Proceedings of the 11th World Congress on New Technologies (NewTech'25)
Paris, France - August, 2025
Paper No. ICEPR 169
DOI: 10.11159/icepr25.169

Assessment of Indoor Air Quality and Inhalation Risk of Formaldehyde from Consumer Perfumes

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Abstract **–** The objective of this study is to assess the indoor air quality and inhalation exposure risk during the use of perfumes. The air quality parameters, such as Formaldehyde (HCHO), particulate matter (PM10, PM2.5, PM1.0), carbon monoxide (CO), carbon dioxide (CO_2), total volatile organic compounds (TVOC), ozone (O_3), and air quality index (AQI), are measured indoors after spraying perfumes. The average values of thirteen perfumes after spraying three times are as follows: PM2.5 concentration is 97.2 µg/m³, HCHO level is 3.7 ppm, and CO_2 concentration is 526.6 ppm. The TVOC stands at 5.18 ppm, while the AQI is 210. Additionally, the PM10 level is 68.8 µg/m³, CO (carbon monoxide) is at 11.15 ppm, O3 (ozone) is measured at 0.69 ppm, and PM1.0 is 30.96 µg/m³. These readings signify high concentrations of different pollutants emitted into the air, which may contribute to indoor air contamination and health effects upon frequent exposure. The high concentration of PM2.5 and PM10 may lead to respiratory discomfort, such as asthma and impaired lung function. HCHO induces irritation in the eyes, nose, and throat, and long-term exposure can result in aggravated respiratory conditions. The presence of high TVOC levels can cause headaches, dizziness, etc. High levels of CO can hinder the process of oxygen supply in the body, which can result in cardiovascular problems. The research identifies a high possible carcinogenic hazard related to the use of the perfumes tested, as indicated by HQ values greater than 1. These results emphasize the need for regulation and surveillance of fragrance ingredients in order to maintain consumer safety.

Keywords**:** inhalation risk, perfumes, personal cloud, TVOC

1. Introduction

Indoor air quality (IAQ) is a very simple measure of human health and well-being, given that human beings spend approximately 90% of their time indoors [1]. Indoor air pollution has been linked with an extremely wide range of adverse health outcomes, from respiratory illness to cardiovascular, allergic, and even cancer [2]. The items, such as deodorants, lotions, hair dyes, cosmetics, shampoo, and makeup products, fall under the category of personal care products (PCPs) and were employed for everyday beautification and maintenance. There is a growing concern regarding PCPs due to their adverse impact on individuals, public health, and the environment in general. PCPs contain a large number of chemicals and compounds that can be harmful. For example, PCPs generally have phthalates, parabens, triclosan, and artificial scents [3]. Such compounds can be absorbed into the human body through skin, breathing, or hand-mouth actions. Inside the body, certain compounds can become endocrine disruptors, which can lead to hormonal changes, an imbalance in reproduction, higher chances of specific types of cancers, and multiple health issues [4]–[6]. Among the various indoor air pollution causes, consumer care products, including perfumes and deodorants, have gained significant interest due to their widespread usage and release of volatile organic compounds (VOCs), which are easily able to pollute [7]. Consumer care products release complex mixtures of chemicals, such as terpenes, alcohols, esters, and aldehydes, and have direct effects on indoor air composition and can cause chemical interactions leading to secondary pollutants [8]–[12]. In addition to the indoor environment, every individual is surrounded by a personal cloud created by personal emissions like breath, skin secretions, and applied chemicals like perfumes. Research has indicated that people release VOCs continuously into indoor environments, and personal hygiene practices like showering frequency and product application manage these emissions. For instance, unshowered people release more carboxylic acids, and the use of fragranced products modifies ozone-skin and ozone-product interactions, leading to dynamic indoor chemistry changes [13]. When perfumes are sprayed, they emit a mixture of VOCs that not only directly contribute to degrading IAQ but also interact with oxidants like ozone (O_3) indoors to produce secondary pollutants [14], [15]. The significant air pollutants in perfumes are formaldehyde, benzene, toluene, limonene, linalool, and a series of esters, all of which have been reported to have toxic respiratory and neurological effects [16], [17]. Such chemicals are prone to photochemical and oxidative reactions, particularly in the presence of ozone, to yield secondary organic aerosols (SOAs), formaldehyde, and ultrafine particulate matter (PM1.0). Such indoor SOAs have the potential to cause extreme health hazards owing to their very minute particle size and ability to travel deep within the respiratory system [8], [9]. The indoor air chemistry gets especially complex when oxidizing chemicals like O_3, NOx, and hydroxyl radicals react with the ingredients in perfumes to form a series of secondary irritants, most of which have higher toxicity compared to the parent VOCs [18]. The objective of this study is to assess the indoor air quality and inhalation exposure risk during the use of perfumes.

