common type of NOx produced by humans [83]. NO_2 is also involved in the production of ozone (O_3) and nitrogen oxide (NO). Since NO_2 interacts swiftly with water whereas NO is nearly insoluble, plants absorb gaseous NO_2 more rapidly than NO [85]. The existence of NO and NO_2 in the lower atmosphere is inextricably connected to O_3 levels at the ground level. Plants absorb O_3 mostly through their stomata; O_3 is easily dissolved in water and interacts with apoplastic structures and plasma membranes to produce reactive oxygen species (ROS) such O_2, H_2O_2 and the $OH^•$ radical (**Scheme-II**).

The ozone (O_3) or reactive oxygen species (ROS) can disrupt cell membrane integrity and damage protein sulfhydryl (SH) groups or ring amino acids, resulting in phytotoxicity. First, chemical interactions with reactive chemicals generated by plants, notably monoterpenes, can remove O_3 from the air [86]. Activated charcoal or carbon filters, due to their adsorptive property are also used as air purifiers. When air passes through filters, the carbon adsorbs all contaminants and the air is purified [87]. Many of these techniques have been used for a long time and have proven to be quite successful. The level of pollution has risen dramatically as a result of urbanization and industrialization. As a result, more effective approaches for improving indoor air quality are required. There must be inexpensive, ordinary and minimal care options. HEPA filters can be an excellent alternative for indoor air pollution remediation in the rural regions, however they are very expensive. Activated charcoal filters, like HEPA filters, can't be cleaned very often, making them inexpendable and expensive.

Because of the limitation of these procedures, bioremediation a newer natural technique has emerged. Bioremediation, a waste management technology that employs microorganisms to remove or neutralize contaminants from contaminated sites (*e.g.* soil, water and air). It employs mechanisms such as phytostabilization, phytovolatilization, rhizo-degradation and rhizofiltration for organic contaminants [88]. Phytovolatilization, phyto-stabilization, rhizo-filtration and phytoaccumulation are also utilized for inorganic pollutants. In comparison to other carbons (graphene, CNTs), carbon soot offers the rewards of reliability and industrial scalability in its synthesis. A communal daily waste, carbon soot, can be used to create a low-cost absorbent (CS sponge) that can remove oil pollutants from water. These suggest that the CS-Sponge could be useful in ecological remedy intended for large-scale, low-cost oil exclusion from water [89,90].

Mitigation by biochars: Two precise mechanisms are functional for mitigation of VOCs through biochars. The first being adsorption within carbonized reign and second being partitioning in the non-carbonized organic reign. The determination of the carbonized part is done by different methods namely chemical adsorption through covalent bond, dipole interactions, H-bonding, physical adsorption through hydrophobic interactions and columbic interaction. Hence, several parameters are responsible for performance of biochars *i.e.* source, surface alteration, and pyrolysis temperature [91]. The morphology, surface area, O/C and H/C molar ratio from diverse origin differ remarkably, although being synthesized at similar temperature. For an instance, the specific area of biochar from switchgrass and bamboo was recorded as 15 m^2/g and 375 m^2/g at 60 ºC, respectively. Apart from this, the functioning surroundings such as humidity, temperature and flow velocity too knowingly affect the extenuation of VOCs *via* biochar. Till date total 15 forms of biochars have been formed from raw resources for the absorption of VOCs gas. Amongst, the component with



Scheme-II

highest adsorption capacity and least adsorption capacity was acetone (483.09 mg/g), and methanol (10.6 mg/g), respectively [92]. The extent of adsorption is largely affected by the surface area and non-carbonized organic material of the biochar. The exclusion of VOCs *via* biochar declines as per the surge of the temperature of raw material [93]. Biochar flourishes as one of the capable adsorbents for VOCs, being comparatively cost-effective and vast availability.

