

Article

Under the Salon Lights: Assessment of Occupational Exposure to PAHs and Potential Health Risk—First Results

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Abstract

This study characterised the profiles of 16 polycyclic aromatic hydrocarbons (PAHs) in the indoor air of hairdressing, beauty, and nail salons and assessed the associated incremental cancer risk (ILCR). A distinctly divergent exposure pattern, particular to the nature of the service, was exhibited: light PAHs, notably naphthalene, prevailed in nail salons, while in hairdressing salons, the profile was thermally conditioned, with a preponderance of polycyclic compounds such as fluoranthene, pyrene, and benzo(g,h,i)perylene. The most severe, carcinogenic profile (including benzo(a)anthracene and dibenzo(a,h)anthracene) and the highest individual ILCR value (3.3×10^{-6}) were observed in a beauty salon, though nail salons also exhibited elevated risk levels (1.9×10^{-6}). In all premises, however, ILCR remained below the 10^{-5} threshold. The findings are consistent with earlier reports indicating that beauty salons are complex microenvironments with multiple concurrent emission sources, with significant contributions from cosmetic products and thermal processes in determining pollutant concentrations. The findings underscore the necessity for preventive measures customised to the nature of the salon, such as product substitution and enhanced general and local ventilation. Moreover, they highlight the imperative for further research to be conducted into personal exposure over extended time frames.

Keywords: polycyclic aromatic hydrocarbons; PM_{2.5}; beauty salons; occupational exposure; cancer risk; indoor/outdoor air quality

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1. Introduction

In recent years, the cosmetic services sector has undergone significant, rapid expansion worldwide, with Poland serving as an example of this trend. This growth is reflected not only in the increasing number of salons but also in the rising demand for a wide range of aesthetic and personal care treatments. Modern cosmetic salons offer diverse services, including hairdressing, skincare procedures, and nail care, and have become a critical, continually expanding component of the service economy. Multiple

socio-economic and cultural factors, including lifestyle changes, increased awareness of personal appearance and health, and widespread access to advanced cosmetic technologies and products, fuel the sector's development. As a result, cosmetic services are no longer a luxury but have become an integral part of daily life, leading to sustained increases in both consumer demand and employment in the sector.

Despite their economic and social relevance, the occupational hazards and indoor air quality of cosmetic salons remain poorly understood. Salon personnel are daily exposed to a complex mixture of chemical pollutants generated during routine procedures. These pollutants include volatile organic compounds (VOCs), fine and ultrafine particulate matter (PM_{2.5} and PM₁), polycyclic aromatic hydrocarbons (PAHs), and various other chemical substances released from cosmetic products, solvents, disinfectants, and operational processes such as spraying, sanding, polishing, or chemical hair treatments. Exposure occurs near emission sources and often persists for prolonged periods, increasing the likelihood of cumulative and long-term health effects. The variability in salon layouts, ventilation systems, service types offered, and workflow practices further complicates the accurate assessment of occupational risk.

Fine particulate matter (PM_{2.5}) and ultrafine particles (UFP, <100 nm) originate from both outdoor infiltration sources and indoor emissions. The generation of fine particulate matter (PM_{2.5}) is primarily associated with combustion processes, thermal processing, operation of electric heating devices, evaporation of liquid droplets, resuspension of settled dust, and the use of consumer products that emit aerosols or volatile organic compounds (VOCs) [1]. Fine particles can be emitted directly as primary particles or formed secondarily by gas-to-particle conversion processes involving VOCs, whereas ultrafine particles are commonly generated during thermal processes and the condensation of hot vapours [2,3]. In indoor environments, secondary organic aerosols often form from the reaction of ozone and VOCs, producing low-volatility compounds that nucleate or condense on existing particles. Ultrafine particles can then grow through coagulation and condensation processes, contributing to the fine particle fraction [2,3]. In beauty workplaces, these mechanisms can be amplified by activities specific to beauty treatments. Hair salons often use heat-generating devices such as hair dryers, straighteners, and curling irons, which can contribute to the formation of ultrafine particles via thermal emission and vapour condensation [1,2]. In beauty salons, the application and curing of gel products, as well as the use of solvents and aerosol-based products, can directly release particulate matter and promote secondary aerosol formation by emitting volatile organic compounds (VOCs) [2,3]. Beauty salons commonly use sprays, perfumes, and other cosmetic products that generate airborne droplets and fine particles, while cleaning activities, operating electrical appliances, and the resuspension of settled dust from staff and customer traffic can further contribute to indoor PM_{2.5} and UFP levels [1]. Therefore, both direct emissions and secondary pathways play an important role in determining particulate matter concentrations in beauty, cosmetic, and hair salons [1–3].

Particular concern has been raised regarding fine particulate matter (PM_{2.5}), which can penetrate deeply into the respiratory tract and systemic circulation. In cosmetic salons, PM_{2.5} frequently carries adsorbed PAHs, which are highly toxic and possess carcinogenic, mutagenic, and teratogenic properties. Importantly, PAHs in indoor environments exist not only in particle-bound form but also as gaseous compounds, especially lower-molecular-weight PAHs such as naphthalene, fluorene, and phenanthrene. Gaseous PAHs diffuse more readily through indoor air, contributing to overall inhalation exposure and potentially reaching different regions of the respiratory system than particle-bound PAHs. This dual exposure pathway—through PM_{2.5}-bound and gaseous PAHs—

underscores the complexity of the occupational environment in cosmetic salons and the need for comprehensive assessment.

Exposure to PAHs occurs primarily via inhalation, although dermal absorption and, to a lesser extent, ingestion can also contribute. Particle-bound PAHs can deposit deep in the alveoli, while gaseous PAHs can be absorbed along the upper and lower airways and subsequently enter the bloodstream. Dermal contact, though typically associated with industrial settings involving tar, asphalt, or petroleum products, may also occur in salons when using certain cosmetic products containing hydrocarbon-based ingredients or impurities. The co-occurrence of multiple PAHs in different physical states, coupled with prolonged exposure, creates a complex occupational exposure scenario that is currently under-investigated.

