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Review on the generation, characteristics and control methods of indoor ozone pollution

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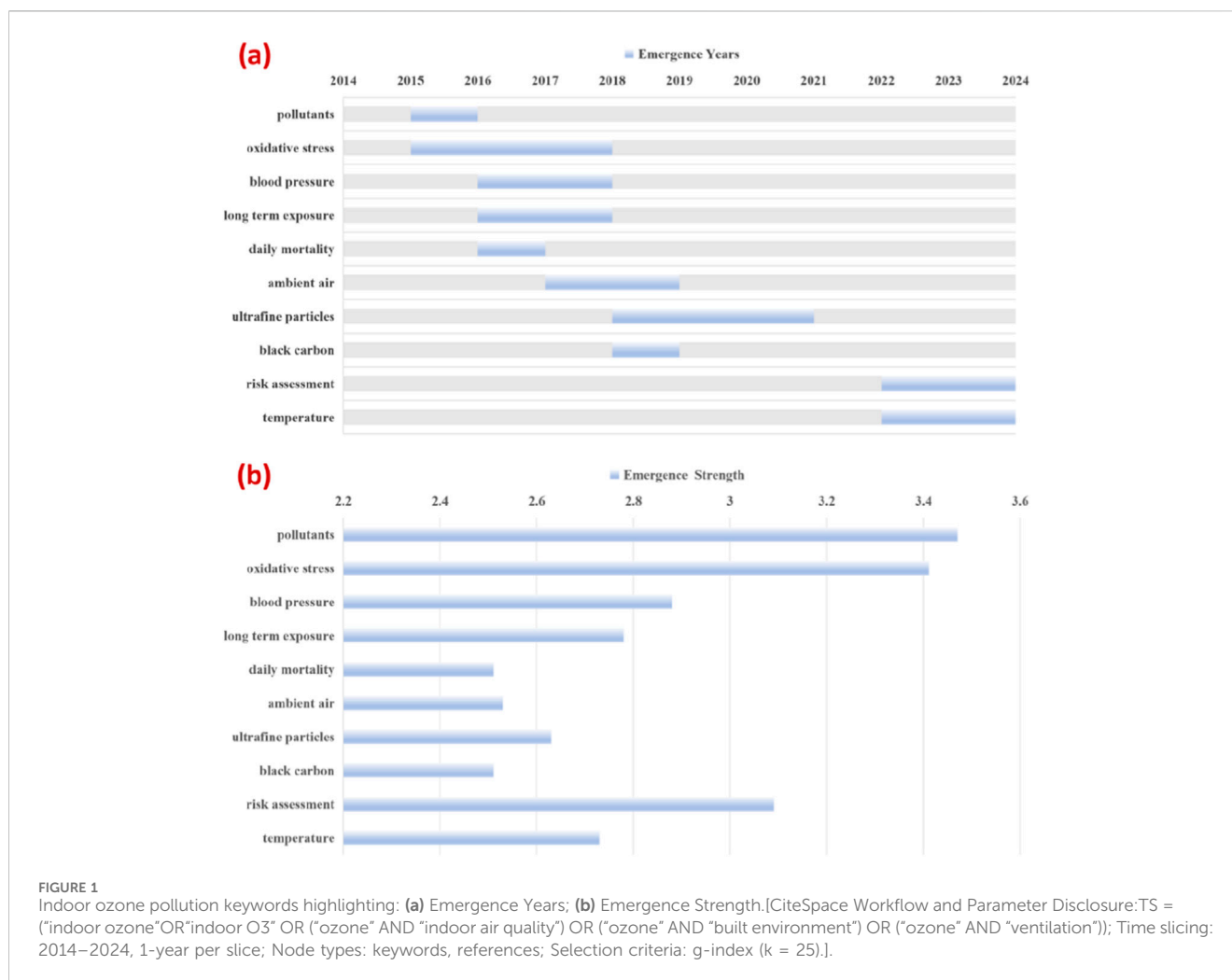
Under the dual effects of outdoor ozone (O₃) pollution intrusion and indoor pollution source generation, the formation mechanism, characterization, prevention and control methods of indoor O₃ pollution have been one important scientific issue in the field of indoor air quality (IAQ) research. To have a systematic understanding of this issue, this study summarizes the trends and hotspots of indoor ozone pollution research, systematically reviews the sources, hazards, and characteristics of indoor ozone pollution and analyzes the different prevention and control methods of indoor ozone pollution, including active and passive ozone removal technologies. On this basis, the engineering applications of indoor ozone pollution prevention and control methods in residential, educational, and commercial scenarios are further discussed. Furthermore, the development trends and technical challenges of indoor ozone pollution prevention and control are pointed out. The development of efficient and low-cost ozone removal materials, the optimization of intelligent monitoring systems, and integrated pollution control strategies adapted to climate change should be focused on in the future, in order to provide healthier and safer indoor air environment. The insights could inform designers, engineers, and policymakers seeking to integrate ozone-responsive strategies into building ventilation, material selection, IAQ management, and air-cleaning systems.

KEYWORDS

health hazards, indoor air quality, indoor ozone pollution, ozone control technologies, prevention and control methods, synergistic control

1 Introduction

Ozone in the stratosphere absorbs the energy of ultraviolet photons and is protective of life on earth. However, ozone in the troposphere, especially in indoor environments, can adversely affect human health and even negatively impact socio-economics and productivity (Wang et al., 2022). Due to (i) the difficulty of accurately measuring ozone with past detection technologies, (ii) the public's lack of awareness about the hazards of ozone, and (iii) the delayed effects of ozone on human health, indoor pollution research has focused more on substances such as PM_{2.5}, formaldehyde, and carbon dioxide, while neglecting the harm of indoor ozone to humans. In recent years, ozone measurement technology has developed rapidly, such as Kernbach (2026) had proven an efficient electrochemical method for measuring ozone concentration through long-term field tests, this type of research has laid the foundation for subsequent research on indoor ozone pollution. More and more data show that the high concentration of outdoor ozone

