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Beauty under the scrutiny: comparative assessment of volatile and inorganic air pollutants in beauty salons versus outdoor air

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Abstract: The aim of this study was to assess indoor air quality in twelve beauty salons located in the Upper Silesian agglomeration (Poland) and to evaluate the influence of service type and surrounding environment on gaseous pollutant levels. A four-week monitoring campaign was conducted using passive samplers to determine concentrations of volatile organic compounds (VOCs), formaldehyde (HCHO), ammonia (NH_3), nitrogen dioxide (NO_2), ozone (O_3), and sulfur dioxide (SO_2) in the workers' breathing zones, with reference to outdoor background levels.
The results demonstrated a clear predominance of indoor emission sources. The mean indoor total VOC concentration (1485.5 μg/m³) was approximately ten times higher than outdoor concentration, confirming the significant contribution of cosmetic products and treatment procedures. The greatest spatial variability was observed in ammonia concentrations (26.6–1086 μg/m³), strongly associated with the use of hair treatment products. Nitrogen dioxide showed moderate indoor enrichment, whereas sulfur dioxide remained at urban background levels. Notably, indoor ozone concentrations were over an order of magnitude lower than outdoor levels, indicating effective ozone removal through reactions with VOCs and the potential formation of secondary pollutants. Although most concentrations did not exceed occupational exposure limits, long-term exposure to complex mixtures of primary and secondary pollutants may pose health risks, highlighting the need for systematic monitoring and improved ventilation strategies in beauty salons.

Introduction

Air pollution has emerged as one of the most pressing environmental concerns of the 21st century, affecting both outdoor and indoor environments. Its adverse effects on human health are well documented, with evidence demonstrating impacts on population health, quality of life, and social and economic productivity (Maji et al. 2023). This issue is particularly important in both outdoor and indoor environments, where people spend a substantial proportion of their time, including workplaces such as beauty salons, where cosmetic procedures generate substantial chemical emissions.

Indoor air pollution in beauty salons is a significant concern due to extensive use of chemical products in small, enclosed workspaces with limited air exchange. Products such as hair dyes, hair lighteners, nail polishes, acrylic formulations, and hair sprays contain a wide range of chemical compounds, including hydrocarbons, alcohols, esters, phenols, and organic acids, which are released during application and contribute to indoor air contamination. This phenomenon has been documented in previous studies, in which the use of cosmetic products was associated with increased concentrations of particulate matter and organic carbon in beauty salon environments (Rogula-Kopiec et al. 2019). While outdoor air quality is mainly affected by industrial and vehicle emissions, beauty salons are burdened by indoor sources related to the continuous use of cosmetic products, hair treatments, nail services, and cleaning agents, all of which release volatile organic compounds (VOCs) throughout the workday. The problem is exacerbated by the fact that many beauty salons operate in spaces with inadequate ventilation systems (Evtyugina et al. 2021, Tagesse et al. 2021), where pollutant concentrations can significantly exceed outdoor ambient levels and pose sustained exposure risks to workers who spend entire shifts in these environments. Consequently, increasing attention has been paid to indoor air quality and chemical exposure in beauty salons, particularly regarding the potential long-term health effects associated with chronic low-level exposure (Han et al. 2022, Kezic et al. 2022, Lamplugh et al. 2019, Rogula-Kopiec et al. 2023). Although concentrations of individual pollutants often remain below occupational exposure limits, their repeated and combined occurrence may still be relevant from the perspective of cumulative exposure assessment, especially among workers experiencing daily, prolonged contact with indoor air contaminants (Horvat et al. 2025, Ndlovu & Nkeh-Chungag, 2024).

Indoor air pollution in beauty salons is influenced by both indoor and outdoor sources. While chemical compounds released from cosmetic products during their use constitute a major source of contamination, some pollutants may also infiltrate from outdoor air. Cosmetic and hair care products commonly contain formaldehyde (HCHO), volatile organic compounds (VOCs) such as benzene, toluene, ethylbenzene, and xylene, as well as ammonia (NH_3), which are used as solvents, preservatives, and active ingredients. Specific beauty treatment processes—such as hair dyeing and bleaching, nail styling (e.g., use of gels, acrylics, and removers), and the application of sprays or solvents—may lead to the release of these compounds into indoor air. In addition to primary emissions, chemical transformations occurring indoors may contribute to the formation of secondary pollutants. For example, ozone (O_3) is typically not emitted directly indoors but primarily infiltrates from outdoor air, where it may subsequently react with VOCs and other reactive compounds. Nitrogen oxides (NO_x) are mainly associated with outdoor sources (e.g., traffic emissions or heating systems) and can penetrate indoors, although minor indoor contributions related to the degradation processes cannot be excluded. Similarly, sulfur oxides (SO_x) are generally linked to outdoor combustion processes, while their potential indoor formation from sulfur-containing cosmetic ingredients is considered limited.

Even at relatively low concentrations, volatile and particulate compounds present in beauty salons (e.g., solvents, formaldehyde, and fine particulate matter) may act as respiratory irritants and have been associated in occupational studies with acute mucosal irritation, toxic effects, and potential long-term carcinogenic risk, affecting both salon workers and clients (Brunekreef & Holgate, 2002). Previous studies have shown that concentrations of these irritants in occupational settings may exceed those typically observed in residential environments (Lis, 2021, Norback et al. 1990). Prolonged exposure has been associated with respiratory and circulatory disorders (Raju et al. 2020), impaired immune function (Brunekreef & Holgate, 2002), an increased prevalence of allergic reactions (Logue et al. 2012, Maji et al. 2023), and elevated cancerogenic risk (Ghaffari et al. 2021, Li et al. 2024).

Another significant air quality concern in beauty salons is fine particulate matter ($PM_{2.5}$ and PM_{10}). In salon environments, particulate matter originates from multiple sources, including infiltration from outdoor urban air (Starzomska & Strużewska, 2024), as well as indoor activities such as hair cutting and styling, nail filing and buffing, the use of powder-based cosmetics, and aerosol emissions generated during spray applications (Evtyugina et al. 2021, Rogula-Kopiec et al. 2019).

Previous studies indicate that activities such as nail filing or the use of spray products are associated with increased PM concentrations in salon environments. Rogula-Kopiec (2019) reported that indoor PM_4 and total suspended particulate matter (TPM) levels were 2–10 times higher indoors than outdoors. Additional sources of particulate matter included activities such as burning candles and incense, which further contributed to elevated PM_4 concentrations in salon environments. Indoor PM_4 concentrations ranged from 92.8 to 170.2 µg/m³, compared to outdoor levels of 19.4–105.0 µg/m³, yielding indoor/outdoor ratios of up to 9.6 — substantially exceeding those recorded in residential environments. These findings are consistent with those reported by Evtyugina et al. (2021), who observed average indoor $PM_{2.5}$ concentrations of approximately 20–30 µg/m³, with peaks reaching ~100 µg/m³ during treatments, while PM_{10} concentrations averaged 30–50 µg/m³ and reached maxima of ~150–200 µg/m³. Short-term increases in PM concentrations have been strongly associated with specific activities, such as nail filing and the use of spray products, confirming that indoor sources and performed tasks are key determinants of exposure in salon environments (Park et al. 2021, Vinnikov et al. 2023, Yan et al. 2022, Matković et al. 2025).