2. Methodology

2.1. Measurement of air pollutants

Thirteen different perfumes from the market were chosen for analysis to assess their effect on indoor air quality, representing both men's and women's fragrances from various brands. The perfumes were anonymized and labeled as P1 to P13. Tests were conducted under a closed indoor condition with poor external ventilation in order to replicate typical usage conditions. The ambient air quality inside the indoor room was measured as a baseline. Five sprays of each perfume were released into the enclosed room, and air quality parameters were measured two minutes after spraying. Measurements were taken using a high-resolution indoor air quality monitor that was equipped with specialized sensors, each selected for resolution, sensitivity, and accuracy appropriate for low-level indoor exposure. Parameters being monitored were Formaldehyde, PM1.0, PM2.5, PM10, Total Volatile Organic Compounds (TVOCs), Carbon Monoxide (CO), Carbon Dioxide (CO_2), Ozone (O_3), particle number, and the Air Quality Index (AQI).

2.2. Exposure risk assessment

The carcinogenic risk assessment was approximated using the United States Environmental Protection Agency (USEPA) method of risk assessment [19]. The carcinogenic risk was approximated by the Lifetime Cancer Risk (LCR), which is a quantification of the chance that an individual will develop cancer in their lifetime as a result of prolonged exposure to a carcinogen such as formaldehyde. The LCR was calculated from equations 1 and 2.

$$LCR = CDI * SF \tag{1}$$

$$CDI = \frac{C * IR * ET * EF * ED}{BW * ALT * NY} \tag{2}$$

Where CDI is the chronic daily intake (mg/kg/day) and SF is the slope factor for formaldehyde, set at 0.0455 $(mg/kg/day)^{-1}$ from the USEPA's Integrated Risk Information System (IRIS). In equ.2, C represents formaldehyde concentration (mg/m^3), IR the inhalation rate (16 m^3/h), ET the duration of exposure (5 min/day = 0.083 h/day), EF the frequency of exposure (365 days/year), ED the duration of exposure (50 years), BW the body weight (55 kg), ALT the average lifetime (70 years), and NY the number of days of exposure a year (365). The acceptability of LCR values adheres to WHO standards, in which values $<10^{-6}$ are considered negligible risk, 10^{-6}–10^{-5} potential risk, 10^{5}–10^{-4} probable risk, and $>10^{-4}$ certain risk.

Non-carcinogenic risk was estimated through the use of the Hazard Quotient (HQ) given in equation 3, and EC is the exposure concentration computed based on equation 4.

$$HQ = \frac{EC}{RfC} \tag{3}$$

$$EC = \frac{C * ET * EF * ED}{ALT} \tag{4}$$

Where RfC is the reference concentration (3.94×10^{-5} mg/m^3), and EC was calculated from the same parameters. An HQ > 1 indicates potential non-carcinogenic effects on health, whereas HQ < 1 indicates an insignificantly small risk.