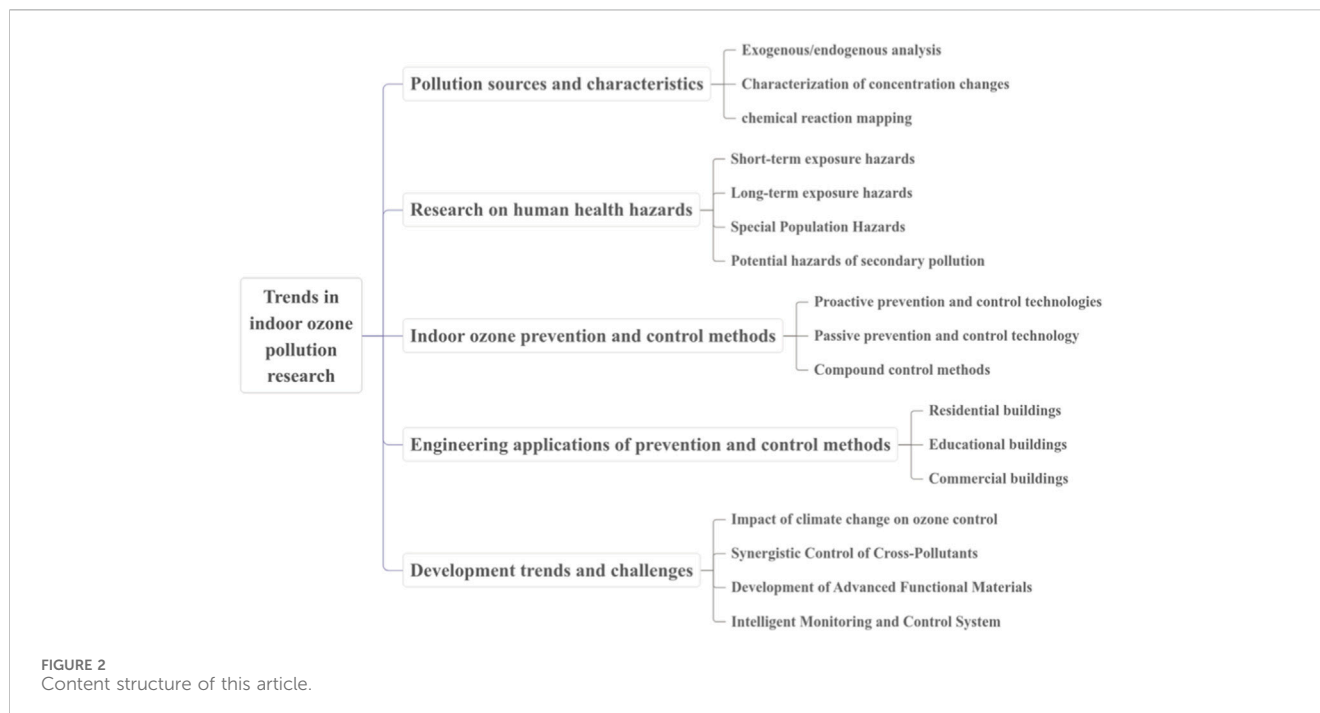


can enter indoor environment through ventilation, infiltration and other channels. Which causes indoor ozone concentration to be close to or even exceeding the health standard, bringing many pathological hazards to humans. Therefore, indoor ozone pollution has become a typical pollution problem that can't be ignored.

Along with the development of industrialization and urbanization, ozone pollution is becoming increasingly serious, and has been attracted attention for its potential health and ecological hazards. Fadeyi (2015) reviewed the progress of indoor ozone research from 2000 to 2015, told us that high-performance buildings are a fundamental requirement for the 21st century. And called on us to properly consider ozone and its induced chemical products for their impact on human physiological, psychological and social conditions. Kong et al. (2022) observed that the negative health effects of ozone were not caused by other pollutants or precursors but by the nature of ozone itself, with higher ozone concentrations resulting in greater negative health effects. In addition, it has been found that ozone pollution exposure can induce cardiovascular disease. Therefore, it is a significant task in IAQ research field to grasp the formation mechanism and hazardous effects of indoor ozone pollution, and to construct its prevention and control methods.

In order to better grasp the latest research trend and research hotspots in indoor ozone pollution field, this study adopts CiteSpace to visualize the relevant literature in the Web of Science database in the past 10 years, seen in Figure 1. Figure 1 shows the "high intensity emergent keywords" for studies related to indoor ozone pollution from 2014 to 2024, listing the top 10 keywords with the highest emergent intensity. It can be found that the health risks of indoor ozone pollution have received a high level of attention in a given year. Secondly, "pollutants" and "oxidative stress" had significant emergence in 2015–2016 and 2015–2018, respectively, showing the importance of pollutants and oxidative stress in earlier studies. Meanwhile, "risk assessment" and "temperature" appeared in 2022–2024, indicating a gradual focus on pollutants and oxidative stress in recent years. In addition, from the perspective of timeline changes, keywords such as "ultrafine particles" and "black carbon" appeared more frequently in 2016–2021 and 2018–2019. Which reflects the attention paid by scholars in related fields to the synergistic effect of various indoor pollutants.

According to the following structure, shown in Figure 2, this study analyzes the sources and health effects of indoor ozone from its concentration change characteristics, reaction mechanism and chemical characteristics perspectives. Then, the existing ozone prevention and control technologies are summarized, and the



advantages and disadvantages of active and passive control methods are compared. Thirdly, the engineering application of ozone control technology is discussed for different types of buildings. Finally, the key problems and development trends for future research are pointed out.