Dosimetry and health risk assessment: Occupational exposure to pollutants at the given average concentration (*e.g.* mg/m^3) throughout a day may result in a particular inhaled dose of that pollutant. This depends on several factors including substance properties such as shape and size of the particle, and the individual's property such as patterns of breathing, morphology of respiratory tract and physiology. Certain portions of inhaled doses are deposited in the respiratory tract and supposed to be assimilated and transported to different organs systematically and may also be reserved in the body [94]. Dosimetry practice encompasses determination of rate distribution and amount of pollutant or particle in the body. These dosimetry models are widely used in risk assessment of various applications. Uses of dosimetry models include biologically operative dose approximation, adjustment of point of departure (POD), Sequential dose adjustment, internal estimation of dose in a population and dose normalization over out-of-date and alternate testing approaches. Correspondingly, dosimetry models permit science-based estimations of dose covering different species as for many substances data on human health outcomes are unavailable therefore study data on animal toxicology are applied in order to detect an effect level. Selection of dosimetry model for practicing particular health risk evaluation is based on certain goals of risk assessment including screening, degree of knowledge regarding biological mode of action (MOA), specificity of available data and level of details [95]. Biological MOA may be defined as arrangements of crucial events and procedure including interface of an agent with the cell, happening over anatomical and functional variations and finally resulting in toxicity such as cancer. In model hierarchy, the increase in intricacy of the models surges the specific data requirements; but then again, the benefits embrace better precision [96,97]. The simplest approach of health risk assessment has been depicted in Fig. 6. The usage of mode-of-action data is to determine the choice of the suitable dose metric for exact notability for the implementation in a risk assessment.

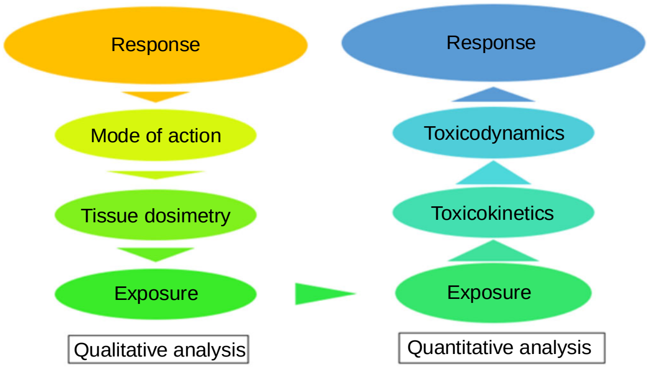


Fig. 6. Risk assessment process

As an instance, a multi-path dosimetry model used in quantification of dose accumulation in human respiratory tract principally age-wise scenario in Portugal revealed that infants aged 3-month displayed 4-fold higher accumulation doses compared to their mothers [98]. The primary accumulation of PM_{10} was in the head area (87%), whereas $PM_{2.5}$ and ultrafine particles (UFP) deposition chiefly occurred in pulmonary region *viz.* 39% and 43%, respectively. It was observed that higher particulate matter accumulation in the lungs was in lower lobe *viz.* 37% and 30% in left lobe and right lobe, respectively [99, 100] also, right lobes are more susceptible to respiratory disorders as asymmetric accumulation was detected. These finding were attained for $PM_{2.5}$, PM_{10} and UFP fractions. Therefore, the results clearly indicated that younger toddlers are more prone towards the air pollutants. Considering the above site-specific study focussing on respiratory system, quantification of particle accumulation in a particular site assistance to predict better health related consequences from inhaled pollutants [101].

Some work has also been done on accessing hazards of engineered nanoparticles, with partial studies on toxicology. Therefore, it may be valuable for analysing the data related to dose retaliation of inspired fine and ultrafine particles in rodents and may also be used in quantitative risk assessment (QRA) in humans. Recognized methods to QRA may be practised on the available data of dose -retaliation of animals in order to provide risk approximations on the exposure of such particles [102,103]. It would help in providing ground for contrast evaluation and estimation of probable contrary health hazards resulting in acquaintance to engineered nano particles.

Conclusion

This article explores the field of indoor air research, with the intention to review the indoor air quality (IAQ) sector from rural and urban Indian environment aspect. The major sources of health hazards along with technical interventions to tackle indoor air pollutants is also discussed. This review commends future studies directing towards detailed evaluation of exposure concentration in both the urban and rural environments separately. In addition, the blooming technologies in the field indicate towards development and awareness regarding indoor air pollutants. Thus, it is highly recommended that more research should be conducted in the field of technology so as to challenge the these pollutants.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

REFERENCES

1. N. Agarwal, C.S. Meena, B.P. Raj, L. Saini, N. Gopalakrishnan, A. Kumar, N.B. Balam, T. Alam, N.R. Kapoor and V. Aggarwal, *Sustain Cities Soc.*, **70**, 102942 (2021); https://doi.org/10.1016/j.scs.2021.102942