The health impacts of PAH exposure are multifaceted. Epidemiological studies link chronic exposure to increased risks of lung, skin, and bladder cancers. Beyond carcinogenic effects, PAHs are associated with adverse impacts on the respiratory, cardiovascular, immune, and reproductive systems. Prenatal exposure poses additional risks, including low birth weight, preterm birth, congenital anomalies, and neurodevelopmental impairments. While most existing studies focus on industrial exposure, emerging evidence suggests that service sectors, including cosmetic salons, can also contribute to meaningful PAH exposure. Sources in salons include the thermal degradation of hair dyes, chemical nail treatments, heated waxes, aerosol sprays, and certain cosmetic formulations, all of which can emit both particulate and gaseous PAHs. Indoor concentrations may fluctuate during daily work routines, depending on the number of simultaneous procedures, room volume, and ventilation efficiency.

Protective strategies are essential to minimise occupational exposure. Technological improvements, such as substituting high-emission products with low-emission alternatives, modernising procedures, and limiting high-temperature operations, can reduce pollutant generation. Effective ventilation, whether natural or mechanical, is crucial for controlling both particulate and gaseous pollutants. Personal protective equipment (PPE), including masks, gloves, and protective clothing, adds another layer of protection, particularly during procedures involving high emission potential. Complementing environmental monitoring with biomonitoring enables a more accurate assessment of total internal dose, accounting for exposure through all routes, including inhalation of particles and gases and dermal contact. Biomarkers such as urinary 1-hydroxypyrene serve as reliable indicators of integrated PAH exposure and facilitate assessment of cumulative risk in occupational settings.

The significance of PAH exposure in cosmetic salons lies not only in the presence of particle-bound PM_{2.5} but also in the contribution of gaseous PAHs. Low-molecular-weight PAHs, due to their volatility, can penetrate indoor spaces even in well-ventilated environments and interact with workers over extended periods. Combined exposure to particle-bound and gaseous PAHs may exacerbate oxidative stress, DNA damage, and systemic inflammatory responses, thereby amplifying long-term health risks. Additionally, intermittent window openings, the use of shared corridors, and infiltration of outdoor air from traffic and industrial sources can further modulate indoor concentrations, creating dynamic exposure patterns that are challenging to quantify.

In conclusion, the rapid expansion of cosmetic services and the variety of procedures performed in salons have created a unique occupational environment where workers are exposed to complex mixtures of chemical pollutants, including PM_{2.5}-bound PAHs and volatile gaseous PAHs. Despite the potential health implications, indoor air quality and occupational exposure in this sector remain poorly characterised. Therefore, this study aimed to quantify concentrations of particle-bound and gaseous PAHs in cosmetic salons

and to identify key factors influencing indoor air quality and occupational exposure levels.

The novelty of this approach lies in the comprehensive and comparative nature of the research project. Previous studies often focus on general indoor air quality parameters or are limited to a single workplace type. However, this study allows for the simultaneous quantification of gaseous and particle-phase concentrations of 16 priority PAHs in three types of beauty service environments, namely hairdressing salons, beauty salons, and cosmetology salons. This approach allows for a more precise differentiation of service-specific emission sources, such as high-temperature thermal processes and solvent evaporation, and helps fill a significant gap in research on occupational exposure in highly urbanised areas.

2. Materials and Methods

2.1. Characteristics of Sampling Sites and Measurement Points

The study was conducted in the Upper Silesian Agglomeration (southern Poland), a highly urbanised and industrialised region characterised by elevated particulate matter (PM) concentrations associated with industrial activity, residential heating, and traffic emissions [4,5]. A total of eight sampling sites were selected, including six indoor environments serving as a preliminary case study of beauty service facilities and two outdoor background locations. The indoor sites comprised two hairdressing salons (Ha and Hb), two beauty studios (Ca and Cb), and two nail salons (Na and Nb). Rather than providing a statistically representative sample for the entire regional industry, these specific venues were selected to conduct an exploratory assessment of distinct service profiles and their varying working conditions. The outdoor sites (B1 and B2) were used to characterise ambient air quality in the vicinity of the investigated facilities. The locations of all measurement points are presented in Figure 1.

Three groups of sampling sites were distinguished. The first group, comprising Hb, Ca, and B2, was located in the Miechowiec district in the western part of Bytom. The sites were situated approximately 200 m apart in an area characterised by low-rise residential and commercial buildings, most of which were connected to a district heating network. The surroundings included allotment gardens (250–500 m), the Miechowiec Forest complex within approximately 500 m, and transport infrastructure, including national road No. 94, located about 200 m from the sites. Additional emission sources included a combined heat and power plant located approximately 1.7 km to the south and industrial facilities, including mining and coking operations, situated about 2.5 km to the southeast. Site B2 served as the local outdoor background reference. Indoor measurements were conducted in two salons located on the ground floor of residential buildings. Each facility consisted of two rooms, each approximately 20 m², connected by a corridor. Salon Hb operated as a hairdressing studio, whereas Salon Ca provided cosmetic treatments. Each room contained two active workstations, and PM_{2.5} samplers were placed within 2 m of the workstations.

The second group consisted of sites Cb and Nb, located in the city centre of Bytom within a residential building adapted for commercial use. The area was characterised by dense urban development, high traffic intensity, and proximity to major transport hubs, including the city market square (approximately 100 m away) and railway and bus stations located within 500 m. Drogowa Trasa Średnicowa, one of the main transport routes in the region, was situated approximately 1.2 km from the sites, while post-industrial areas were located about 1 km to the south. Despite the high degree of urbanisation, urban green spaces were present within a radius of approximately 500 m. The facility consisted of five separate rooms, each approximately 18 m², designated for specific services. Salon Cb offered a broad range of cosmetic treatments, including

advanced skincare procedures, whereas Salon Nb specialised in nail care services such as manicures, pedicures, and nail extensions. Two workstations were active in each room, and PM_{2.5} samplers were positioned within 2 m of the emission sources.