2 Sources and regularity of indoor ozone pollution

On the one hand, the permeability of ozone is strong, and it is difficult to completely isolate ozone in the outside air. On the other hand, ozone is chemically active and it is easy to react with indoor Volatile Organic Compounds (VOCs) to generate more secondary pollutants. Therefore, the sources of indoor ozone pollution include two major parts: external infiltration (exogenous) and indoor generation (endogenous). The concentration distribution shows obvious characteristics, and will react violently with other indoor chemical substances, generating new types of pollutants. The following is described from three aspects: pollution source, concentration distribution law and ozone chemical reaction.

2.1 Sources of indoor ozone pollution

2.1.1 External sources

Atmospheric ozone concentration is significantly affected by seasonal and climatic factors, and ozone concentration is higher in summer under high temperature and strong ultraviolet irradiation. Outdoor ozone indirectly increases the indoor ozone level when it enters indoors through the ventilation system or building crevices, which is the primary source of indoor ozone. [Zhong et al. \(2017\)](#)

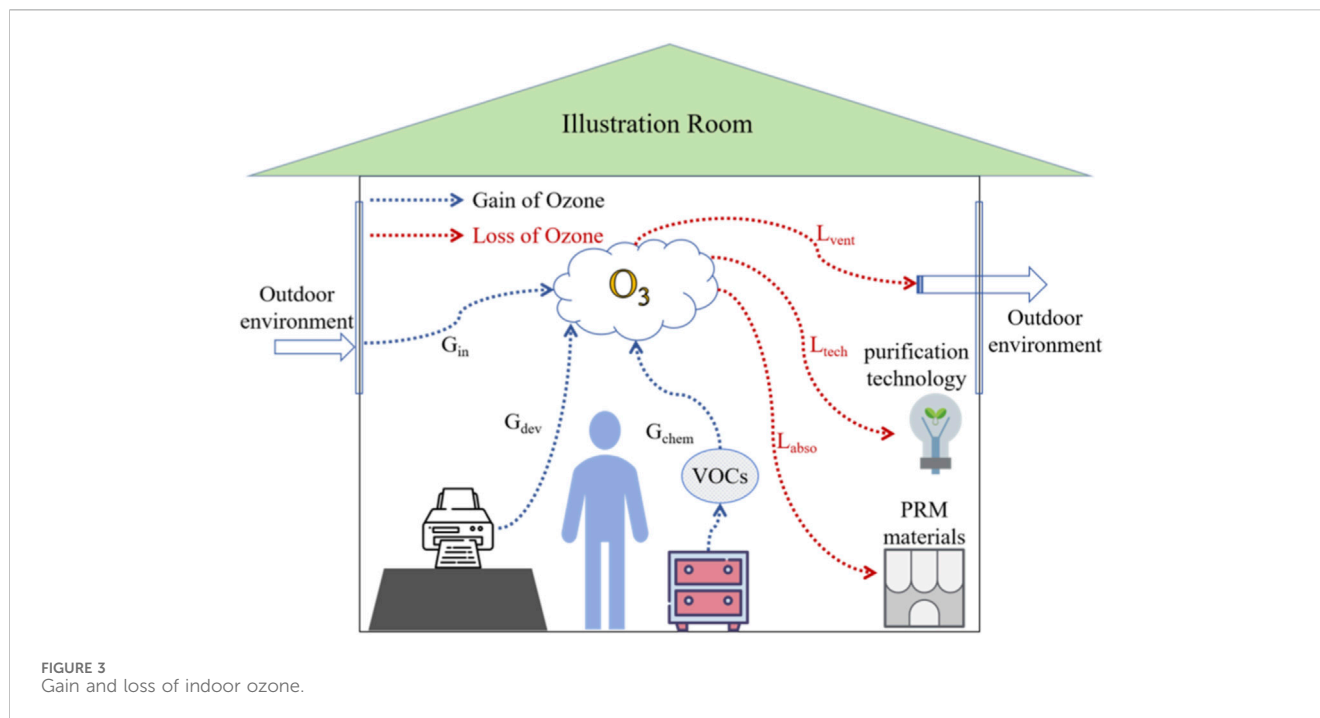
analyzed the relationship between climate change and indoor ozone, and found that climate change directly affects atmospheric ozone concentration, while indoor ozone concentration depends largely on the ozone concentration around the building. [Xu F. et al. \(2023\)](#) measured indoor ozone concentration under different window opening conditions in 24 residential buildings in Nanjing, China. The data showed that the average outdoor ozone concentration under the test conditions was $68.2 \mu\text{g}/\text{m}^3$, the average indoor concentration when the window was closed was $21.2 \mu\text{g}/\text{m}^3$, and the average indoor concentration when the window was open was $35.3 \mu\text{g}/\text{m}^3$. From these results, it can be seen that the outdoor ozone concentration has a significant effect on the indoor ozone concentration.

2.1.2 Internal sources

In addition to external sources, some indoor devices generate ozone through high-voltage discharges or photochemical reactions and release it into indoor air during operation. [Guo et al. \(2019\)](#) conducted field sampling measurement and noted that the average ozone emission rate for ducted air purifiers, photocopying machines, laser printers, and other small devices was 62.8, 76.3, 4.6, 3.3, 0.8, and 0.4 mg per hour (mg/h), respectively. Ozone concentrations were significantly higher in environments where these devices are frequently used than in ordinary residential environments. Therefore, reducing the time and frequency of use of such equipment can help reduce indoor ozone concentration.

2.2 Indoor ozone concentration analysis

Factors affecting indoor ozone concentration include outdoor environmental infiltration, indoor equipment generation, chemical reactions, ventilation removal, purification technology removal and



plant absorption, seen in Figure 3. The specific changes in indoor ozone concentration are shown in Equation 1:

$$\frac{d(O_3)}{dt} = G_{in} + G_{dev} + G_{chem} - L_{vent} - L_{tech} - L_{abso} \quad (1)$$

There G_{in} represents the ozone infiltration from outdoor environment; G_{dev} is the ozone generated by the indoor equipment; G_{chem} represents the ozone produced by indoor chemical reaction; L_{vent} is the ozone removed by ventilation; $L_{tech, purification}$ represents the ozone removed by technology removal; L_{abso} is the ozone absorbed by PRM materials.