2. T. Ahmed, P. Kumar and L. Mottet, *Renew. Sustain. Energy Rev.*, **138**, 110669 (2021); https://doi.org/10.1016/j.rser.2020.110669
3. S. Sonwani, Source Apportionment of Polycyclic Aromatic Hydrocarbons in Atmosphere of South Delhi, India; 2nd International Conference on Atmospheric Dust - DUST2016, ProScience Conference Proceedings of ScientEvents, Italy, vol. 3, pp. 111-116 (2016).
4. D. Fowler, P. Brimblecombe, J. Burrows, M.R. Heal, P. Grennfelt, D.S. Stevenson, A. Jowett, E. Nemitz, M. Coyle, X. Liu, Y. Chang, G.W. Fuller, M.A. Sutton, Z. Klimont, M.H. Unsworth and M. Vieno, *Phil. Trans. R. Soc. A*, **378**, 20190314 (2020); https://doi.org/10.1098/rsta.2019.0314
5. A. Eliassen, J. Saltbones, F. Stordal, H. Oystein, I. Isaksen and F. Stordal, *J. APPL. METEORAL*, **21**, 1645 (1982); https://doi.org/10.1175/1520-0450(1982)021<1645:ALLRTM>2.0.CO;2
6. A.K. Upadhyay, A. Singh, K. Kumar and A. Singh, *BMC Public Health*, **15**, 300 (2015); https://doi.org/10.1186/s12889-015-1631-7
7. A.J. Lawrence, T. Khan and I. Azad, *Global NEST J.*, **22**, 28 (2019); https://doi.org/10.30955/gnj.003105
8. https://www.who.int/ceh/capacity/Indoor_Air_Pollution.pdf (accessed on 7-oct-2021).
9. J.P.D. Abbatt and C. Wang, *Environ. Sci. Process. Impacts*, **22**, 25 (2020); https://doi.org/10.1039/C9EM00386J
10. M. Li, F. Bao, Y. Zhang, W. Song, C. Chen and J. Zhao, *Proc. Natl. Acad. Sci. USA*, **115**, 7717 (2018); https://doi.org/10.1073/pnas.1804481115
11. M.Y. Wang, Y.W. Lu, F. Wu, X.J. Zhang and C.X. Yang, *Procedia Eng.*, **121**, 521 (2015); https://doi.org/10.1016/j.proeng.2015.08.1023
12. https://www.nap.edu/catalog/1889/rethinking-the-ozone-problem-in-urban-and-regional-air-pollution (accessed on-8-Oct-2021).
13. J.N. Pitts Jr., H.W. Biermann, E.C. Tuazon, M. Green, W.D. Long and A.M. Winer, *JAPCA*, **39**, 1344 (1989); https://doi.org/10.1080/08940630.1989.10466629
14. C.W. Spicer, R.W. Coutant, G.F. Ward, D.W. Joseph, A.J. Gaynor and I.H. Billick, *Environ. Int.*, **15**, 643 (1989); https://doi.org/10.1016/0160-4120(89)90087-1
15. J. Barbara, F. Pitts and J.N. Pitts, Indoor Air Pollution: Sources, Levels, Chemistry and Fates, In: Chemistry of the Upper and Lower Atmosphere, Academic Press, Chap. 15, pp. 844-870 (2000).
16. C.J. Weschler, H.C. Shields and D.V. Naik, *Environ. Sci. Technol.*, **28**, 2120 (1994); https://doi.org/10.1021/es00061a021
17. C.J. Weschler, M. Brauer and P. Koutrakis, *Environ. Sci. Technol.*, **26**, 179 (1992); https://doi.org/10.1021/es00025a022