In a previous study by one of the authors, indoor PM levels were measured, and the average concentrations of PM4 and total suspended particulate matter (TPM) were found to be 2–10 times higher indoors than outdoors. Indoor PM_4 concentrations measured across four beauty salons ranged from 92.8 to 170.2 µg/m³, compared to outdoor levels of 19.4–105.0 µg/m³, yielding indoor/outdoor ratios of up to 9.6, substantially exceeding those recorded in residential environments (Rogula-Kopiec, 2019). These findings are consistent with results reported in another study (Evtyugina et al. 2021), where indoor $PM_{2.5}$ concentrations averaged approximately 20–30 µg/m³ (with peaks up to ~100 µg/m³ during treatments), and PM_{10} reached mean levels of 30–50 µg/m³ (with maxima up to ~150–200 µg/m³), compared to lower outdoor levels ($PM_{2.5}$: ~10–20 µg/m³, PM_{10}: ~20–40 µg/m³). In addition, another study reported that daily median concentrations of respirable PM in beauty salons ranged from 34 to 290 µg/m³, highlighting substantial variability between salons and reinforcing the importance of occupational activities as determinants of exposure (Park et al. 2021, Vinnikov et al. 2023, Yan et al. 2022, Matković et al. 2025). The studies demonstrated that short-term increases in PM concentrations were strongly associated with specific activities, such as nail filing and the use of spray products, confirming that indoor sources and work-related tasks performed are key determinants of exposure in salon environments. Moreover, elevated exposure to particulate matter in beauty salon workplaces has been associated with adverse respiratory health outcomes among workers, including an increased prevalence of dyspnea and allergic conditions.

The indoor air quality challenge in beauty salons extends beyond direct product emissions, as chemical reactions between volatile organic compounds (VOCs) and oxidizing agents have been demonstrated to generate secondary pollutants which have been shown to be more toxic than the original compounds (Ramírez et al. 2023, Rogula-Kopiec et al. 2019). For instance, the reaction between terpenes present in fragranced products and ozone has been shown to yield formaldehyde and ultrafine particles. It is challenging to predict and control these transformation processes, as they depend on intricate interactions among product chemistry, ambient conditions, and ventilation patterns (Hernandez et al. 2020, Ricklund et al. 2023). This chemical complexity underscores the need for comprehensive air quality monitoring in beauty salon environments to characterize actual exposure conditions rather than relying solely on product ingredient lists. Such monitoring should support occupational exposure assessment by measuring concentrations of key pollutants (e.g., VOCs, aldehydes, ammonia, and particulate matter). This approach enables a more accurate evaluation of real-world exposure scenarios experienced by both workers and clients.

Increasing attention has been devoted to indoor air quality and chemical exposure in beauty salons, with studies confirming the presence of BTEX compounds (benzene, toluene, ethylbenzene, and xylene) in salon indoor air as a consequence of cosmetic product use and beauty treatments (Han et al. 2022, Kezic et al. 2022, Lamplugh et al. 2019, Rogula-Kopiec et al. 2023). Although recorded concentrations frequently remain below established occupational exposure limits, their chronic occurrence raises justified concerns about long-term health effects, particularly among workers who, unlike transiently exposed members of the public, face repeated exposure to pollutants throughout regular eight-hour shifts (Horvat et al. 2025, Ndlovu & Nkeh-Chungag, 2024). Indoor pollutant levels are further modulated by external factors, including salon location, surrounding urban characteristics, and traffic intensity in the immediate vicinity (Badyda, 2013, Rybak et al. 2015). Despite this growing body of evidence, existing studies remain limited in scope: most focus on individual classes of pollutants analyzed in isolation, which restricts the assessment of workers' overall exposure profile. Data from Central European countries are particularly scarce, and comprehensive characterization of simultaneous exposure to both organic and inorganic gaseous pollutants — achievable through passive sorbent-based sampling, a non-invasive approach that does not disrupt normal salon operations — remains largely incomplete.

Indoor pollutant levels are also modulated by external factors, including salon location, surrounding urban morphology, and traffic intensity in the immediate vicinity (Badyda, 2013, Rybak et al. 2015). However, existing studies often focus on individual pollutant classes in isolation, which limits the ability to assess integrated exposure profiles. Data from Central European countries remains particularly scarce, and comprehensive characterization of simultaneous exposure to multiple gaseous pollutants using passive sampling techniques is still limited, despite its potential to capture real-world occupational conditions.

The aim of this study was to assess indoor air quality in twelve beauty salons located in the Upper Silesian agglomeration, Poland, and to evaluate the influence of service type and the surrounding environment on levels of gaseous pollutant, including VOCs (C_2–C_{28}), formaldehyde, ammonia, nitrogen dioxide, ozone, and sulfur dioxide.

Materials and Methods

Locations

The study was conducted in the Upper Silesian agglomeration, one of the most heavily industrialized regions in Poland and Europe. The area is characterized by industrial plants, which may contribute to elevated air pollution levels, particularly during the heating season and under unfavorable meteorological conditions. At the same time, the presence of parks and green spaces may locally affect air quality. The location of all measurement points is shown in Figure 1, while the parameters of salons are provided in Table 1. All the locations are within 20 km from each other. Although the salons were located within the same outdoor air quality zone PL2401 (Dz.U. 2025), we conducted outdoor air sampling at two locations, even though a single location would be considered representative. The locations were divided into five categories: nail salons designated (Na), hairdressing salons (Ha), general beauty salons (Co), indoor background (In), and outdoor background (Out).

The sampling sites were distributed across four cities within the Upper Silesian agglomeration (Bytom, Zabrze, Gliwice, and Ruda Śląska) and were selected to represent a range of urban environments, including residential districts, city centers, and areas with different levels of industrial influence. The locations were situated in densely populated urban settings characterized by mixed residential and service functions, as well as varying traffic intensity and building density.

Sites in Bytom included peripheral residential areas (Na1/Ha1/Co1) and a low-density residential neighborhood used as a background location (Out1). The city center of Bytom (Na2/Ha2) was characterized by dense residential and commercial development and higher traffic exposure. Exposure conditions in these locations have been previously described in the literature (Rogula-Kopiec et al. 2023, Rogula-Kopiec et al. 2025, Rogula-Kopiec et al. 2019). In Zabrze (Ha3), the site was located in a central urban area with mixed residential and service functions and moderate availability of urban green spaces.

In Ruda Śląska, three locations were selected to reflect different urban contexts. The Bykowina district (Ha4/Co2) represented an urban area with industrial influence, while the Kochłowice district (Na4/Out2) represented a residential area with mixed surrounding land use and included one background measurement site. Exposure conditions characteristic of these locations have also been described in earlier studies (Rogula-Kopiec et al. 2023, Rogula-Kopiec et al. 2025, Rogula-Kopiec et al. 2019). The Ruda district (Na3/Co3) was situated along a main traffic corridor within a dense urban fabric.