Although the sources of indoor ozone have been identified, real-time monitoring of its concentration remains a significant challenge. Choi et al. (2023) developed a detection method utilizing o-dianisidine as a reaction reagent coated on a polydimethylsiloxane (PDMS) substrate, with a limit of detection of about 1.79 ppb, which is able to meet the indoor low concentration ozone. Indoor ozone concentrations at different measurement points are affected by a variety of factors. Nazaroff and Weschler (2022) concluded that outdoor ozone penetration is closely related to building parameters, mainly reflected in the following seven aspects: (i) ozone removal from mechanical ventilation systems, (ii) ozone permeability through the building envelope, (iii) the rate of air exchange, (iv) the rate of ozone loss from fixed indoor surfaces, (v) the rate of ozone loss from human occupants, (vi) ozone loss through homogeneous reaction with nitric oxide, and (vii) ozone loss through reaction with gas-phase organic matter.

In terms of temporal distribution, by observing the data from <https://www.aqistudy.cn/>. It is found that ozone concentrations are usually higher in summer and daytime than in winter and nighttime, directly leading to an increase in the infiltration of outdoor ozone. In terms of spatial distribution, Zhang et al.

(Zhang et al., 2024) mentioned that ozone concentration increases with the rise of floors, which is due to the better air circulation in the upper floors of high-rise buildings, which makes it easy for outdoor ozone to infiltrate. Through the literature search (Nazaroff and Weschler, 2022; Mandin et al., 2017; Branco et al., 2015; Che et al., 2021; Uchiyama et al., 2015; Kalimeri et al., 2016; Jovanović et al., 2014; Nørgaard et al., 2014; Demirel et al., 2014; Othman et al., 2020; Barkjohn et al., 2021), the average indoor ozone concentrations of different types of buildings in some regions were summarized, as shown in Figure 4. It can be seen that the degree of indoor ozone pollution is different in different regions. This disparity is caused by differences in sampling locations of different samples, measurement seasons, recording methods, indoor ozone removal strategies, sample sizes, and other factors.

2.3 Chemical reaction mapping of ozone

The physicochemical properties and molecular structure of ozone are fundamental to understanding its behavior in the air. The bond in the ozone molecule involves a resonance structure in which a double bond is formed between two oxygen atoms and a single bond is formed between the third oxygen atom and one of the oxygen atoms. Due to its strong oxidizing properties, indoor ozone can react with a wide range of VOCs to produce complex secondary pollutants, including aldehydes and ketones, which are harmful gasses, as shown in Figure 5.

Ozone production involves two main precursors, VOCs and NOx. As mentioned in the papers by Weschler and Nazaroff (2023) and Rim et al. (2018), indoor ozone and the reaction by-products undergo a more complex chemical reaction on the surface of the human skin and surrounding environment, with 30%–55% of the

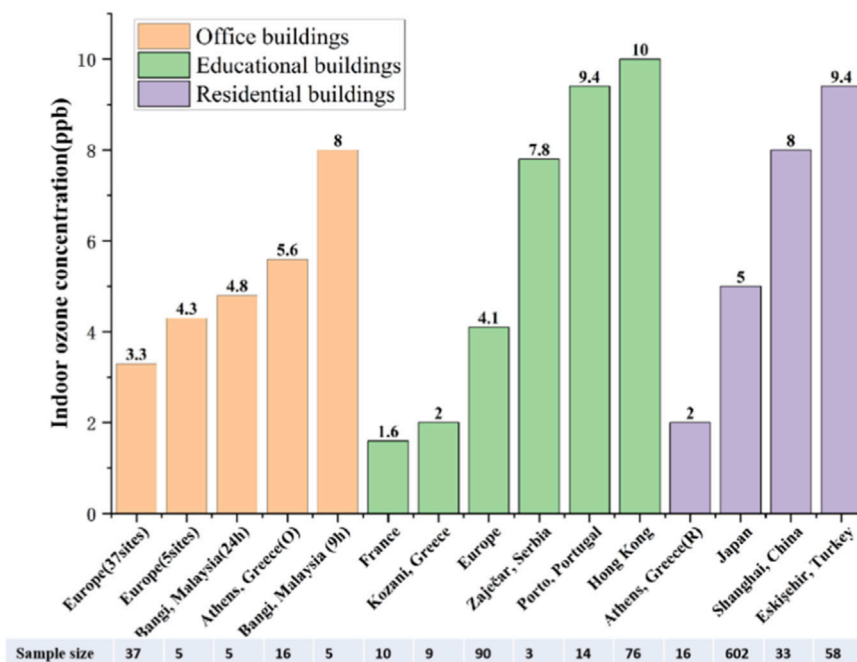


FIGURE 4 Indoor ozone concentrations in different types of buildings in selected areas. [Data comes from 11 related articles on science.direct.com.Reference (Nazaroff and Weschler, 2022; Mandin et al., 2017; Branco et al., 2015; Che et al., 2021; Uchiyama et al., 2015; Kalimeri et al., 2016; Jovanović et al., 2014; Nørgaard et al., 2014; Demirel et al., 2014; Othman et al., 2020; Barkjohn et al., 2021)].