18. J. Zhang, W.E. Wilson and P.J. Lioy, *Environ. Sci. Technol*., **28**, 1975 (1994); https://doi.org/10.1021/es00060a031
19. R. Reiss, P.B. Ryan, P. Koutrakis and S.J. Tibbetts, *Environ. Sci. Technol*., **29**, 1906 (1995); https://doi.org/10.1021/es00008a007
20. J. Zhang, W.E. Wilson and P.J. Lioy, *J. Expo. Anal. Environ. Epidemiol.*, **4**, 25 (1994).
21. T. Grontoft and M. Raychaudhuri, *Atmos. Environ.*, **38**, 533 (2004); https://doi.org/10.1016/j.atmosenv.2003.10.010
22. E. Gall, E. Darling, J.A. Siegel, G.C. Morrison and R.L. Corsi, *Atmos. Environ.*, **77**, 910 (2013); https://doi.org/10.1016/j.atmosenv.2013.06.014
23. L.S. Pandrangi and G.C. Morrison, *Atmos. Environ.*, **42**, 5079 (2008); https://doi.org/10.1016/j.atmosenv.2008.02.009
24. S. Zhou, M.W. Forbes, Y. Katrib and J.P.D. Abbatt, *Environ. Sci. Technol. Lett.*, **3**, 170 (2016); https://doi.org/10.1021/acs.estlett.6b00086
25. D.G. Poppendieck, H.F. Hubbard, C.J. Weschler and R.L. Corsi, *Atmos. Environ.*, **41**, 7614 (2007); https://doi.org/10.1016/j.atmosenv.2007.05.049.
26. H. Wang and G. Morrison, *Indoor Air*, **20**, 224 (2010); https://doi.org/10.1111/j.1600-0668.2010.00648.x
27. D. Rim, E.T. Gall, R.L. Maddalena and W.W. Nazaroff, *Atmos. Environ.*, **125**, 15 (2016); https://doi.org/10.1016/j.atmosenv.2015.10.093
28. E.T. Gall, R.L. Corsi and J.A. Siegel, *Atmos. Environ.*, **45**, 3338 (2011); https://doi.org/10.1016/j.atmosenv.2011.03.032
29. F. Hanisch and J.N. Crowley, *Atmos. Chem. Phys.*, **3**, 119 (2003); https://doi.org/10.5194/acp-3-119-2003
30. A. Wisthaler and C.J. Weschler, *Proc. Natl. Acad. Sci. USA*, **107**, 6568 (2010); https://doi.org/10.1073/pnas.0904498106
31. T. Salthammer and E. Uhde, Organic Indoor Air Pollutants: Occurrence, Measurement, Evaluation, Wiley, Ed.: 2 (2009); https://doi.org/10.1002/9783527628889
32. J.R. Wells, G.C. Morrison, B.K. Coleman, C. Spicer and S.W. Dean, *J. ASTM Int.*, **5**, 101629 (2008); https://doi.org/10.1520/JAI101629
33. J. Gumulka and L.L. Smith, *J. Am. Chem. Soc.*, **105**, 1972 (1983); https://doi.org/10.1021/ja00345a052
34. J. Fick, L. Pommer, A. Astrand, R. Ostin, C. Nilsson and B. Andersson, *Atmos. Environ.*, **39**, 6315 (2005); https://doi.org/10.1016/j.atmosenv.2005.07.013
35. S. Shu and G.C. Morrison, *Atmos. Environ.*, **47**, 421 (2012); https://doi.org/10.1016/j.atmosenv.2011.10.068
36. W.-T. Chan and I.P. Hamilton, *J. Chem. Phys.*, **118**, 1688 (2003); https://doi.org/10.1063/1.1531104