3. Results and discussion

The measurement of air quality parameters following exposure to thirteen various perfumes (designated P1–P13) in a controlled indoor environment indicates considerable variation in pollutant concentrations from the baseline. Baseline readings before perfume application indicated low pollutant levels: PM2.5 at 28 µg/m^3, formaldehyde (HCHO) at 0.02 ppm, CO_2 at 460 ppm, TVOC at 0 ppm, AQI at 46, and low PM10, CO, and ozone levels. Nevertheless, when the perfumes were sprayed, these values exhibited different levels of increase in all samples, which implies a direct contribution of perfume components to indoor air pollution. The concentrations of the air pollutants released via perfumes, along with the indoor air quality index, are given in Figure 1. Perfumes such as P5, P7, and P8 recorded exceptionally high PM2.5 values (698, 470, and 728 µg/m^3, respectively), which far exceed the WHO's indoor air quality guideline of 25 µg/m^3 for 24-hour exposure. Elevated PM10 and PM1.0 counts in these samples further corroborate their significant particulate emissions, likely due to aerosolized fragrance carriers and the reaction of VOCs with indoor oxidants. Fine and ultrafine particles (e.g., >0.3 µm, >1.0 µm) were markedly higher in these perfumes, with P8 showing >29,000 particles at 0.3 µm, highlighting potential respiratory health risks due to deep lung penetration. Notably, several perfumes exhibited HCHO levels of 5 ppm - P1, P2, P3, and all sprays of P4, P5, P6, and P9 reached or exceeded common indoor limits. Across all perfumes, TVOC concentrations surged from 0 to consistent levels around 5.62 ppm in most cases, indicating high VOC loading. TVOCs include compounds like limonene, linalool, and benzene derivatives, which are typical in fragrances and can react with ozone to form harmful secondary pollutants like formaldehyde and SOAs [20]. Additionally, CO_2 levels also increased (e.g., P9 peaked at 1051 ppm). While ambient ozone levels were low before spraying (0.02 ppm), perfumes such as P4 (9.99 ppm), P11 (1.69 ppm), and others showed sharp ozone spikes. This may not stem from the perfume directly but rather from secondary reactions between emitted terpenes and background ozone, forming ozone indoors through radical propagation cycles [13]. These reactions contribute to SOA formation and exacerbation of respiratory symptoms. The AQI values, computed based on multiple pollutants, reached the maximum threshold (999) in samples such as P5, P7, and P8, signifying hazardous indoor air conditions. Given the cumulative emissions of VOCs, particles, and ozone from perfumes, there is strong evidence that frequent use in enclosed spaces could elevate short-term exposure to toxic compounds and increase long-term risks for respiratory and systemic effects.

The Spearman correlation matrix was plotted to understand the relation between the pollutants. PM2.5 and PM10 have large correlations with almost all other parameters, such as CO, CO_2, TVOCs, AQI, and ultrafine particle size fractions, reflecting that perfumes releasing particulate matter also discharge large amounts of gaseous pollutants. As an example, PM2.5 has statistically significant correlations ($*p < 0.001$) with TVOCs, AQI, and PM10, reflecting that perfumes discharging high emissions of PM2.5 likely increase overall air toxicity and visible air quality indexes. In the same way, TVOCs are highly correlated with AQI and CO, highlighting the importance of volatile organic compounds in indoor air quality degradation. Notably, ultrafine particles of all size bins (<30 nm, <50 nm, <100 nm, <200 nm) have positive correlations with TVOCs and PM values as well, supporting the notion that perfumes emitting more VOC content could also be a nucleation and growth source for airborne nanoparticles.