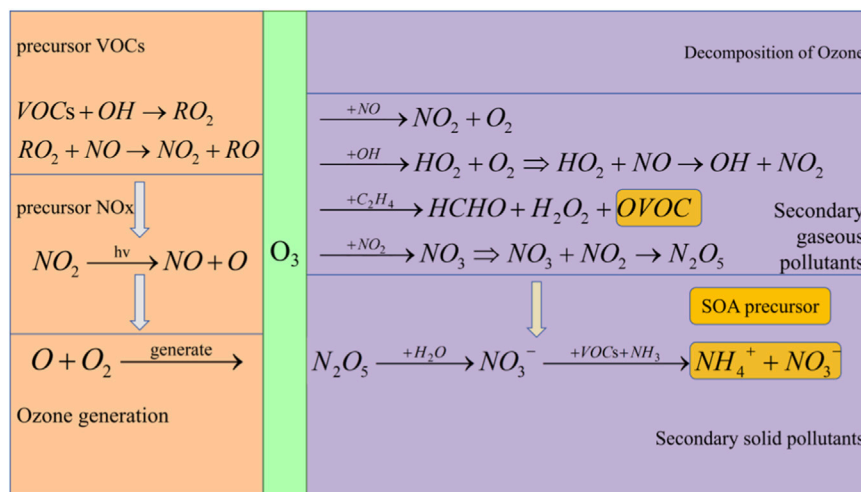


FIGURE 5 Chemical reaction mapping of indoor ozone.

ozone secondary reactions possibly being caused by human skin oils. In addition to human skin oils, complex ozone-related reactions can also occur on the surfaces of other materials indoors. Quarcoo et al. (2019) used a mass-balance indoor/outdoor ratio expression to model indoor ozone to simulate indoor particles of Secondary Organic Aerosol (SOA) generated by ozone-induced chemical reactions. Shen and Gao (2018) showed that chemicals contained in indoor materials react with ozone to generate SOA, and Hassan

et al. (2025) found that the increase in ozone concentration raised the concentration of VOCs in air filters and the odor indoors. It is worth noting that chemical reactions are usually affected by temperature, humidity and air flow rate, but the strong oxidizing properties of ozone allow these reactions to take place at room temperature. The reaction products are further hydrolyzed with moisture in the air and slowly evaporate indoors over a long period of time, making them difficult to remove.

3 Study on the hazards of indoor ozone pollution

The hazards of ozone exposure to humans are related to the duration of exposure, the strength of the body's immune system, and the secondary hazards of complex products, as shown in Table 1. This section provides an overview from four aspects of the hazards: (i) short-term exposure hazard; (ii) long-term exposure hazard; (iii) health risks to vulnerable populations, and (iv) the potential health effects of the secondary products of ozone.

3.1 Health hazards of short-term exposure

Short-term exposure to high ozone concentrations can irritate the human respiratory system, leading to airway inflammation, airway allergic reactions, and other acute symptoms, even asthma. Regarding the period of high outdoor ozone concentration, Yue (2024) used large-scale population data analysis to propose that ozone-exposed groups have a significantly higher risk of lung health, especially among those who have frequent outdoor activities in summer. Verstraelen et al. (2024) carried out an *in vitro* study on the effects of ozone on the lungs of people exposed to ozone in a simulated indoor environment of ozone and limonene, etc. The results showed that ozone-induced oxidative products were significantly toxic to airway cells, short-term exposure to high ozone concentrations caused pronounced damage to airway epithelial cells, as evidenced by increased apoptosis and increased expression of inflammatory factors. Tan et al. (2024) analyzed ozone exposure at the cellular level, and found that short-term exposure may induce early cardiovascular injury, partly through oxidative protein damage and TGF- β_1 signaling. Woller et al. (2025) studied 25,083 venous thromboembolism (VTE) cases in Utah's Wasatch and found that during the wildfire season, elevated ozone was associated with an increased odds of VTE at lag 1-day (OR, 1.05; 95% CI, 1.00–1.10; $P = 0.0545$), mean 3-day lagged average (OR, 1.06; 95% CI, 1.00–1.13; $P = 0.05$), and mean 7-day lagged average (OR, 1.09; 95% CI, 1.01–1.18; $P = 0.037$). Therefore, short-term exposure to high concentrations of ozone can lead to a variety of health problems, prevention and control of ozone pollution is important for the public to prevent cardiovascular risk early.

3.2 Health hazards of long-term exposure

Compared to short-term exposure, long-term exposure to low-level ozone is more difficult to detect, but the resulting health hazards cannot be ignored. Zhong et al. (2017) tracked and analyzed the health of different populations in low-level ozone environments, and found that long-term exposure to low-level ozone can cause chronic damage to multiple systems, exacerbating the risk of lung function decline and chronic respiratory disease. He et al. (He et al., 2025) analyzed the clinical data, and the results showed that continuous exposure to an indoor environment with ozone concentrations of 29 ± 13 ppb for 24 h led to a 1% (0.3%–1.6%) decrease in FVC and a 0.8% (0.2%–1.5%) decrease in FEV₁ in healthy adults. Li et al. (2024) analyzed the

relationship between ozone exposure and cardiorespiratory fitness by monitoring indoor ozone concentrations during sleep (mean $20.3 \mu\text{g}/\text{m}^3$) and repeated measurements of lung function indices, heart rate variability (HRV) in 81 healthy adults aged 18–28 years. The relationship between ozone exposure and cardiorespiratory function was found to be significantly reduced by ozone exposure (e.g., FEF25-75 decreased by 9.60%). Shi et al. (2024), purposively recruited 32,541 males aged 22 and 65 and used generalized linear models to evaluate the relationship between ozone exposure and sperm quality parameters. The study results suggest that ozone may be a risk factor for reduced sperm quality in men. Rodrigu et al. (2024) pointed out that long-term ozone exposure induced oxidative damage in the nervous system. Following this work, Zhang et al. (2025) focused on the mechanism of action of ozone, and pointed out that ozone affected intercellular signaling, which results in central nervous system disorders (e.g., ischemic stroke). In summary, long-term exposure to low concentrations of ozone can cause chronic damage to various bodily functions that is difficult to detect, and its obvious delayed effects often lead people to overlook this harm.