In Gliwice (Ha5), the site was situated in a residential district (Szobiszowice) characterized by moderate traffic intensity and proximity to urban green areas. Two background measurement sites (Out1 and Out2) were included to represent outdoor urban air conditions in residential settings within the study area. Exposure studies in salon environments have previously been conducted at the Gliwice site (Ha5) and at both background locations (Out1 and Out2) (Rogula-Kopiec et al. 2023, Rogula-Kopiec et al. 2025, Rogula-Kopiec et al. 2019).

All sites were selected to ensure coverage of different urban exposure contexts while maintaining comparability within the same regional agglomeration.

Air Sampling

In the study, all samplers were purchased together with a certified analytical service from Gradko International Ltd. (Winchester, UK). Passive samplers for VOCs, formaldehyde, ammonia, nitrogen dioxide, ozone, and sulfur dioxide were used. Based on the maximum recommended sampling duration for individual samplers, 15 samplers per compound were deployed (12 salons, 1 indoor background, and 2 outdoor background sites over a 28-day sampling period), except for formaldehyde, which has a maximum sampling period of 7 days, for this compound, 60 samplers were used. Laboratory blanks (unexposed tubes) were also analyzed, in the case of formaldehyde, each sampler included an internal blank section. Sampling at all locations was conducted from 25 July to 22 August 2025. The mean sampling duration for the 28-day exposure period was 40,253.5 minutes (690.9 hours, 27.95 days), with minimum and maximum durations of 40,120 and 40,320 minutes, respectively. For formaldehyde (7-day maximum sampling period), the mean exposure time was 10,050 minutes (167.5 hours, 6.98 days) with a minimum of 9,864 minutes and a maximum of 10,083 minutes.

As passive samplers operate continuously, sampling could not be interrupted during night-time or weekends, therefore, all measurements represent time-integrated exposure over the full deployment period. Prior to exposure, all samplers were prepared according to the manufacturer's instructions (Table 2). Sampling locations were selected to ensure adequate air circulation, maintaining a minimum distance of 5 cm from surfaces and other samplers, and avoiding areas of stagnant air or excessive turbulence. Samplers were mounted at breathing-zone height (approximately 1.5 m) at representative locations within each beauty salon, including workstations and client waiting areas. After sampling, all samplers were sealed and stored according to the manufacturer's instructions. Analytical reports from Gradko included the mass of collected compounds in the tube, as well as concentrations expressed in µg/m^3 and ppb, including expanded uncertainties. In this study, the term "total VOC" refers to the sum of VOCs from C2-C28 collected on a polymeric sorbent.

Results

Formaldehyde and other VOCs

The formaldehyde concentrations measured in all beauty salons ranged from 12.16 to 38.59 µg/m^3 (Figure 2) and were well below both the WHO indoor air guideline of 100 µg/m^3 (WHO, 2021) and the 8 h occupational limit of 370 µg/m^3 (Dz.U., 2018). The indoor background site (In) showed a concentration range of 6.48–10.94 µg/m^3, while the outdoor background (Out1–Out2) remained at 2.18–3.86 µg/m^3. Formaldehyde levels in nail salons (Na1–Na4) ranged from 16.35 to 38.59 µg/m^3, and in general beauty salons (Co1–Co3) from 19.04 to 35.97 µg/m^3. These levels are approximately two to four times higher than indoor background levels. Hairdressing salons using cosmetic products (Ha1–Ha5) exhibited intermediate elevations of 12.16–25.51 µg/m^3, which remained significantly above both indoor and outdoor background levels. This finding indicates that cosmetic procedures substantially increase indoor formaldehyde levels relative to a low baseline.

At the same time, total VOC (C2-C28) concentrations exhibited an inverse pattern, with higher concentrations indoors. Mean indoor VOC levels across all tested beauty salons reached 1485.5 µg/m^3, while outdoor concentrations remained at136.6-142.9 µg/m^3 (outdoor background), indicating approximately a tenfold indoor accumulation. The highest total VOC concentrations (Figure 3) were observed at Co1 (3976.2 µg/m^3), Na4 (2995.4 µg/m^3), and

Table 1: Characteristics of ventilation and occupancy of investigated salons.

Site	City	Ventilation	Window types	Volume [m^3]	Number of workers in the salon at the same time	Average daily customers (average)
Co1	Bytom	air conditioning	casement windows	110	1	8
Co2	Ruda Śląska	mechanical ventilation	tilt windows	160	1	8
Co3	Ruda Śląska	mechanical ventilation	inset windows	208	1	10
Ha1	Bytom	mechanical, air conditioning	casement and tilt windows	45	2	6
Ha2	Bytom	air conditioning	tilt windows	135	2	5
Ha3	Zabrze	gravity ventilation	casement windows	195	2	15
Ha4	Ruda Śląska	gravity ventilation	tilt windows	82.8	2	8
Ha5	Gliwice	gravity ventilation + air conditioning	casement windows	306	3	13
In	Gliwice	gravity ventilation + air conditioning	inset windows	112	3	18
Na1	Bytom	gravity, air conditioning	casement windows	92.5	2	3
Na2	Bytom	air conditioning	casement windows	220	4	8
Na3	Ruda Śląska	mechanical ventilation	inset windows	208	2	16
Na4	Ruda Śląska	gravity ventilation	inset windows	84	1	8