37. R. Criegee, *Angew. Chem. Int. Ed. Engl.*, **14**, 745 (1975); https://doi.org/10.1002/anie.197507451
38. J. Kroll, N. Donahue, V. Cee, K. Demerjian and J. Anderson, *J. Am. Chem. Soc.*, **124**, 8518 (2002); https://doi.org/10.1021/ja0266060
39. Z. Zhou, S. Zhou and J.P.D. Abbatt, *Environ. Sci. Technol.*, **53**, 12467 (2019); https://doi.org/10.1021/acs.est.9b04460
40. C. Lai, B. Finlayson-Pitts and W. Willis, *Chem. Res. Toxicol.*, **3**, 517 (1990); https://doi.org/10.1021/tx00018a005
41. D. Zhang and R. Zhang, *J. Am. Chem. Soc.*, **124**, 2692 (2002); https://doi.org/10.1021/ja0115181
42. N. Heine, F.A. Houle and K.R. Wilson, *Environ. Sci. Technol.*, **51**, 13740 (2017); https://doi.org/10.1021/acs.est.7b04197
43. R. Zhao, C.M. Kenseth, Y. Huang, N.F. Dalleska, X.M. Kuang, J. Chen, S.E. Paulson and J.H. Seinfeld, *J. Phys. Chem. A*, **122**, 5190 (2018); https://doi.org/10.1021/acs.jpca.8b02195
44. P.S.J. Lakey, G.C. Morrison, Y. Won, K.M. Parry, M. von Domaros, D.J. Tobias, D. Rim and M. Shiraiwa, *Commun. Chem.*, **2**, 56 (2019); https://doi.org/10.1038/s42004-019-0159-7
45. H. Destaillats, B.C. Singer, S.K. Lee and L.A. Gundel, *Environ. Sci. Technol.*, **40**, 1799 (2006); https://doi.org/10.1021/es050914r
46. B.T. Mmereki and D.J. Donaldson, *J. Phys. Chem. A*, **107**, 11038 (2003); https://doi.org/10.1021/jp036119m
47. S.M. Zhou, M. Shiraiwa, R.D. McWhinney, U. Poschl and J.P.D. Abbatt, *Faraday Discuss.*, **165**, 391 (2013); https://doi.org/10.1039/C3FD00030C
48. U. Poschl, T. Letzel, C. Schauer and R. Niessner, *J. Phys. Chem. A*, **105**, 4029 (2001); https://doi.org/10.1021/jp004137n
49. S. Zhou, L.W.Y. Yeung, M.W. Forbes, S. Mabury and J.P.D. Abbatt, *Environ. Sci. Process. Impacts*, **19**, 1292 (2017); https://doi.org/10.1039/C7EM00181A
50. P. Sotero and R. Arce, *J. Photochem. Photobiol. Chem.*, **199**, 14 (2008); https://doi.org/10.1016/j.jphotochem.2008.04.011
51. T. Salthammer, A. Bednarek, F. Fuhrmann, R. Funaki and S. Tanabe, *J. Photochem. Photobiol. Chem.*, **152**, 1 (2002); https://doi.org/10.1016/S1010-6030(02)00212-5
52. A. Gandolfo, V. Bartolomei, E. Gomez Alvarez, S. Tlili, S. Gligorovski, J. Kleffmann and H. Wortham, *Appl. Catal. B*, **166-167**, 84 (2015); https://doi.org/10.1016/j.apcatb.2014.11.011
53. A. Gandolfo, L. Rouyer, H. Wortham and S. Gligorovski, *Appl. Catal. B*, **209**, 429 (2017); https://doi.org/10.1016/j.apcatb.2017.03.021