3.3 Health risks for vulnerable populations

People with relatively low immunity, such as children and the elderly, are highly sensitive to ozone pollution, and these populations tend to exhibit more severe health risks. Yen et al. (2020) demonstrates that prolonged exposure of children to indoor environments with ozone concentrations exceeding 10 ppb may cause irreversible respiratory system developmental damage. Liu et al. (2021) recruited 46 healthy children aged 11–14 and monitored the ozone concentration in the classroom in real time, analyzing the children's metabolic characteristics. The results showed that ozone exposure (average concentration 8.7 ± 6.6 ppb) caused significant changes in nine metabolites in the children's urine, such as abnormalities in amino acid metabolism and bile acid secretion. Due to the low immunity of the elderly, ozone exposure is associated with higher blood pressure, increased cardiac load, and increased incidence of cardiovascular disease. Qu et al. (2023) found that for every $10 \mu\text{g}/\text{m}^3$ increase in ozone concentration, serum brain-derived neurotrophic factor (BDNF) and neurofilament light chain (NfL) increased by 74% and 197%, respectively, in 34 people with an average age of 63.7. It can be seen that vulnerable populations face more severe health risks when exposed to ozone pollution, therefore, they should pay more attention to prevent indoor ozone pollution and live in an environment with better IAQ indicators.

3.4 Potential hazards of secondary reaction products

In addition to the direct health hazards associated with indoor ozone pollution, the indirect effects of secondary reaction products (aldehydes, ketones, etc.) resulting from the reaction of indoor ozone with indoor wood paneling and cleaning agents should not be underestimated (Xu J. et al., 2023; Xue et al., 2022). Waring and Wells (2015) employed a time-averaged equation based on Monte

TABLE 1 Summary of indoor ozone hazards.

Hazard type	Form	Research approach	Quantitative indicators	Sources
Short-term exposure hazards	Lung Diseases	Large-scale data research	Unquantified	Yue (2024)
	Airway epithelial cell apoptosis	environmental simulation	Ozone concentration 417 μ g/m ³	Verstraelen et al. (2024)
	cardiovascular damage	Cellular level analysis	VTE incidence increased by 9%	Tan et al. (2024), Woller et al. (2025)
Long-term exposure hazards	Decreased airway function FVC, etc.	Clinical data, experimental research	FVC decreased by 0.6%–1.0%	Zhong et al. (2017), He et al. (2025), Li et al. (2024)
	Decreased sperm quality in men	clinical data	Sperm concentration and total count decreased by 4.17% and 6.54% (every 10 μ g/m ³ Ozone increased)	Shi et al. (2024)
	Oxidative damage to the nervous system	Cellular level analysis	Unquantified	Rodrigu et al. (2024), Zhang et al. (2025)
Vulnerable Population Hazards	Developmental impairment of the respiratory system in children	Sample analysis 46	Endotoxin negatively correlates with lung function. (Ozone concentration>0.1 ppm)	Yen et al. (2020), Liu et al. (2021)
	Risk of neurological injury in the elderly	Sample analysis 34	BDNF and NFL increased by 74% and 197%	Qu et al. (2023)
Potential hazards of secondary products	Produces VOCs that irritate the eyes etc.	Theoretical analysis, data modeling	Unquantified	Xu J. et al. (2023), Xue et al. (2022), Waring and Wells (2015)
	Production of SOA triggers inflammation	chemical analysis	Ozone diffusion rate is between 0.1–0.7 m/s	Shen and Gao (2018)

Carlo-driven modeling effort and found that ozone participates in complex chemical reactions to generate VOCs in typical residential buildings. Shen and Gao (2018) investigated the heterogeneous reaction of ozone with indoor surface materials (e.g., wall paints) and found that the chemicals contained in these materials react with ozone secondarily to generate SOA, which further contributes to the deterioration of IAQ. In addition to the secondary pollutants already summarized above, ozone in indoor environments will certainly generate some potential harmful substances that have not yet been discovered. These substances constantly threaten people's health and require further in-depth research by scholars.

4 Prevention and control methods of indoor ozone pollution

Indoor ozone pollution prevention and control methods are endless, can be summarized probably can be divided into active, passive and composite control strategy three categories. The following will be respectively from the specific technical means of these prevention and control methods, the application effect and applicability will be analyzed, shown in Table 2.

4.1 Active control methods

Active ozone removal methods are those that actively remove indoor ozone through external equipment or energy inputs, and include two broad categories: the use of purification technologies and the optimization of ventilation strategies. These methods are

generally more efficient and can quickly reduce indoor ozone concentrations, and are suitable for locations with high ozone concentrations or where rapid ozone removal is required in a short period of time.

4.1.1 Air purification technology

Some purification devices are able to capture or decompose ozone molecules during air circulation. Namdari et al. (2021) and Khararood et al. (2022) analyzed a wide range of purification devices, and in total concluded that (i) air purifiers with HEPA filters, (ii) activated charcoal, (iii) photocatalytic filtration systems, as well as (iv) electrostatic filtration and ultraviolet decomposition functioned air treatment technologies are capable of removing indoor ozone quickly and efficiently. Some new technologies can also remove indoor ozone. Xu et al. (2018) found that ozone removal devices containing nanoporous TiO₂ films and Mn-Fe catalysts were able to reduce ozone content from 250 to 75 ppb. Duan et al. (2024) found that manganese oxide (MnOx)-based catalysts could decompose ozone into oxygen at room temperature without generating a large number of by-products through comparative studies. These approaches are certainly effective, but they require energy consumption, have high equipment maintenance costs, and some may produce other by-products during operation.

4.1.2 Rational ventilation strategies

Reasonable design of ventilation strategies and regular window opening can help to dilute indoor ozone, optimizing the filtration system when ventilating can improve the quality of the supplied air. Coffaro and Weisel (2022) analyzed the reaction and products of squalene and ozone, and Wang and Chen (2016) established the theoretical model for the chemical reaction between ozone and

TABLE 2 Comparative analysis of different prevention and control methods.