The third group included sites Ha, Na, and B1, located in the Bykowina district of Ruda Śląska. The measurement points were situated 200–600 m apart in an area characterised by mixed residential and service development, interspersed with green spaces, allotment gardens, a tram line, and local roads. The surroundings also included a post-mining waste heap located approximately 350 m from the sites and former mining areas associated with the Polska-Wirek coal mine situated about 1.5 km away. Site B1 served as the outdoor background location for this area. Indoor measurements were conducted in ground-floor service premises. The salons generally consisted of rooms of approximately 15 m², except for Salon Ha, which contained a larger room of approximately 55 m² with five workstations. Salon Ha provided hairdressing services, whereas Salon Na specialised in nail care. PM_{2.5} samplers were positioned within 2 m of active workstations.

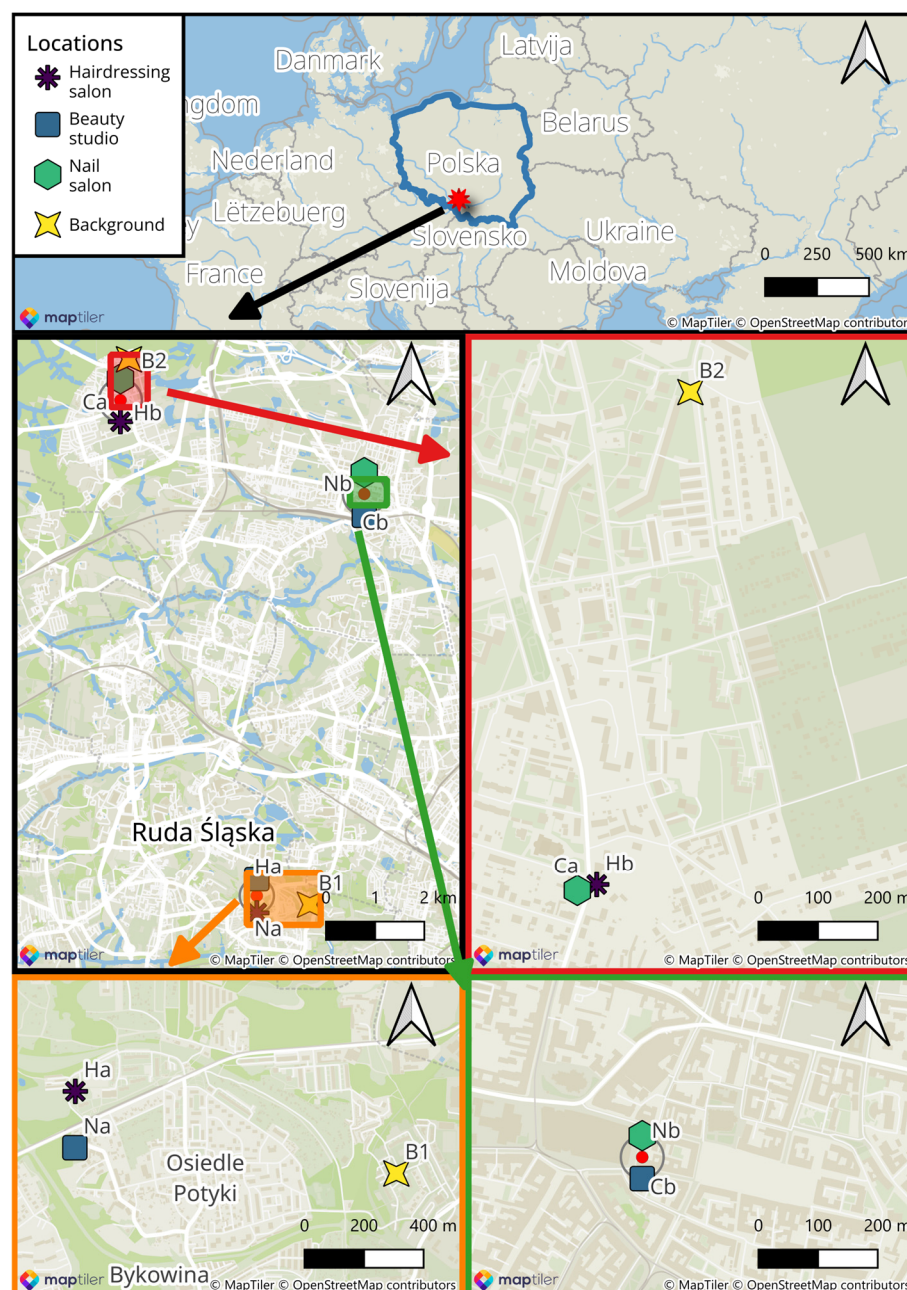


Figure 1. Location of sampling points with a preview map of Europe.

2.2. Ventilation and Operational Conditions

All indoor environments relied on natural ventilation. Windows remained closed during working hours and were opened only after the end of daily operations. Air exchange during operation occurred primarily through door openings between rooms and adjacent corridors.

Sampling was initiated after routine cleaning procedures to minimise the influence of resuspended particles. Measurements were conducted under typical working conditions, including continuous customer presence and active use of cosmetic products, ensuring representative exposure conditions.