54. H. Schwartz-Narbonne, S.H. Jones and D.J. Donaldson, *Environ. Sci. Technol. Lett.*, **6**, 92 (2019); https://doi.org/10.1021/acs.estlett.8b00685
55. T. Salthammer and F. Fuhrmann, *Environ. Sci. Technol.*, **41**, 6573 (2007); https://doi.org/10.1021/es070057m
56. E. Uhde and T. Salthammer, *Atmos. Environ.*, **41**, 3111 (2007); https://doi.org/10.1016/j.atmosenv.2006.05.082
57. S. Chino, S. Kato, J. Seo and Y. Ataka, *Build. Environ.*, **44**, 1337 (2009); https://doi.org/10.1016/j.buildenv.2008.07.003
58. A. Bope, S.R. Haines, B. Hegarty, C.J. Weschler, J. Peccia and K.C. Dannemiller, *Environ. Sci. Process. Impacts*, **21**, 1268 (2019); https://doi.org/10.1039/C9EM00050J
59. T. Salthammer, S. Mentese and R. Marutzky, *Chem. Rev.*, **110**, 2536 (2010); https://doi.org/10.1021/cr800399g
60. P. Wolkoff and S.K. Kjaergaard, *Environ. Int.*, **33**, 850 (2007); https://doi.org/10.1016/j.envint.2007.04.004
61. J. Qiu, S. Ishizuka, K. Tonokura, A.J. Colussi and S. Enami, *J. Phys. Chem. A*, **122**, 7910 (2018); https://doi.org/10.1021/acs.jpca.8b06914
62. S. Zhou, S. Joudan, M.W. Forbes, Z. Zhou and J.P.D. Abbatt, *Environ. Sci. Technol. Lett.*, **6**, 243 (2019); https://doi.org/10.1021/acs.estlett.9b00165
63. B.J. Finlayson-Pitts and J.N. Pitts, Chemistry of the Lower and Upper Atmosphere, Academic Press: New York (2000).
64. A. Botle, R.K. Singhal, H. Basu, M. v and J. Masih, *Environ. Technol. Innov.*, **19**, 100857 (2020); https://doi.org/10.1016/j.eti.2020.100857
65. Y. Qiu, F.A. Yang and W. Lai, *Popul. Environ.*, **40**, 388 (2019); https://doi.org/10.1007/s11111-019-00317-6
66. M. Sekar, T.R. Praveen Kumar, M. Selva Ganesh Kumar, R. Vaníèková and J. Maroušek, *Fuel*, **305**, 121544 (2021); https://doi.org/10.1016/j.fuel.2021.121544
67. https://learn.kaiterra.com/en/air-academy/air-pollution-solutions-technology (accessed on-7-Oct-2021).
68. A. Ahlawat, A. Wiedensohler and S.K. Mishra, *Aerosol Air Qual. Res.*, **20**, 1856 (2020); https://doi.org/10.4209/aaqr.2020.06.0302
69. G. Hoek, *Curr. Environ. Health Rep.*, **4**, 450 (2017); https://doi.org/10.1007/s40572-017-0169-5
70. J. Irwin, A Historical Look at the Development of Regulatory Air Quality Models for the United States Environmental Protection Agency, In: IR Quality Modeling-Theories, Methodologies, Computational Techniques, and Available Databases and Software, The EnvironComp Institute and Air & Waste Management Association, Chap. 18, vol. II, p. 18 (2005).
71. K. Liao, X. Huang, H. Dang, Y. Ren, S. Zuo and C. Duan, *Atmosphere*, **12**, 686 (2021); https://doi.org/10.3390/atmos12060686
72. B. Liu, X. Yu, J. Chen, Q. Wang, *Atmos. Pollut. Res.*, **12**, 101144 (2021); https://doi.org/10.1016/j.apr.2021.101144
73. M. Zhou, Y. Huang and G. Li, *Environ. Sci. Pollut. Res. Int.*, **28**, 23405 (2021); https://doi.org/10.1007/s11356-020-12164-2
74. M. Arulprakasajothi, U. Chandrasekhar, K. Elangovan and D. Yuvarajan, *Int. J. Ambient Energy*, **41**, 511 (2020); https://doi.org/10.1080/01430750.2018.1472651
75. J.K. Gourav, Rekhi, P. Nagrath and R. Jain, Eds.: V. Jain, G. Chaudhary, M. Taplamacioglu and M. Agarwal, Forecasting Air Quality of Delhi Using ARIMA Model, In: Advances in Data Sciences, Security and Applications; Lecture Notes in Electrical Engineering, vol 612, Springer: Singapore (2020); https://doi.org/10.1007/978-981-15-0372-6_25
76. https://www.rollingnature.com/blogs/news/spider-plant-nasa-approved-natural-air-purifier (accessed on;08-oct-2021).
77. USEPA Nitrogen Oxides, (NOx), Why and How They are Controlled. Washington, DC: United States Environmental Protection Agency, Publication No. EPA-456/F-99-006R (1999).
78. X. Wei, S. Lyu, Y. Yu, Z. Wang, H. Liu, D. Pan and J. Chen, *Front. Plant Sci.*, **8**, 1318 (2017); https://doi.org/10.3389/fpls.2017.01318