Prevention and control category	Prevention and control methods	Principle	Suitability	Removal effect	Sources
proactive	air purification technology	activated carbon adsorption; photocatalytic decomposition	Needs to be removed quickly in a short period of time Stronger air circulation	Single-pass removal 3%–98% (typical ~20–90%)	Namdari et al. (2021), Khararood et al. (2022), Xu et al. (2018), Duan et al. (2024)
	ventilation strategy optimization	Weakening of external sources Fresh air replacement at night	Lower outdoor ozone concentrations during some hours (e.g., nighttime)	The indoor-to-outdoor concentration ratio can be reduced to 20%–50%	Wang and Chen (2016), Ben-David and Waring (2018)
passive	PRM deposition removal	Reducing the release of VOCs Catalytic decomposition by manganese oxides etc.	Choosing and rationalizing environmentally friendly building materials in the pre-decoration stage	deposition velocity 0.02–0.06 cm/s (typical indoor surfaces)	Darling et al. (2016), Jing et al. (2022a), Ye et al. (2020), Ranesi et al. (2024), Jiang et al. (2022)
	Ozone absorption by plants	Natural absorption of low ozone concentrations	Non-energy-consuming supplemental ozone absorption, but with limited effect	Efficiency is about 10%–30%	Abbass et al. (2017)
complex control	Ventilated coupled PRM	Combination of active and passive	Suitable for most indoor scenes	Overall removal of 60%–80%	Gall and Rim (2018)
	Synergistic control of pollutants	Reducing precursor emissions Control of concentrations of PM _{2.5} etc.	Control of multiple pollutant emissions and efficient improvement of the environment	Reduce O ₃ and secondary product concentrations by 50%–95%	Hong et al. (2019), Kong et al. (2024), Xu et al. (2025)

squalene on the surface of the human body. The results of the study showed that, under replacement ventilation, increasing the air exchange rate is conducive to reducing exposure to ozone and its secondary pollutants. Ben-David and Waring (2018) investigated the effects of ventilation and filtration on PM_{2.5} and ozone exposure of office buildings in the U.S. Analysis of the differences showed that ventilation and filtration are complementary, the use of high-efficiency filters can mitigate the negative impacts of ventilation, and a higher ventilation rate can improve the filtration efficiency. It can reasonably be inferred that adding filtration during ventilation can reduce the ozone concentration in the fresh air entering indoors, preventing high concentrations of outdoor ozone from entering the interior. In fact, in addition to the above methods, the low ozone concentration at night can also be used for air exchange, which can also reduce the accumulation of ozone during the day.

4.2 Passive control methods

Passive ozone removal methods are those that do not require an external energy input and rely on the properties of the materials themselves to reduce ozone concentrations, usually through the selection of special decorative materials, or houseplants. Passive methods are usually energy-neutral, low-cost, suitable for long-term use and environmentally friendly, but are slow to remove ozone and are suitable for relatively low indoor ozone concentrations or as a means of routine maintenance.

4.2.1 Ozone removal by PRM settling

Eco-friendly furniture, coatings, and paints have low VOC emissions, which can effectively reduce the formation of indoor

ozone through chemical processes. Moreover, there are even materials that can passively remove ozone. Darling et al. (2016) presented the idea that Passive Removal Materials (PRMs) have a certain ozone-removal potential without the formation of a large number of harmful reaction products. Jing et al. (2022a) found that the ozone-removal ability of PRMs was correlated with the material area, migration-limited deposition rate, air change rate, and so on. Ye et al. (2020) and Ranesi et al. (2024) analyzed the deposition of ozone on seven common indoor materials and the effectiveness of eight paints in reducing ozone concentration when applied to indoor walls and ceilings, respectively. The results showed that the deposition rate of ozone varied among different materials, with the clay-based stucco and gypsum stucco with the incorporation of tree bark showing the best ozone removal activity. In addition to conventional building materials and furniture, Jiang et al. (2022) measured the ozone removal and ozone deposition rate of fine coffee powder to be 58.5% and 0.62 cm/s, respectively, which implies that the use of similar hydrocarbon materials for IAQ control is also feasible.

4.2.2 Indoor plant applications

Plants have a relatively limited effect on ozone removal, but have a complementary role as an energy-free green means. Abbass et al. (2017) studied the effect of five indoor plants (Peace Lily, Ficus, Caribbean Begonia, Tropical Calla Lily, and Golden Greenery) on ozone removal, and the results showed that all of these plants were able to settle indoor ozone more or less efficiently, with a settlement rate of between 0.5 and 5.5 m/h. However, the effectiveness of ozone removal is limited by plant species, indoor environmental conditions, and it is usually more effective at removing low concentrations of ozone.

4.3 Compound control methods

4.3.1 Ventilated coupled PRM

Active ozone removal technology is highly efficient, while passive ozone removal technology is more environmentally friendly and cost-effective. Combining the two is a good option for removing indoor ozone. [Gall and Rim \(2018\)](#) tested the effect of surface quality accumulation on ozone surface deposition by deploying clean borosilicate glass plates in two indoor environments: a mechanically ventilated (MV) office and a naturally ventilated (NV) residence, both located in Singapore. The test results show that the ozone removal rates before and after PRM material deployment were $(0.06\text{--}0.74) \times 10^{-6}$ and $(0.15\text{--}1.2) \times 10^{-6}$, respectively. Removal rate of 4.3 nmol O₃/mg for the NV residence and 2.4 nmol O₃/mg for the MV office. These findings demonstrate that integrating active and passive ozone removal strategies not only enhances overall removal efficiency but also improves system robustness across diverse ventilation conditions, offering a more comprehensive and stable approach for indoor ozone mitigation.

4.3.2 Synergistic control of PM2.5 and ozone

Synergistic prevention and control of different types of pollutants can reduce invisible and hard-to-detect ozone generation pathways. [Hong et al. \(2019\)](#) made several suggestions on synergistic control of PM2.5 and ozone pollution in the atmosphere. [Kong et al. \(2024\)](#) pointed out that, the implementation of a multipollutant emission reduction control strategy aimed at the prevention and control of PM2.5 and ozone pollution is the only means to realize the coordinated control of PM2.5 and ozone. [Xu et al. \(2025\)](#) proposed a composite fiber material based on microbial carbon coating (MBC@PET) for the efficient removal of indoor PM2.5 and ozone, with an ozone removal rate of up to 91.42%. Through the synergistic design of physical adsorption and chemical decomposition of microbial charcoal and the composite material, the efficient removal of indoor ozone was achieved, which provides a new idea for the green air purification technology.