2.3. PM_{2.5} Sampling

PM_{2.5} was collected on 37 mm quartz fibre filters (Whatman QMA, Cytiva, Marlborough, MA, USA) using Gilian 12 pumps (Sensidyne, St. Petersburg, FL, USA) with BGI Cyclone GK2.05 ($d_{50} = 2.5 \mu\text{m}$ at 4 L min^{-1} , Mesa Labs, Inc., Lakewood, CO, USA). Pumps ran at 4.0 L min^{-1} for 8 h (typically 10:00–18:00) on every working day of two 14-day campaigns (11–25 September 2023 and 12–26 March 2024), totalling 20 samples per site. All filter conditioning, weighing, and quality-control procedures were performed by the ISO/IEC 17025-accredited laboratory according to its standard protocols (equilibration at controlled T/RH, microbalance readability, field-blank correction, flow calibration before/after with primary standard, LOD/LOQ from field blanks) [6].

2.4. Gas-Phase PAH Sampling

Gas-phase PAHs were trapped on pre-cleaned XAD-2 sorbent tubes (SKC 226-30-04, SKC Ltd., Eighty Four, PA, USA) using Gilian 12 pumps (Sensidyne, St. Petersburg, FL, USA) at 1.7 L min^{-1} for the same 8 h periods and locations. Tubes were sealed, transported refrigerated, and stored at $-18 \text{ }^{\circ}\text{C}$.

2.5. PAH Extraction and Analysis

Sixteen US EPA priority PAHs were determined in both the XAD-2 tubes and the quartz filters: naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, dibenz[a,h]anthracene, and benzo[g,h,i]perylene.

2.5.1. Extraction of Gas-Phase PAHs

The XAD-2 resin was extracted with 15 mL of acetonitrile (J.T.Baker™; Avantor, Radnor, PA, USA) in an ultrasonic bath for 30 min. The extract was concentrated to 1 mL under a nitrogen stream (MultiVap, LabTech, Sorisole, Italy) and filtered through a $45 \mu\text{m}$ PTFE filter (Whatman™; Cytiva, Marlborough, MA, USA).

2.5.2. Extraction of Particulate-Bound PAHs

The QMA filters were extracted with 15 mL of dichloromethane (J.T.Baker™) in two stages. First, the filter was sonicated for 30 min as above. After removing the solvent, the residue was redissolved in 15 mL of fresh DCM and sonicated again.

The extracts were concentrated to 1 mL under nitrogen and filtered ($45 \mu\text{m}$ PTFE). All solvents were HPLC- or analytical-grade.

2.5.3. HPLC-UV/Vis Analysis

The obtained extracts were analysed using a Thermo Scientific TRACE 1300 (Rodano, Italy) gas chromatograph coupled with an ISQ 7000 mass spectrometer (Thermo Fisher Scientific Inc., Waltham, MA, USA), fitted with a Thermo Scientific™ TraceGOLD™ TG-5MS capillary column (30 m × 0.25 mm i.d. × 0.25 µm film thickness) (Thermo Fisher Scientific Inc., Waltham, MA, USA). The analytical workflow incorporated strict quality assurance procedures, including the use of blank samples and internal standards to maintain accuracy and precision. Method validation was based on the determination of detection and quantification limits, as well as estimation of measurement uncertainty. Each sample was run in duplicate. QA/QC encompassed field blanks, laboratory blanks, internal standards, and estimation of measurement uncertainty conducted according to the procedure described in [7].

2.6. Cancerogenic Risk Calculation

Exposure estimates were calculated using the methodology provided by Health Canada [8]. While occupational exposure to PAHs can theoretically occur through multiple pathways, including inhalation, dermal contact, and incidental ingestion, the quantitative risk assessment in the present study was restricted exclusively to the inhalation route. This focus was dictated by the study design, which relied solely on active indoor air sampling. Assessment of dermal and ingestion exposure would require additional data from settled dust or contaminated surfaces, which were not collected as part of the present investigation. The estimated average daily intake from inhalation, time-adjusted over a lifetime ($EDI_{inh}TL$), expressed in µg/(kg·day), is directly proportional to the air concentration (CA , µg/m³). It was calculated according to the formula presented below. The parameter values used in this study are provided in Table 1.

$$EDI_{inh}TL = \frac{CA \cdot IR_A \cdot RAF_{inh} \cdot D_1 \cdot D_2 \cdot D_3 \cdot D_4}{BW}$$

Table 1. Parameters for cancerogenic risk calculation and their values.

Symbol	Description	Value
IR_A	receptor intake rate by inhalation (m ³ /day)	16.6
RAF_{inh}	relative absorption factor of a chemical for inhalation as compared with absorption within the toxicity study used to derive the slope factor (unitless)	1.0
D_1	fraction of hours per day spent at site (unitless)	8/24
D_2	fraction of days per day spent at site (unitless)	5/7
D_3	fraction of weeks per day spent at site (unitless)	47/52
D_4	fraction of years per lifetime spent at site (unitless)	47/65
BW	body weight of receptor (kg)	70.7

Receptor intake (IR_A) and body weight (BW) were used according to [9]. The exposure time fractions (D) were defined as follows: D_1 equal to 8 h per day, D_2 equal to 5 days per week, D_3 equal to 47 working weeks per year (assuming 5 weeks of holidays), and D_4 equal to 47 working years (from 18 to 65 years of age).

The incremental lifetime cancer risk (ILCR) was calculated as the sum of the products of inhalation intake and the corresponding slope factors for each PAH. The slope factor values for the 16 analysed PAHs are provided in Table 2.

Table 2. Slope factors for 16 PAHs.

PAH	Inhalation Slope Factor $\times 10^{-3} (\mu\text{g/kg-d})^{-1}$
Acenaphthene	NA
Acenaphthylene	NA
Anthracene	NA
Benzo(a)anthracene	0.0137
Benzo(a)pyrene	0.137
Benzo(b)fluoranthene	0.0137
Benzo(ghi)perylene	0.0013
Benzo(k)fluoranthene	0.0137
Chrysene	0.00137
Dibenzo(a,h)anthracene	0.0137
Fluoranthene	0.000137
Fluorene	NA
Indeno(1,2,3-cd)pyrene	0.0137
Naphthalene	NA
Phenanthrene	0.000137
Pyrene	NA

NA—not available.