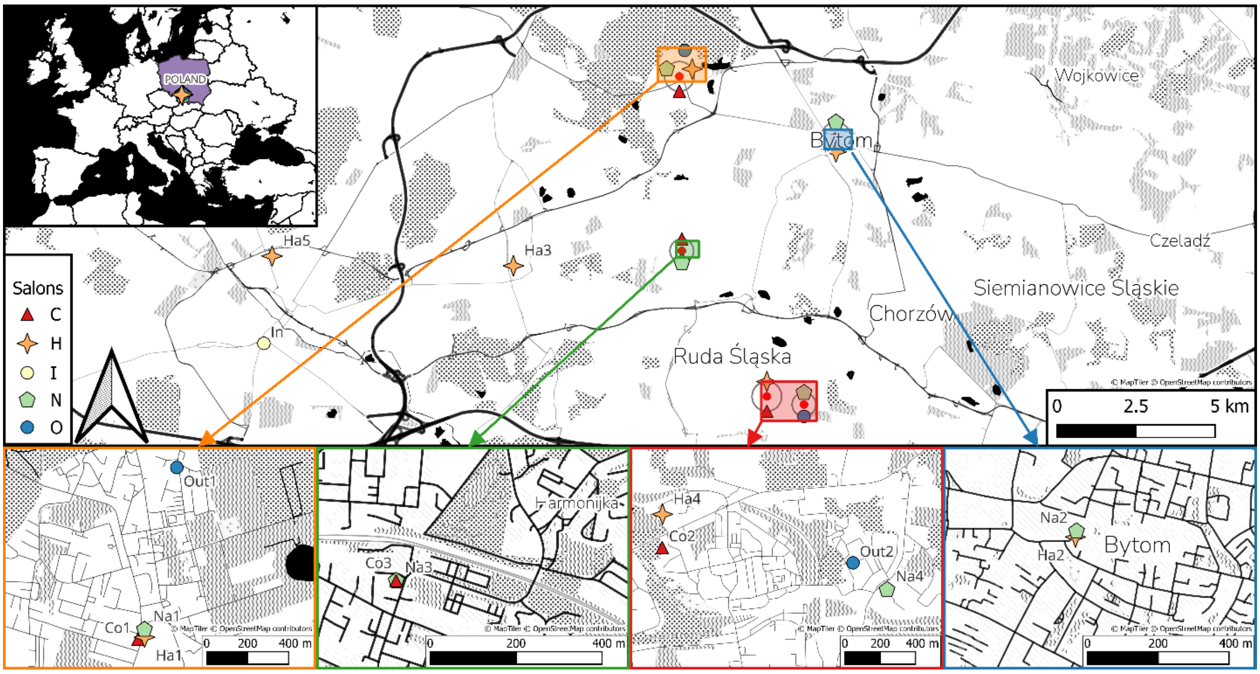

Fig 1. Location of sampling points with an overview map of Poland in upper left corner. The more precise locations of sites of overlapping locations are presented in bottom maps, from left to right: Bytom-Miechowice with general cosmetics salon (Co) Co1, nail care salon(Na) Na1, hairdressing salon (Ha) Ha1, and outdoor background (Out) Out1, Ruda Śląska Co3 and Na3, Ruda Śląska Kochłowice Co2, Na4, Ha4, and Out2, Bytom-Centre Na2 and Ha2. The locations of Ha3, Ha5, and indoor background (In) are presented in main panel of figure.

Ha3 (2123.8 µg/m³). In contrast, the lowest concentrations occurred at Na3 (606.1 µg/m³), Na2 (629.5 µg/m³), and Co3 (752.7 µg/m³). The indoor background concentration was 361.5 µg/m³.

Inorganic air pollutants

A consistent indoor–outdoor difference was observed for several gaseous pollutants across the beauty salons studied. The most pronounced contrast between indoor and outdoor

Table 2: Parameters of the passive samplers used in the study for specific compounds, including sampling method and medium, method of analysis, limit of detection and literature reference.

Compound	Sampling method and medium	Method of analysis	Limit of detection	Reference
VOCs: C2-C28 volatile and semi-volatile organic compounds	TENAX thermal desorption tube with solid polymer absorbent	GC/MS, UKAS accredited Gradko in-house method GLM 13	0.1 ppb	(Gradko Environmental, 2023b)
Formaldehyde	DIF700UMEX-F with tape containing 2,4-dinitrophenylhydrazine	HPLC with UV detection, UKAS accredited Gradko in-house method GLM 18	0.2 ppb	(Gradko Environmental, 2024c)
Ammonia	DIF 400 RTU passive tube with absorbent	Ion chromatography, UKAS accredited Gradko in-house method GLM 8	0.8 µg/m³	(Gradko Environmental, 2023a)
Nitrogen dioxide	DIF100-20WA passive sampling tubes with 20% triethanolamine (TEA) absorbent and deionised water	UV/VIS spectrophotometry, UKAS accredited Gradko in-house method GLM 7	1.5 µg/m³	(Gradko Environmental, 2024a)
Ozone	DIF300RTU-RA passive tube sampler with absorbent and one-micron porosity filter	Ion Chromatography, UKAS accredited Gradko in-house method GLM 2.	<10 µg/m³	(Gradko Environmental, 2023b)
Sulphur dioxide	DIF600RTU-RA passive tube sampler with absorbent and one-micron porosity filter	Ion Chromatography, UKAS accredited Gradko in-house method GLM 1.	<2 µg/m³	(Gradko Environmental, 2024b)

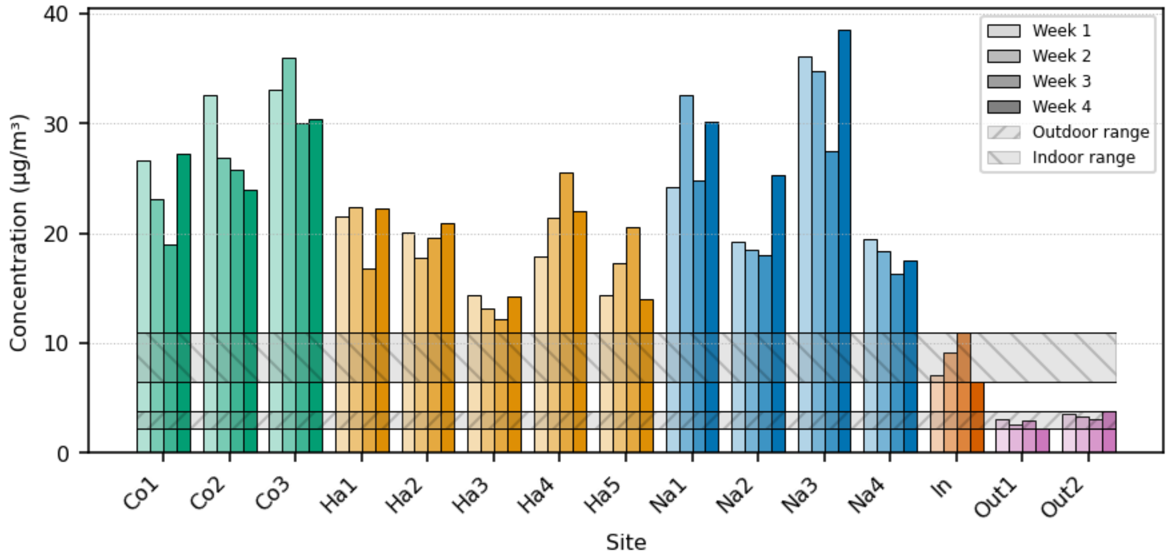

Fig 2. Concentrations of formaldehyde (µg/m³) measured at individual beauty salon sites during four consecutive weekly sampling periods. Bars represent weekly mean values at each location, while shaded bands indicate the ranges of indoor and outdoor background concentrations. Co – denotes general cosmetics salon, Na – nail care salon, Ha – hairdressing, Out – outdoor background (Out), and In – indoor background.

concentrations was observed for ozone (Fig. 6), which exhibited opposite behavior. Outdoor ozone concentrations remained high and stable, with measured values of 55.7 µg/m³ at Out1 and 71.1 µg/m³ at Out2, yielding a mean outdoor level of approximately 63.4 µg/m³. In contrast, indoor concentrations were substantially lower, ranging from below the reporting limit (<4.1 µg/m³) to 7.8 µg/m³, with an indoor background reference of 13.6 µg/m³. This indicates more than an order-of-magnitude decrease in indoor air infiltration.