5 Engineering applications of prevention and control methods

The prevention and control of indoor ozone pollution have their own needs in different types of building environments. The following three common building types, namely, residential, educational, and commercial, are introduced to introduce the application of ozone control engineering in different environments, with an emphasis on the prevention and control strategies and their implementation effects that are suitable for each type of building.

5.1 Applications for residential type buildings

Ozone prevention and control in residential buildings should emphasize the rational design of ventilation systems and careful selection of decorative materials in order to provide a comfortable

environment while reducing the risk of pollution. [Ma et al. \(2023\)](#) focused on typical envelope airflow paths used in homes in the Philadelphia area of the United States, and indoor ozone prediction models based on inputs from the environmental investigations can be effective in predicting. Predicting ozone concentrations during the architectural design phase allows for the early development of control strategies, thereby improving and creating a healthy living environment. [Jing et al. \(2022b\)](#) found that the increase in ozone deposition rate will cause more ozone to be removed by indoor surfaces, thus reducing indoor ozone concentration, which is very suitable for residential buildings. The selection of environmentally friendly materials with ozone adsorption or decomposition ability, such as activated carbon coatings and titanium dioxide catalysts, can effectively reduce ozone content in the home environment and safeguard the health of occupants. This passive prevention and control method not only does not produce more pollutants, but also improves IAQ indicators by decomposing ozone.

5.2 Applications for educational type buildings

In educational buildings such as kindergartens, school buildings, and libraries, where IAQ is critical to the health of children and adolescents, low ozone-emitting equipment and materials should be prioritized. [Salonen et al. \(2018\)](#) reviewed dozens of papers and calculated median ozone concentrations in school and office environments to be 8.50 µg/m³ (mean 0.8 µg/m³–114 µg/m³) and 9.04 µg/m³ (mean 0–96.8 µg/m³), respectively, indicating a risk of exceeding the WHO 8-h guideline value (100 µg/m³). Effective ozone control in educational buildings can be achieved by (i) optimizing ventilation schedules to avoid outdoor ozone peaks, (ii) isolating printers or photocopiers in dedicated exhausted rooms, and (iii) applying passive removal materials (PRMs) such as manganese oxide-based coatings, activated-carbon-enhanced wall materials, or low-VOC treated wood. These methods can sustainably remove ozone without increasing energy consumption and are particularly suitable for classrooms and corridors.

5.3 Applications for commercial type buildings

In commercial spaces such as shopping malls, hotels, and restaurants, ozone prevention and control needs to take into account the characteristics of heavy foot traffic and diverse equipment. [Tang et al. \(2022\)](#) evaluated the ozone removal performance of 14 commercially available air purification devices used in building ventilation systems, which retained their efficiency over long periods of time in the building ventilation system. In commercial buildings, ozone mitigation can be enhanced through ventilation–filtration coupling strategies using advanced media such as MERV 13+ activated carbon. Optimize airflow distribution to limit ozone intrusion, incorporating catalytic ozone decomposition units—including MnO_x catalysts, TiO₂–VUV photocatalytic modules—into HVAC systems for high single-pass removal efficiency. Apply PRM coatings, catalytic panels near diffusers,

and airflow optimization (e.g., CFD-based design) to reduce ozone accumulation in atriums, corridors, and other large open spaces. These methods can significantly reduce ozone levels, enhance customer experience, and are ideal for commercial buildings.

6 Conclusion

The rising demand for the prevention and control of indoor ozone pollution has led to the emergence of new technologies and methods, which shows a broad development prospect from the development of advanced functional materials, intelligent monitoring and control systems, synergistic cross-pollutant management, and so on. This paper summarizes the sources of indoor ozone pollution, health hazards, concentration distribution characteristics, and the application of its prevention and control technologies. Synthesizing the existing literature and research results, the following main conclusions are drawn:

Firstly, indoor ozone pollution comes from a variety of sources, including the infiltration of outdoor ozone and the generation of indoor equipment. Ozone in the indoor environment not only poses a direct hazard to the respiratory, cardiovascular and nervous systems, but also generates potential secondary pollutants by reacting with other chemicals, exacerbating the threat to human health.

Secondly, ozone pollution prevention and control technologies have made significant progress in recent years, including active, passive and combined control methods. Active methods include air purification techniques and optimization of ventilation strategies; passive methods include the use of PRM materials with ozone decomposition or adsorption capacity and the use of indoor plants to absorb ozone.

However, there are still a number of challenges and scientific issues that need to be addressed for indoor ozone prevention and control. How to make the new PRM materials play an efficient ozone removal role while meeting the economic requirements is a key direction for future research; the Internet of Things (IoT)-driven air quality monitoring and control technology under the premise of disciplinary crossover is facing technical problems such as cost, data compatibility and system stability. Therefore, future research on indoor ozone pollution shows the following two trends:

On the one hand, the development of advanced nanomaterials and composite functional coatings with efficient ozone decomposition ability has been a major research focus in recent years. On the other hand, an intelligent ozone monitoring device based on the IoT needs to be developed to track indoor ozone levels in real-time and promptly detect potential hazards. Of course, further research on indoor ozone prevention and control technology relies on government policy support, and synergy

between academia and industry to create a healthier, safer, and higher IAQ level living environment. It is hoped that relevant scholars will further study the above issues that need to be resolved in order to more comprehensively address the health threats posed by indoor ozone pollution.

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JW: Writing – original draft, Writing – review and editing. QW: Investigation, Writing – original draft, Formal Analysis. TW: Writing – original draft, Methodology, Data curation.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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