3. Results and Discussion

Figure 2 illustrates the average concentrations of selected polycyclic aromatic hydrocarbons (PAHs) measured in the indoor air of nail styling salons, beauty salons, and hairdressing salons. The data demonstrate substantial variability in PAH profiles across salon types, consistent with earlier findings on occupational exposure in service-sector environments [10,11]. The particulate-bound fraction of individual PAHs across the investigated salon samples is presented in Table 3.

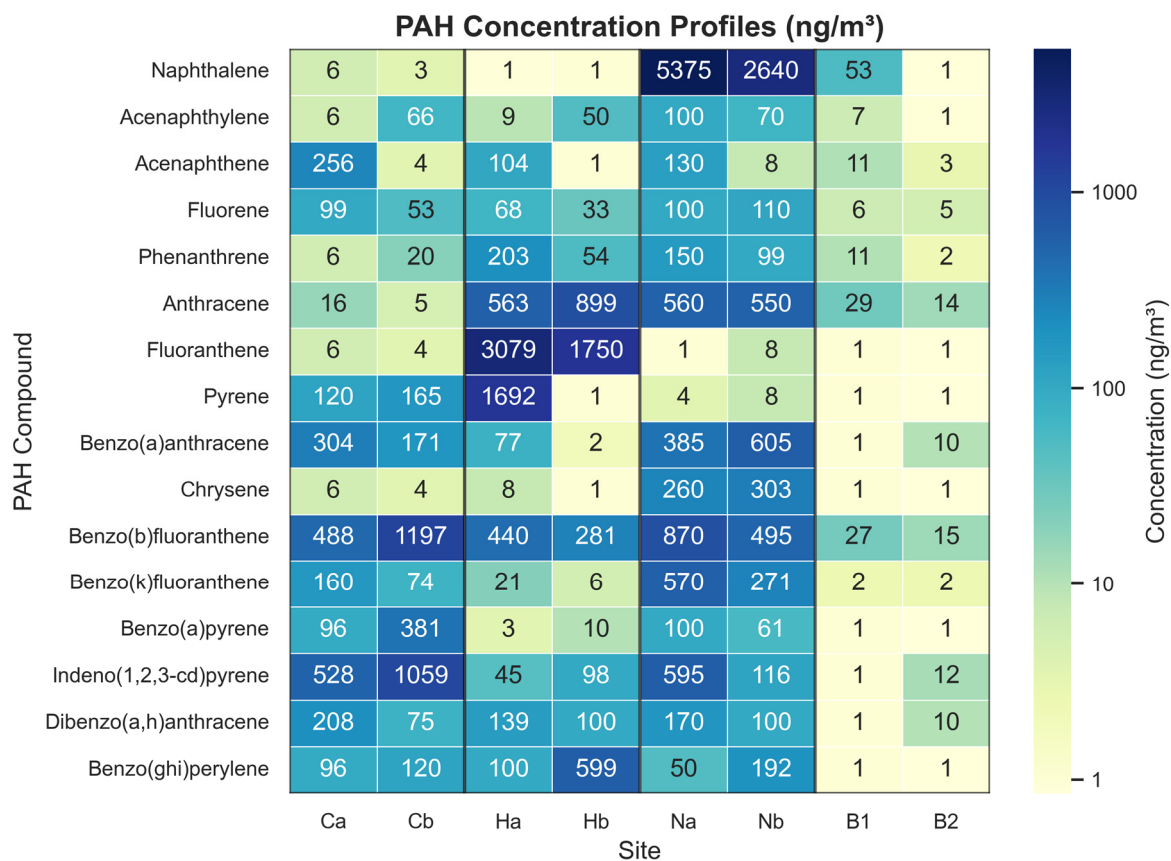


Figure 2. Heatmap of concentrations of 16 PAHs at six sites. Hairdressing salons (Ha and Hb), beauty studios (Ca and Cb), and nail salons (Na and Nb), together with background site concentrations (B1 and B2). The detailed values are provided in the article.

Table 3. Particulate-bound fractions of individual PAHs across the investigated salon samples.

PAH	Average (%)	Median (%)	Standard Deviation (%)
Naphthalene	47.2	43.2	22.2
Acenaphthylene	56.0	47.7	30.9
Acenaphthene	61.2	58.8	23.4
Fluorene	56.6	50.5	28.6
Phenanthrene	54.4	48.9	27.1
Anthracene	51.8	46.6	29.5
Fluoranthene	70.8	69.9	14.3
Pyrene	69.5	67.2	15.0
Benzo[a]anthracene	79.9	79.9	10.7
Chrysene	74.1	73.1	13.0
Benzo[b]fluoranthene	74.2	73.4	12.0
Benzo[k]fluoranthene	75.2	75.8	10.7
Benzo[a]pyrene	78.5	78.5	9.6
Dibenzo[a,h]anthracene	86.4	86.1	13.0
Indeno[1,2,3 cd]pyrene	86.0	85.9	16.4
Benzo[g,h,i]perylene	95.1	94.9	5.2

The levels of naphthalene in cosmetic and hairdressing salons were lower than those measured in ambient air (background, grey region in Figure 2). The only sites with concentrations above ambient levels were nail salons (approximately 10 times the highest background concentration). Although raw naphthalene is banned as an ingredient in cosmetics, it may originate from dyes or gel nail polishes [12]. However, as on-site product sampling and direct chemical testing were not conducted in this study, attributing the elevated naphthalene levels strictly to these specific cosmetics remains a hypothesis. Further research involving direct product analysis would be required to definitively confirm this emission source.