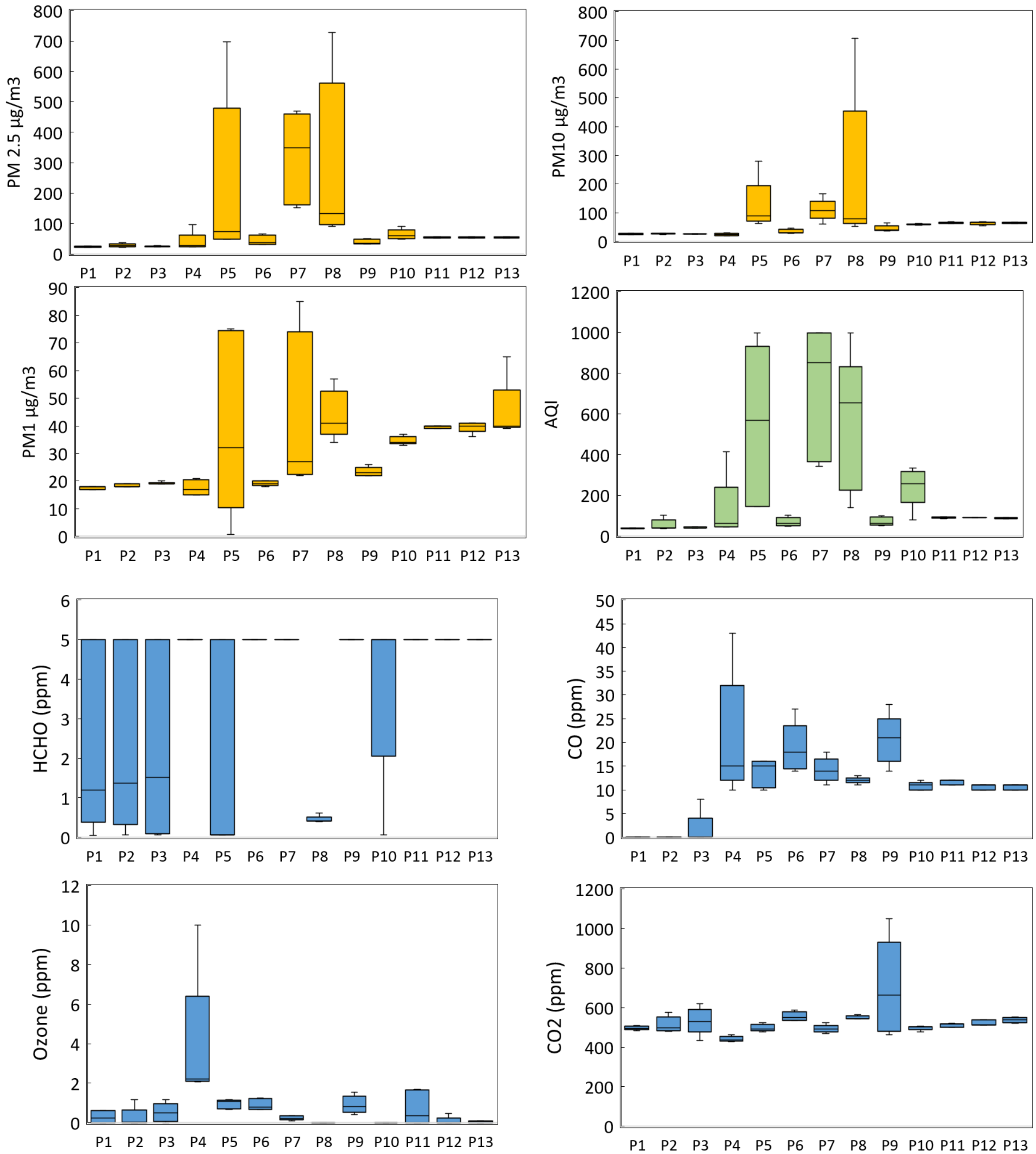
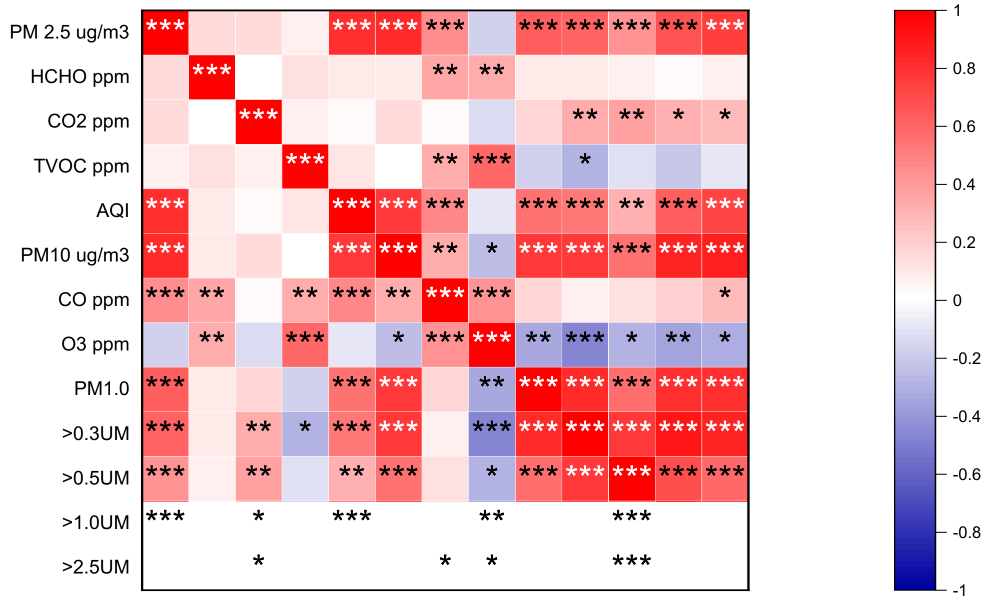