Concentrations of nitrogen dioxide (Figure 4) ranged from 5.5 (Ha5) to 40.1 µg/m³ (Co1), whereas outdoor levels were 8.09–12.78 µg/m³, indicating contributions from both outdoor infiltration and indoor chemical processes. Although most measured concentrations remained within typical ambient air ranges , peak values reached 40 µg/m³, comparable to the EU annual limit value under Directive 2008/50/EC) and approximately twice the revised EU annual limit of 20 µg/m³ under Directive (EU) 2024/2881, and above the WHO recommended annual guideline of 10 µg/m³. For comparison, the EU 2008 1-hour limit is 200 µg/m³ (max. 18 exceedances/year), the EU 2024 1-hour limit remains 200 µg/m³ (max. 3 exceedances/year), the EU 2024 daily limit is 50 µg/m³, and the WHO 24-hour guideline is 25 µg/m³, indicating the potential for elevated short-term exposure (WHO, 2021, EU, 2008, EU, 2024). Elevated concentrations in beauty and hair salons may be associated with a combination of outdoor traffic-related

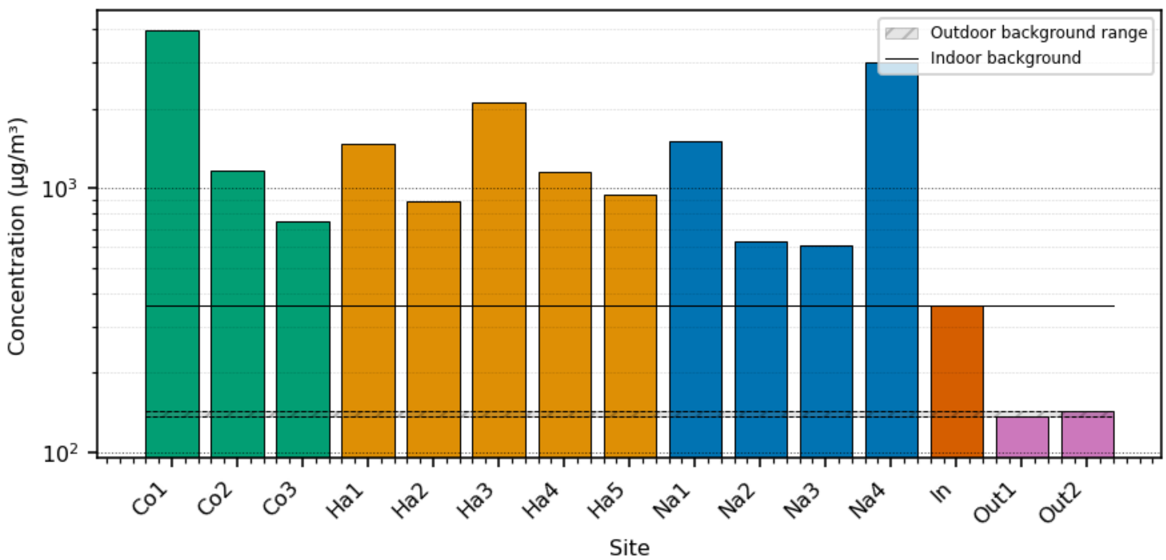

Fig 3. Concentrations of VOCs (µg/m³) measured at individual beauty salon sites during four consecutive weekly sampling periods. Bars represent weekly mean values at each location, while shaded bands indicate the ranges of indoor and outdoor background concentrations. Co – denotes general cosmetics salon, Na – nail care salon, Ha – hairdressing, Out – outdoor background (Out), and In – indoor background.

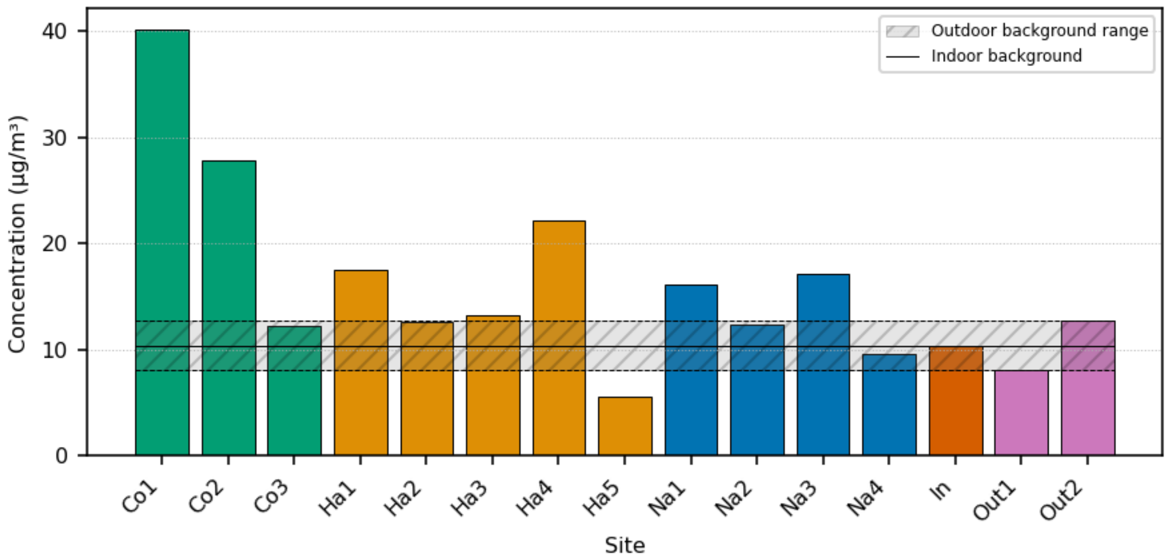

Fig 4. Concentrations of NO2 (µg/m³) measured at individual beauty salon sites during four consecutive weekly sampling periods. Bars represent weekly mean values at each location, while shaded bands indicate the ranges of indoor and outdoor background concentrations. Co – denotes general cosmetics salon, Na – nail care salon, Ha – hairdressing, Out – outdoor background (Out), and In – indoor background.

emissions and limited ventilation during intensive service periods (Ramírez et al. 2023, Rogula-Kopiec et al. 2019).

Ammonia (Figure 5) exhibited substantial variability across beauty salons, ranging from 26.6 µg/m³ (In), 37.5 µg/m³ (Ha4) to 1086 µg/m³ (Ha3), reflecting a strong dependence on specific cosmetic treatments and product use. Very high spatial variability of ammonia was observed, spanning an order of magnitude between beauty salons, with the lowest levels comparable to typical indoor background concentrations (around 35 µg/m³), whereas the highest values exceeded 1 mg/m³, clearly indicating strong indoor sources. Ammonia can irritate the eyes and respiratory tract, leading to symptoms such as coughing and a burning sensation, particularly during short-term peak exposures associated with hair treatments (Kezic et al. 2022, Elihollund et al. 1998). Although the measured concentrations were below occupational limits, according to regulation (Dz.U. 2018 r), the permissible exposure limit is 14 mg/m³ (8-hour average) and the short-term exposure limit is 28 mg/m³, indicating that peak exposures should still be carefully controlled. This variability reflects differences in treatment types, particularly the use of ammonia-containing products such as hair dyes, bleaching agents, and nail care chemicals. The results confirm that ammonia concentrations in such occupational microenvironments are primarily driven by specific cosmetic activities and product-use patterns, rather than by outdoor air infiltration.