Acenaphthylene reached its highest concentrations in nail salons. In both hairdressing and nail salons, the recorded values were partially or completely above the atmospheric background range, indicating the presence of additional indoor emission sources. Acenaphthylene may originate from incomplete combustion, the evaporation of volatile organic compounds from cosmetic formulations, and the thermal degradation of synthetic ingredients during styling procedures [13]. In beauty salons, median concentrations remained closer to background levels; however, maximum values exceeded the environmental range, suggesting occasional episodes of elevated concentrations.

In the case of acenaphthene, the highest concentrations were also observed in nail salons. In each group of salons, some results fell within the atmospheric background range, although considerable differences between individual facilities were observed, indicating varying impacts from indoor emission sources. Potential sources of acenaphthene include combustion-related emissions, infiltration of outdoor polluted air, and volatilisation of organic compounds from cosmetic products [14,15].

Fluorene showed the highest concentrations in hair salons, where the greatest variability in results was also observed. The concentration range in these salons partially overlapped with atmospheric background levels, suggesting a lower influence of indoor sources compared to the other salon types. Nevertheless, in all salon categories, the

median and most measured values remained above background levels, indicating characteristically elevated concentrations of this compound. Fluorene may be associated with aerosols generated during hair treatments, heating devices, and volatilisation from dyes, sprays, and styling agents [16].

For phenanthrene, concentrations in beauty salons were almost entirely within the environmental background range; however, higher values exceeded background levels, indicating periodic increases. In hair and nail salons, most results exceeded atmospheric background levels, suggesting the presence of indoor emission sources of phenanthrene. Only the lowest values recorded in hair salons overlapped with the upper end of the environmental background range. Phenanthrene is commonly associated with emissions from combustion-related indoor activities and evaporation of organic compounds present in cosmetic products [17].

Anthracene exhibited the greatest variability in hair salons, where the highest concentrations were also recorded. Only in beauty salons did concentrations remain below the maximum atmospheric background values, suggesting a lower influence of indoor sources in this type of facility. Anthracene may be associated with thermal processing, heated styling tools, and indoor accumulation of airborne PAHs that may be released during cosmetic procedures [17].

Fluoranthene concentrations in hair salons were clearly above the environmental background range, indicating a significant influence of indoor emission sources. In beauty and nail salons, this influence appeared lower, as most measured values remained closer to background levels. Fluoranthene is frequently linked to incomplete combustion and pyrogenic processes and may be associated with emissions from heated cosmetic equipment and volatilisation of organic residues, as fluoranthene may be formed during high-temperature thermal degradation and combustion-related aerosol generation [18].

Pyrene reached its highest concentrations in hair salons, where values exceeded atmospheric background levels by approximately 1000 times. This group of salons also showed the greatest variability in results. In one facility, concentrations significantly exceeded background levels, whereas in another, values remained within the background range. The exceptionally high concentration observed at one hair salon may be related to increased use of aerosol cosmetics, intensive use of heat-generating hair-care appliances (e.g., hair dryers, straighteners, and curling irons), or insufficient ventilation during the sampling period. However, as detailed information on salon activities was not recorded, these explanations remain hypothetical. In beauty salons, all obtained results were above background levels, suggesting a strong dependence on indoor emissions. In nail salons, some values still overlapped with the atmospheric background range, suggesting a lower impact from indoor sources than in beauty salons. Pyrene is commonly considered a marker of combustion-derived pollution and may originate from thermal cosmetic treatments, aerosol formation, and volatilisation of aromatic compounds from cosmetic products [17].

Benzo(a)anthracene showed the highest median concentrations in nail salons. In hair and beauty salons, most results remained closer to background environmental levels, suggesting a weaker influence from indoor emission sources. Potential indoor sources of benzo(a)anthracene may include heating devices, solvent-containing products, and degradation of aromatic organic substances used during nail styling procedures [16].

For chrysene, the highest concentrations were recorded in nail salons, where values exceeded the atmospheric background range. In hair and beauty salons, the concentration ranges partially overlapped with the environmental background, indicating a lower impact of indoor emissions. Chrysene is frequently associated with pyrogenic emissions and may be generated during thermal decomposition of organic cosmetic ingredients and aerosol-producing activities [18].

For benzo(b)fluoranthene, concentrations in all salon types exceeded the maximum environmental background levels, indicating the presence of strong indoor emission sources. Elevated concentrations of benzo(b)fluoranthene may be associated with combustion aerosols and the accumulation of semi-volatile organic compounds in enclosed spaces and may be consistent with the hypothesis that frequent use of chemicals such as nail polishes, hardeners, adhesives, and removers may contribute to increased occupational burden of airborne PAHs in these spaces [19].

Benzo(k)fluoranthene reached its highest concentrations in nail salons, where values exceeded the atmospheric background range. A similar pattern was observed in beauty salons. In hair salons, only part of the results exceeded background levels, while the lower values still overlapped with the environmental range, suggesting that not all facilities were characterised by elevated concentrations. This compound may be associated with heating processes, volatilisation of aromatic ingredients, and indoor accumulation of particulate-bound PAHs that may be generated during cosmetic procedures [20].

Benzo(a)pyrene was one of the most important and most toxic polycyclic aromatic hydrocarbons (PAHs), commonly regarded as an indicator of total PAH air pollution [21]. The highest concentrations of benzo(a)pyrene were observed in beauty salons, where both median and maximum values were higher than or comparable to the highest values measured in nail salons. In most analysed samples, concentrations exceeded atmospheric background levels, clearly indicating the presence of additional indoor emission sources. Only in one hair salon did the lowest recorded values overlap with the upper end of the environmental background range. The considerable variability in the results suggests substantial differences in benzo[a]pyrene concentrations between individual salons. These differences may result from ventilation conditions, the type of cosmetic products used, the intensity of the treatments, and the frequency of use of heat-emitting devices. Potential sources of benzo(a)pyrene may include products containing aromatic substances, thermal processes that may occur during cosmetic and styling treatments, and secondary emissions that may arise from aerosols and volatile organic compounds in cosmetic products [21]. Due to its high toxicity and well-documented mutagenic and carcinogenic properties, benzo(a)pyrene is considered a particularly important indicator of indoor air quality [22]. Elevated concentrations may indicate increased exposure of both employees and customers to harmful chemical compounds and may contribute to long-term respiratory and carcinogenic risks associated with occupational PAH exposure [23].