Fig. 1: Air pollutants released from perfumes (ranges from 1 – 5 sprays)



* p<=0.05 ** p<=0.01 *** p<=0.001

Fig. 2: Correlation matrix of Air pollutants released from perfumes (ranges from 1 – 5 sprays)

Ozone (O_3), a secondary pollutant, demonstrates moderate correlations with other parameters, especially with TVOCs and PM10, indicating a possible connection through photochemical reactions. Of particular interest are also some of the negative correlations, e.g., between TVOCs and the lower ultrafine particle fractions, potentially indicating intricate chemical interactions or dilution effects. On average, the matrix shows robust clustering between groups of pollutants, particularly those associated with combustion-like or VOC-dense emissions, underpinning the viability of clustering perfumes into behaviorally akin groups based on their emission patterns.

The exposure risk of formaldehyde of thirteen perfume samples shows different levels of health risk, with special emphasis on high carcinogenic and non-carcinogenic risks from perfumes with higher formaldehyde levels (Table 1). Of particular interest, perfumes P4, P6, P7, P9, P11, P12, and P13 all had a formaldehyde concentration of 5 ppm, which corresponds to an ambient air concentration of 6.14 µg/m³.

Table 1: Exposure risk to formaldehyde due to perfumes

Perfumes	**HCHO (mg/m^3)**	**CDI (mg/kg/day)**	**LCR**	**EC (mg/m^3)**	**HQ**
P1	2.9	0.05	0.002	0.007	184
P2	2.9	0.05	0.002	0.007	185
P3	2.9	0.05	0.002	0.007	180
P4	6.1	0.11	0.005	0.015	385
P5	2.5	0.04	0.002	0.006	157
P6	6.1	0.11	0.005	0.015	385
P7	6.1	0.11	0.005	0.015	385
P8	0.6	0.01	0.0004	0.001	35

P9	6.1	0.11	0.005	0.015	385
P10	4.7	0.08	0.004	0.012	294
P11	6.1	0.11	0.005	0.015	385
P12	6.1	0.11	0.005	0.015	385
P13	6.1	0.11	0.005	0.015	385

These samples had the maximum chronic daily intake of 0.11 mg/kg/day and lifetime cancer risk of 0.005, well above USEPA's standard of 1.0×10^{-6}, meaning a "definite risk" of cancer due to long-term exposure. Moreover, the HQ for these perfumes was far beyond the safety limit of 1, indicating a high risk for non-carcinogenic effects like respiratory irritation, especially among sensitive persons. In comparison, lower concentration samples such as P8 (0.6 mg/m^3) yielded a much lower LCR of 0.0004 and HQ of 35, although still above safety thresholds. Notably, the exposure situation in this research presumed a typical 5-minute daily exposure time; yet, real-world exposure may differ depending on personal behavior and environmental factors. Evidence indicates that regular perfume use or use in inadequately ventilated areas can significantly elevate instantaneous inhalation doses, which can enhance acute health effects such as eye, nose, and throat irritation [21]. Alternatively, good ventilation and limited use may reduce total exposure. Nonetheless, even frequent, short-term exposures to high formaldehyde levels like those in perfumes with 5 ppm can contribute to cumulative health risks. The findings emphasize the need for rigorous control and awareness among consumers to avoid inhalation risks involving formaldehyde in cosmetic treatments.

4. Conclusion

Air quality analysis indicated that usage of perfumes results in direct exposure of the users to a variety of airborne contaminants such as particulate matter (PM), formaldehyde, CO, CO_2, VOCs, and ozone. These contaminants are capable of posing harmful effects to human health in the form of triggering allergies, lung diseases, and even cancer. The Indoor Air Quality index in some of the perfumes exceeded 100, which could mean potentially unsatisfactory air quality contributing to respiratory irritation or other health issues. The research also proposes a likely elevation in carcinogenic risk connected to all of the perfumes investigated, based on a Hazard Quotient above 1. However, additional work is needed to validate the magnitude of genuine risk and prospective long-term adverse effects on health. The relevant variables, such as individual perfume chemicals used, utilization practices, and sensitivity, would require analysis. It should be remembered that although the existence of pollutants in perfumes and their harmful health impacts have been established, a large percentage of users of such products are not aware of their possible dangers.

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