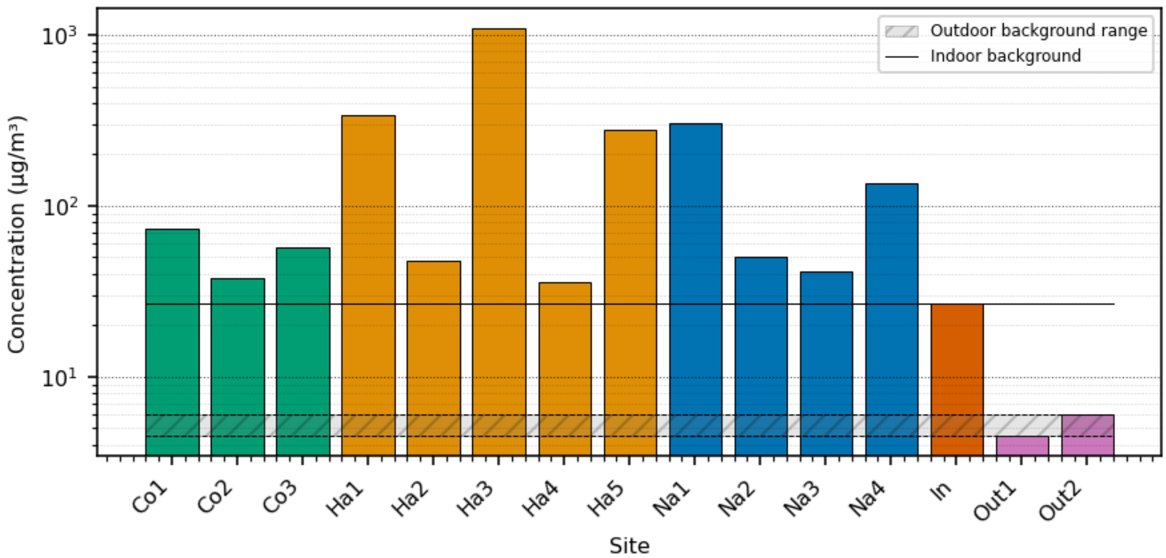

Fig 5. Concentrations of NH3 (µg/m³) measured at individual beauty salon sites during four consecutive weekly sampling periods. Bars represent weekly mean values at each location, while shaded bands indicate the ranges of indoor and outdoor background concentrations. Co – denotes general cosmetics salon, Na – nail care salon, Ha – hairdressing, Out – outdoor background (Out), and In – indoor background.

Sulphur dioxide remained very low, being below the reporting limit in 11 salons, with only one salon reaching 101% of the reporting limit (Na4 1.60 µg/m³), indicating negligible indoor sources. The only reference location above the reporting limit was Out2, where the concentration was 2.35 µg/m³.

Discussion

In Poland, regulations governing workplace air quality impose an obligation on employers to regularly monitor concentrations of chemical substances whenever they may pose a risk to employees' health (Dz.U., 2018). In practice, however, implementing these provisions in beauty salons poses significant challenges. Unlike industrial facilities, where exposure profiles are typically uniform and well characterized, beauty salons exhibit high variability in the chemical products used. The diversity of brands, formulations, and treatment procedures makes it considerably more difficult to identify hazardous agents and conduct standardized, comparable occupational risk assessments for both employees and clients (Goldin et al. 2014, Rogula-Kopiec et al. 2019, Zhong et al. 2019). As a result, variability in products, procedures, and exposure conditions may make it difficult to fully align formal regulatory requirements with real-world exposure assessment practices. This, in turn, can lead to exposure evaluations that are ~~sometimes~~ fragmented or limited in scope, potentially affecting the completeness of occupational health risk characterization in this sector.

Differences in pollutant concentrations were observed between salons, however, the relative contributions of outdoor and indoor sources appear to vary by pollutant. For compounds such as ozone and, to some extent, nitrogen dioxide, outdoor air and infiltration processes may play a noticeable role in shaping indoor concentrations. In contrast, for formaldehyde, total VOCs, and ammonia, the observed patterns suggest a stronger influence of indoor sources, likely related to the type and intensity of cosmetic treatments and the products used. These observations indicate that, while site-specific environmental conditions and urban background levels can contribute to variability in exposure levels for certain pollutants, indoor activities are likely an important factor influencing exposure levels in beauty salons.

One of the most striking findings was the consistent depletion of ozone inside all beauty salons. Despite relatively high outdoor concentrations (55.7-71.1 µg/m³), indoor levels remained uniformly low across all locations. This pattern strongly suggests the presence of efficient indoor removal mechanisms. The simultaneous presence of elevated total VOC concentrations indicates that ozone loss is most likely driven by chemical reactions with reactive organic compounds, especially terpenes commonly emitted from fragranced cosmetic products. Such reactions lead to ozone scavenging and the formation of secondary pollutants, including aldehydes and ultrafine particles.

The most polluted environments were not always associated with locations exposed to strong industrial and traffic emissions. The Ha4 salon in Bytom Miechowice exhibited extremely high total VOC concentrations (3976.16 µg/m³) and the highest NO_2 level (40.13 µg/m³), indicating a strong combined influence of industrial sources and indoor emissions.

In contrast, VOC levels seem to be governed primarily by the type of beauty services provided and secondarily by location. For example, salons in Miechowice (Ba1, Co1, Na1) show relatively high VOC concentrations compared to other sites (ranked 1st, 4th, and 5th), with general cosmetic services contributing most strongly to these levels. A similar pattern is observed for Co2 and Ba4 (ranked 3rd and 6th), where general cosmetic services are also a major contributor to elevated total VOC. Likewise, although Co3 and Na3 exhibit comparable total VOC concentrations (752 and 606 µg/m³,