Indeno(1,2,3-cd)pyrene reached its highest concentrations in beauty salons, where the entire concentration range remained above atmospheric background levels. In hair and nail salons, only the upper portions of the concentration ranges exceeded environmental background values, indicating elevated concentrations in only some facilities. The greatest variability in results was observed in nail salons. This compound is commonly associated with pyrogenic emissions and fine particulate matter that may be generated during high-temperature processes and aerosol formation [18].

Dibenzo(a,h)anthracene showed the highest concentrations in beauty salons, where values were approximately 2–3 times higher than atmospheric background levels. This group of salons also exhibited the greatest variability in results. At the same time, the lowest concentrations recorded in all salon types overlapped with the maximum environmental background values. Dibenzo(a,h)anthracene is considered a highly carcinogenic PAH and may be associated with combustion-related emissions, heated cosmetic equipment, and accumulation of contaminated indoor particulate matter [17].

Benzo(g,h,i)perylene reached its highest concentrations in hair salons, whereas the greatest variability in results was observed in beauty salons. All measured concentrations exceeded atmospheric background levels, ranging from approximately 100 to 1000 times the environmental background, indicating a very strong influence of indoor emission

sources. Benzo(g,h,i)perylene is commonly associated with combustion aerosols and fine particulate emissions that may be generated during thermal and pyrogenic indoor processes [18].

At the same time, the present findings primarily demonstrate differences in PAH concentration patterns between salon types rather than providing direct evidence for specific emission sources. Consequently, the proposed sources discussed above should be interpreted as plausible explanations supported by prior literature, rather than as confirmed mechanisms.

Overall, the patterns observed in Figure 2 confirm that the type of salon, the nature of the products used, and specific work practices substantially influence the profile and levels of occupational PAH exposure, as has been emphasised in previous occupational hygiene and indoor air quality studies [11,24,25]. These results highlight the need for targeted risk assessment and implementation of preventive strategies tailored to the unique characteristics of each salon environment.

The results confirm that cosmetic salons constitute complex microenvironments with multiple concurrent sources of PAHs, where both emission intensity and the physicochemical properties of the compounds govern their distribution. The observed variability between sites reflects not only differences in service profiles but also underlying emission mechanisms and partitioning behaviour between gas and particulate phases [26].

Table 3 presents the particulate-bound fraction of individual PAHs measured in the investigated salon air samples. The data exhibit a clear volatility-driven gradient consistent with classical gas–particle partitioning theory [27]. The lighter 2–3 ring PAHs (naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene) show only moderate binding to particles (47–61%), as their relatively high subcooled liquid vapour pressures maintain a substantial gaseous fraction even at indoor temperatures. With increasing molecular weight and the corresponding exponential drop in vapour pressure, the PM-bound share rises sharply: 4-ring PAHs (fluoranthene, pyrene, benzo[a]anthracene, and chrysene) reach 70–80%, while the 5–6 ring compounds (benzofluoranthenes, benzo[a]pyrene, dibenzo[a,h]anthracene, indeno[1,2,3-cd]pyrene, and benzo[g,h,i]perylene) are almost entirely particle-bound, exceeding 95% in the case of benzo[g,h,i]perylene. This pattern indicates that, despite the elevated air temperatures generated by styling tools (150–230 °C), the saturation vapour pressures of the heavier PAHs remain sufficiently low that, once formed through thermal degradation of non-volatile organic precursors, they condense readily onto the available particulate matter. The partitioning thus faithfully reflects the compounds' intrinsic volatilities, with the particle phase acting as the dominant reservoir for the high-molecular-weight, potentially carcinogenic species.

Table 4 presents the increased lifetime cancer risk (ILCR) estimates for individual monitoring sites, ranked from lowest to highest, alongside their percentage relative to the commonly applied negligible risk benchmark of 10^{-5} . All calculated ILCR values fall well below this threshold, with the lowest (B1, 2.2×10^{-8}) reaching merely 0.22% and the highest (Cb, 3.3×10^{-6}) still only 32.7% of the acceptable level. Even in the most exposed scenario, the estimated incremental risk remains an order of magnitude below the point at which regulatory concern would be triggered. This consistent sub-threshold profile indicates that, despite the documented presence of carcinogenic PAHs in salon air, the chronic inhalation exposure incurred by workers and clients does not translate into a meaningful elevation of lifetime cancer probability based on standard models. The modest inter-site variation likely reflects differences in room volume, ventilation efficiency, the intensity and duration of thermal procedures, and the corresponding airborne PAH concentrations, yet none of these factors push the risk outside the negligible range. However, this baseline

assessment must be interpreted with caution, as stationary sampling and standardised exposure parameters may not fully capture peak personal exposure profiles or the long-term dynamic variations unique to individual workers.

Table 4. Increased lifetime cancer risk (ILCR) for each site, sorted from lowest to highest.