79. X. Zhang, P. Zhou, W. Zhang, W. Zhang and Y. Wang, *Open J. For.*, **3**, 104 (2013); https://doi.org/10.4236/ojf.2013.34017
80. P. Chauhan, M.S. Rawat, *Int. J. Eng. Technol. Sci. Res.*, **4**, 749 (2017).
81. C. Lai, Z. Wang, L. Qin, Y. Fu, B. Li, M. Zhang, S. Liu, L. Li, H. Yi, X. Liu, X. Zhou, N. An, Z. An, X. Shi and C. Feng, *Coord. Chem. Rev.*, 427, 213565 (2021); https://doi.org/10.1016/j.ccr.2020.213565
82. M. Bufalini, *Environ. Sci. Technol.*, **5**, 685 (1971); https://doi.org/10.1021/es60055a001
83. USEPA, Nitrogen Oxides (NOx), Why and How They are Controlled. Washington, DC: United States Environmental Protection Agency, Publication No. EPA-456/F-99-006R (1999).
84. P. Di Carlo, W.H. Brune, M. Martinez, H. Harder, R. Lesher, X. Ren, T. Thornberry, M.A. Carroll, V. Young, P.B. Shepson, D. Riemer, E. Apel and C. Campbell, *Science*, **304**, 722 (2004); https://doi.org/10.1126/science.1094392
85. J. Hao, T. Zhu and X. Fan, Eds.: P. Pluschke and H. Schleibinger, Indoor Air Pollution and its Control in China, In: Indoor Air Pollution, Berlin; Heidelberg: Springer-Verlag, Ed: 2, pp. 1-26 (2014).
86. V.V. Tran, D. Park and Y.C. Lee, *Int. J. Environ. Res. Public Health*, **17**, 2927 (2020); https://doi.org/10.3390/ijerph17082927
87. http://www.naturallivingideas.com/8-ways-to-purify-home-air-naturally/ (Accessed on-07-oct-2021).
88. G. Tiwari and S.P. Singh, *J. Bioremediat. Biodegrad.*, **5**, 248 (2014); https://doi.org/10.4172/2155-6199.1000248
89. Y. Gao, Y.S. Zhou, W. Xiong, M. Wang, L. Fan, H. Rabiee-Golgir, L. Jiang, W. Hou, X. Huang, L. Jiang, J.-F. Silvain and Y.F. Lu, *ACS Appl. Mater. Interfaces*, **6**, 5924 (2014); https://doi.org/10.1021/am500870f
90. Y.H.K.I.S. Gunasinghe, I.V.N. Rathnayake and M.P. Deeyamulla, *Nepal J. Biotechnol.*, **9**, 63 (2021).
91. X. Zhang, B. Gao, A.E. Creamer, C. Cao and Y. Li, *J. Hazard. Mater.*, **338**, 102 (2017); https://doi.org/10.1016/j.jhazmat.2017.05.013
92. Y. Tong, P.J. Mcnamara and B.K. Mayer, *Environ. Sci. Water Res. Technol.*, **5**, 821 (2019); https://doi.org/10.1039/C8EW00938D
93. X. Yue, N.L. Ma, C. Sonne, R. Guan, S.S. Lam, Q.V. Le, X. Chen, Y. Yang, H. Gu, J. Rinklebe and W. Peng, *J. Hazard. Mater.*, **405**, 124 (2020); https://doi.org/10.1016/j.jhazmat.2020.124138
94. H. Clewell, *Regul. Toxicol. Pharmacol.*, **42**, 3 (2005).
95. E.D. Kuempel, L.M. Sweeney, J.B. Morris and A.M. Jarabek, *J. Occup. Environ. Hyg.*, **12**, S18 (2015); https://doi.org/10.1080/15459624.2015.1060328
96. E.D. Kuempel, C.L. Tran, V. Castranova and A.J. Bailer, *Inhal. Toxicol.*, **18**, 717 (2006); https://doi.org/10.1080/08958370600747887
97. R.F. Phalen, M.D. Hoover, M.J. Oldham and A.M. Jarabek, *J. Aerosol Sci.*, **155**, 105755 (2021); https://doi.org/10.1016/j.jaerosci.2021.105755
98. S.G. Goel, S. Somwanshi, S. Mankar, B. Srimuruganandam and R. Gupta, *Air Qual. Atmos. Health*, **14**, 1033 (2021); https://doi.org/10.1007/s11869-021-00996-x
99. V. Raja, R.V. Lakshmi, C.P. Sekar, S. Chidambaram and M.A. Neelakantan, *Arch. Environ. Contam. Toxicol.*, **80**, 144 (2021); https://doi.org/10.1007/s00244-020-00795-y
100. S. Tigala, A.R. Sharma and K. Sachdeva, *Sci. Total Environ.*, **640-641**, 935 (2018); https://doi.org/10.1016/j.scitotenv.2018.05.323
101. J. Madureira, K. Slezakova, A.I. Silva, B. Lage, A. Mendes, L. Aguiar, M.C. Pereira, J.P. Teixeira and C. Costa, *Sci. Total Environ.*, **717**, 137293 (2020); https://doi.org/10.1016/j.scitotenv.2020.137293
102. N. Manojkumar, B. Srimuruganandam and S.M. Shiva Nagendra, *Ecotoxicol. Environ. Saf.*, **168**, 241 (2019); https://doi.org/10.1016/j.ecoenv.2018.10.091
103. Y. Deepthi, S.M. Shiva Nagendra and S. Gummadi, *Sci. Total Environ.*, **650**, 616 (2019); https://doi.org/10.1016/j.scitotenv.2018.08.381