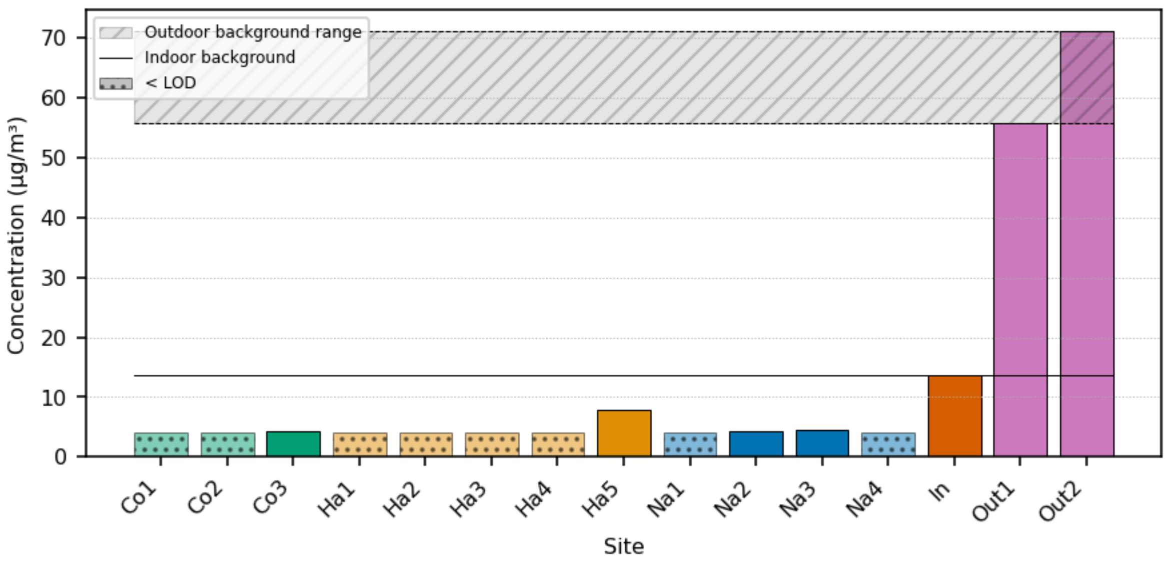

Fig 6. Concentrations of O3 (µg/m³) measured at individual beauty salon sites during four consecutive weekly sampling periods. Bars represent weekly mean values at each location, while shaded bands indicate the ranges of indoor and outdoor background concentrations. Note: Bars representing concentrations below the limit of detection (LOD) are indicated using dotted fill Co – denotes general cosmetics salon, Na – nail care salon, Ha – hairdressing, Out – outdoor background (Out), and In – indoor background.

respectively), the contribution from general cosmetic services in Co3 is higher than that from nail services in Na3.Salons located in close proximity (e.g., Ha1, Na1, and Co1 in Bytom–Miechowice, Co3 and Na3 in Ruda Śląska, and Na2 and Ha2 in Bytom Center, see Figure 1) tend to exhibit similar levels of selected pollutants. With the exception of Co1, indoor NO_2 concentrations appear to be primarily influenced by location, likely due to outdoor infiltration.

The Ha3 site exhibited the highest ammonia concentration among all studied locations (1086 μg/m³). This elevated level may be related to the intensive use of ammonia-containing products commonly applied in hairdressing procedures, such as hair dyes and bleaching agents. Many of these products contain ammonia or release it during application, contributing to elevated indoor concentrations in occupational settings. This elevated level may be related to the use of ammonia-containing products commonly applied in hairdressing procedures, such as.

Lower pollutant levels were observed at selected locations situated in less urbanized surroundings. For example, the Ha5 salon in Gliwice showed moderate total VOC concentrations (948 μg/m³), which were lower than the mean value across all salons (1485.5 μg/m³), and the highest indoor ozone concentration (7.8 μg/m³) among the studied sites. Compared to other salons, where ozone levels were typically below this value, this may indicate differences in indoor–outdoor air exchange or ozone removal processes.

The Ha5 salon in Gliwice, located away from major industrial sources, exhibited moderate VOC levels (948 μg/m³) and the highest indoor ozone concentration (7.8 μg/m³), suggesting better ventilation and weaker ozone scavenging.

The simultaneous ozone depletion and elevated VOC levels indicate that ozone loss is likely driven by reactions with reactive organic species, particularly terpenes emitted from fragranced cosmetic products, leading to ozone scavenging and the potential formation of secondary pollutants such as aldehydes and ultrafine particles.

It is important to note that the highest ammonia concentrations were found in hairdressing salons, i.e., the 1st, 2nd, and 4th highest values. For location Ha5, the samplers were placed directly on a cabinet above the workstation where hair dyes were prepared, which likely explains the relatively strong ammonia influence observed at this site. Na2 exhibited lower VOC concentrations than Na1 and Na4, likely because the samplers were positioned directly next to an air purifier, which may have reduced the measured levels. Na3 and Co3, beauty salons with the highest formaldehyde concentrations, had recently undergone renovation, and the sources of this compound are likely fresh paint or new furniture. The increase in formaldehyde concentration can be attributed to these sources, although the available data do not allow for definitive identification of the specific emission source.

The results clearly demonstrate that beauty salons constitute strong indoor emission environments characterized by elevated concentrations of volatile organic compounds (VOCs). Total indoor VOC concentrations (C2-C28, average from all salons: 1485.54 μg/m³) were approximately ten times higher than outdoor background levels (136.62–142.91 μg/m³), confirming that the intensive use of cosmetic products, solvents, and treatment procedures is the primary source of pollution. These findings align with previous studies demonstrating that salon air is continuously burdened by high emissions of various organic compounds, including aromatic hydrocarbons and chemical solvents, which strongly depend on the frequency and type of cosmetic services (Rogula-Kopiec et al. 2019, 2023, Rybak et al. 2015). Earlier research has shown that BTEX levels in such workplaces, particularly toluene, may reach several tens of μg/m³ due to intensive use of cosmetic products and solvents, confirming the strong influence of indoor emission sources (Rogula-Kopiec et al. 2019, 2023). Similarly, studies on particulate matter composition indicate that organic and elemental carbon, as well as PAHs present in salon air, originate from both outdoor infiltration and indoor activities, including sprays, dyes, and hair treatment procedures (Rogula-Kopiec et al. 2025). Formaldehyde concentrations reported in beauty salons are often associated with emissions from cosmetic products, building materials, and furnishings, particularly following renovations..

In this study, spatial variability was evident in distinct concentration differences between the investigated locations. The highest values were observed in beauty and nail salons (Co, Na), while lower levels were found in hair salons (Ha) and in both indoor and outdoor background samples (In, Out). Elevated concentrations were also observed in recently renovated rooms, which may partially explain the high values recorded in a facility such as Co3, which had undergone renovation shortly before sampling. The observed concentration distribution indicates a significant contribution from indoor sources, including both cosmetic products used during treatments and emissions from finishing materials. Elevated levels of VOCs, BTEX compounds, and formaldehyde in indoor air may be relevant from an occupational exposure perspective, as chronic or repeated exposure to such mixtures has been associated in the literature with eye and respiratory tract irritation, headaches, and other nonspecific symptoms (Quiros-Alcala et al. 2019, Tagesse et al. 2021). These effects are of greater concern for salon workers, who experience prolonged, repeated exposure.

Regarding health effects and occupational risk, it must be emphasized that although overall VOC levels remain below the strict acute occupational exposure limits for individual chemical agents, they still pose a significant concern for long-term occupational health. Chronic, daily exposure of salon personnel to complex mixtures of elevated VOCs—rather than to a single aggregated parameter such as TVOC—has been associated with subjective health complaints, including eye, nose, and throat irritation, headaches, and fatigue, commonly linked to sick building syndrome. Since health effects depend on the composition of the mixture and the presence of specific compounds, the interpretation of exposure should focus on individual VOCs and their combined effects. Accordingly, TVOC was not used as a basis for health risk interpretation in this study, as it represents a heterogeneous mixture and does not reflect the toxicity of individual components.

Approaches to assessing health risks associated with VOC mixtures emphasize cumulative exposure and interactions between components rather than reliance on bulk indicators (Su et al. 2014). Therefore, although the immediate toxicological risk based on individual compounds appears limited, persistent exposure to multi-component chemical mixtures underscores the need for highly efficient ventilation systems to mitigate chronic respiratory and dermal discomfort among workers.