Site	ILCR	Percentage of the Negligible Level (10^{-5}) (%)
B1	2.2×10^{-8}	0.22
B2	3.0×10^{-8}	0.30
Ca	1.4×10^{-6}	14
Cb	3.3×10^{-6}	32.7
Ha	4.1×10^{-7}	4
Hb	3.4×10^{-7}	3.4
Na	1.9×10^{-6}	19
Nb	1.1×10^{-6}	11.5

Elevated indoor PAH concentrations, especially in hairdressing and nail salons (Ha and Na), are consistent with previous studies suggesting that beauty-related activities may contribute to indoor air pollution. The use of chemical products such as hairsprays, dyes, solvents, and nail care products has been associated with emissions of volatile and semi-volatile organic compounds, including PAHs and their precursors [28,29]. Thermal processes, such as the use of hair dryers or straighteners, may further enhance emissions through volatilisation and secondary formation mechanisms. The particularly high concentrations of naphthalene and other low-molecular-weight PAHs in nail salon Na suggest intensive use of solvent-based products, such as nail polishes, removers, and adhesives. These compounds are known for their high volatility and ability to accumulate in indoor environments with insufficient ventilation [30].

In contrast, the PAH profile observed in hairdressing salon Ha, dominated by higher-molecular-weight compounds such as fluoranthene, pyrene, and benzo(a)pyrene, suggests the contribution of high-temperature processes. Beauty salons are known to exhibit elevated concentrations of VOCs, including aromatic hydrocarbons (e.g., BTEX), as well as particulate-bound PAHs associated with cosmetic use and treatment activities [31,32]. High-temperature conditions may promote the pyrolytic transformation of organic compounds. This may contribute to the observed dominance of higher-molecular-weight PAHs. The observed variability between salons of similar type (e.g., Na vs. Nb, Ca vs. Cb) highlights the influence of additional factors, such as product composition, treatment frequency, room volume, and ventilation efficiency. Indoor air quality in service environments has been shown to vary widely across these parameters, even within the same workplace category [29]. The relatively low concentrations observed in Cb and Nb may reflect more effective air exchange, reduced use of high-emission products, or differences in operational practices.

Ventilation conditions may substantially influence indoor PAH concentrations by affecting the dilution and removal of pollutants emitted from cosmetic products and treatment-related activities. Previous studies conducted in beauty salons have shown that indoor pollutant levels strongly depend on cosmetic practices and air exchange conditions, with insufficient ventilation favouring the accumulation of contaminants released during treatments [33]. Since many PAHs may be associated with particle-bound emissions and with volatile organic compounds generated indoors [1], differences in ventilation efficiency among salons could partially account for the variability in PAH concentrations observed in this study.

4. Limitations

Several limitations of this study should be acknowledged. First, the sample size was restricted to six establishments (two per salon type), which limits statistical power and the generalizability of the findings; the study is therefore exploratory in nature. Active air sampling was conducted using stationary samplers over short-duration intervals, so personal breathing-zone concentrations and temporal or seasonal variability were not captured. The estimated incremental lifetime cancer risk (ILCR) values were derived from standard exposure assumptions and average parameter values that may not fully reflect individual working conditions—including work practices, number of clients, product composition, ventilation efficiency, and use of personal protective equipment—and should thus be regarded as approximations rather than precise individual predictions. Furthermore, ventilation rates were not directly measured, preventing a quantitative assessment of their influence on PAH concentrations. Finally, direct experimental evidence linking high-temperature styling tools to the formation of heavier PAHs remains sparse, introducing some uncertainty in source attribution for the observed high-molecular-weight profiles.

5. Conclusions

This study revealed that airborne PAH exposure in nail, cosmetic, and hairdressing salons follows distinct, service-specific chemical profiles with markedly different toxicological implications. The central finding is that total PAH concentration alone is a misleading metric of occupational hazard; toxicity-weighted risk assessment, which accounts for the varying carcinogenic potency of individual compounds, better captures the real threat to workers.

Nail salons carried the highest burden of light PAHs such as naphthalene, linked to chronic respiratory and neurological effects. Cosmetic salons, despite lower total PAH levels, exhibited a heavier, more carcinogenic profile, dominated by dibenzo(a,h)anthracene and benzo(a)anthracene, resulting in the highest incremental lifetime cancer risk estimate in the study ($ILCR = 3.3 \times 10^{-6}$). Hairdressing salons showed a thermally derived signature, with fluoranthene, pyrene, and notably benzo(a)pyrene arising from high-temperature styling processes; their ILCRs were the lowest ($<5 \times 10^{-7}$), but the presence of a potent combustion marker remains a long-term concern. Across all settings, ILCR values fell below the conventional 10^{-5} threshold, indicating a low probability of chronic health effects under standard exposure scenarios. Nevertheless, these baseline risk estimates should be interpreted with caution. These values represent an approximation of risk rather than an absolute guarantee of safety due to the inherent uncertainties of this study, such as the limited sample size, the reliance on stationary rather than personal breathing-zone measurements, and the use of generic exposure assumptions. Therefore, while the sub-threshold metrics are encouraging, they underscore the importance of maintaining proper indoor air hygiene and proactive occupational exposure management in these uniquely complex microenvironments.

The results directly inform sector-specific prevention. In cosmetic salons, where heavy PAHs dominate, priority actions are substituting products that contain high-molecular-weight PAH precursors and increasing general ventilation. For nail salons, reducing light-PAH exposure requires limiting aerosolised products and improving air exchange rates. Hairdressing salons would benefit most from local exhaust ventilation positioned at heat-styling workstations to capture thermally generated emissions. Across all salon types, shortening continuous exposure time and adopting safer chemical formulations remain foundational measures.

Three research priorities emerge from this work. First, longitudinal personal monitoring is needed to capture cumulative, real-world doses. Second, toxicological assessment of the actual PAH mixtures found in salon air would clarify synergistic effects that concentration data alone cannot. Third, the impact of reformulated “green” cosmetic products on indoor emission profiles must be systematically evaluated. Strengthening this evidence base is the essential step toward occupational standards that genuinely protect the beauty industry’s workforce—workers who, without such efforts, will continue to breathe a chemically complex, incompletely regulated hazard every working day.

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