The high variability observed between beauty salons suggests differences in service types, product usage patterns, and ventilation efficiency. The extremely low indoor ozone levels observed in this study represent a key finding. Indoor concentrations were more than an order of magnitude lower than outdoor concentrations, indicating highly efficient removal processes. This phenomenon is most likely explained by reactions between ozone and unsaturated VOCs, particularly terpenes emitted from fragranced products. Such reactions are well documented and lead to the formation of secondary pollutants, including formaldehyde, organic acids, and ultrafine particles (Hernandez et al. 2020, Rogula-Kopiec et al. 2019). Importantly, ozone removal does not imply reduced health risk. Instead, it may increase exposure to more harmful secondary pollutants, which can cause oxidative stress and respiratory irritation (Ricklund et al. 2023).

Spatial stratification analysis indicates that local environmental characteristics significantly affect indoor air quality. Beauty salons located near heavy industry and dense traffic corridors (Co1, Ha4) exhibited the highest pollution burdens (VOCs, NO_2), confirming the role of outdoor sources in shaping indoor exposure levels. In contrast, proximity to green spaces and forest areas was associated with lower pollutant concentrations, likely due to enhanced dilution and reduced background pollution levels. This finding aligns with previous studies demonstrating that urban morphology, industrial proximity, and traffic intensity significantly influence indoor air quality in occupational environments (Badyda, 2013, Rybak et al. 2015).

The pollutant levels measured in this study are comparable to those reported in previous investigations of beauty salons. For example, formaldehyde concentrations reported by Choi et al. (2023) in Korean beauty salons ranged from slightly above the detection limit up to approximately 100 µg/m³. Similarly, formaldehyde air levels found in 22 randomly selected beauty salons in northeastern Iran (Gonabad City) ranged from 1.02 to 41.4 µg/m³ (Ojrati et al. 2025). In comparison, formaldehyde levels measured in the present study ranged from 16.71 to 18.84 µg/m³ indoors and from 27 to 32 µg/m³ outdoors. These findings indicate that indoor formaldehyde concentrations were within the range reported in previous studies and were not elevated relative to outdoor levels, suggesting that cosmetics and beauty treatments are unlikely to be the dominant source of formaldehyde in the investigated salons.

Similarly, indoor ozone levels reported in residential environments usually range between 10 and 30 µg/m³ (Logue et al. 2012), while the values observed in this study were consistently below 4.13 (LOD) µg/m³, indicating exceptionally efficient ozone scavenging processes in beauty salon environments. Ammonia concentrations observed in this study also exceeded those reported for typical residential indoor environments, where levels rarely exceed 100 µg/m³ (Logue et al. 2012), highlighting the impact of hair treatment procedures. However, annual average outdoor concentrations in high traffic areas may also exceed 100 µg/m³ (Miao et al. 2024). Overall, the results suggest that beauty salons represent a unique indoor microenvironment characterized not only by elevated primary emissions but also by intensive secondary chemical transformations.

Although most pollutant concentrations remained below regulatory occupational limits, the findings raise concerns regarding chronic exposure to complex pollutant mixtures and secondary reaction products. As passive sampling provides time-averaged concentrations, short-term activity-related peaks may not be fully captured. Future time-resolved studies could better characterize exposure variability and its relationship to salon activities, ventilation, and secondary pollutant formation.

Conclusions

This study demonstrated that beauty salons constitute complex indoor microenvironments characterized by elevated concentrations of volatile organic compounds and strong activity-dependent emissions of gaseous pollutants. Indoor VOC concentrations were approximately 10 times higher than outdoor levels, confirming that cosmetic products, solvents, and treatment procedures are the dominant sources of pollution. Considerable spatial variability was observed among beauty salons, as indicated by differences in measured pollutant concentrations across sites, which may be related to variations in service types, product usage patterns, ventilation conditions, and proximity to external emission sources such as traffic and industrial activities. Ammonia concentrations showed the highest variability and were strongly associated with the use of ammonia-based hair treatment products, indicating that specific cosmetic activities play a key role in shaping indoor exposure patterns. Nitrogen dioxide exhibited moderate indoor enrichment, suggesting contributions from both outdoor infiltration and indoor chemical processes involving VOCs. In contrast, sulfur dioxide remained at very low background levels, confirming negligible indoor sources in beauty salon environments.

A key finding was the consistently low indoor ozone concentrations, which were more than an order of magnitude lower than outdoor levels. This indicates efficient indoor removal processes, most likely driven by chemical reactions between ozone and reactive VOCs emitted from fragranced products. Such reactions may lead to the formation of secondary pollutants, including aldehydes and ultrafine particles, which can pose additional health risks despite the apparent reduction in ozone concentrations.

The results highlight the potential for chronic exposure to complex mixtures of primary and secondary pollutants among beauty salon workers. These findings emphasize the need for improved ventilation strategies, regular indoor air quality monitoring, and increased awareness of chemical exposure risks in the beauty industry.

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Piękno pod lupą: analiza porównawcza lotnych i nieorganicznych zanieczyszczeń powietrza w salonach kosmetycznych w porównaniu z powietrzem na zewnątrz

Streszczenie. Celem niniejszego badania była ocena jakości powietrza wewnętrznego w dwunastu salonach kosmetycznych zlokalizowanych na terenie Aglomeracji Górnośląskiej (w Polsce) oraz określenie wpływu rodzaju świadczonych usług i otaczającego środowiska miejskiego na stężenia zanieczyszczeń gazowych. Przeprowadzono czterotygodniową kampanię pomiarową z wykorzystaniem próbników pasywnych umieszczonych w strefie oddychania pracowników. Oznaczano stężenia lotnych związków organicznych (LZO), formaldehydu (HCHO), amoniaku (NH_3), dwutlenku azotu (NO_2), ozonu (O_3) oraz dwutlenku siarki (SO_2). Stężenia wewnętrzne porównano z poziomem tła zewnętrznego w celu określenia udziału źródeł emisji wewnątrz pomieszczeń. Uzyskane wyniki wykazały wyraźną dominację źródeł emisji wewnętrznych. Średnie stężenie LZO w powietrzu wewnętrznym (1485,5 $\mu g/m^3$) było około dziesięciokrotnie wyższe niż na zewnątrz, co potwierdza istotny wpływ stosowanych kosmetyków i wykonywanych zabiegów. Największą zmienność przestrzenną odnotowano dla amoniaku (26,6–1086 $\mu g/m^3$), co było ściśle związane z zabiegami fryzjerskimi. Dwutlenek azotu wykazywał umiarkowane wzbogacenie wewnętrzne, natomiast stężenia dwutlenku siarki utrzymywały się na poziomie tła miejskiego. Stężenia ozonu wewnątrz pomieszczeń były ponad rząd wielkości niższe niż na zewnątrz, co wskazuje na jego skuteczne usuwanie w reakcjach z LZO oraz możliwość powstawania zanieczyszczeń wtórnych. Chociaż większość zmierzonych stężeń nie przekraczała dopuszczalnych norm narażenia zawodowego, długotrwała ekspozycja na złożone mieszaniny zanieczyszczeń pierwotnych i wtórnych może stanowić zagrożenie dla zdrowia. Wyniki podkreślają potrzebę wprowadzenia systematycznego monitoringu jakości powietrza oraz poprawy strategii wentylacyjnych w salonach kosmetycznych.