Title

Indoor Air Quality of Nail Salons in the Greater Los Angeles Area: Assessment of Chemical and Particulate Matter Exposures and Ventilation

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Indoor Air Quality of Nail Salons in the Greater Los Angeles Area: Assessment of Chemical and Particulate Matter Exposures and Ventilation

A thesis submitted in partial satisfaction

of the requirements for the degree of Master of Science

in Environmental Health Sciences

by

Charlene Minh Chau Nguyen

2016

ABSTRACT OF THE THESIS

Indoor Air Quality of Nail Salons in the Greater Los Angeles Area: Assessment of Chemical and Particulate Matter Exposures and Ventilation

by

Charlene Minh Chau Nguyen

Master of Science in Environmental Health Sciences

University of California, Los Angeles, 2016

Professor Yifang Zhu, Chair

Nail salon workers face potentially high occupational risks from chemical and particulate matter exposures. Indoor and outdoor VOC (volatile organic compound), PM2.5 (particles with aerodynamic diameter <2.5 μm), and UFP (ultrafine particles, particles with aerodynamic diameter <100 nm) concentrations were measured for 4 hours simultaneously for 7 nail salons in the greater Los Angeles area. VOC concentrations were measured in an additional salon. Air exchange rates (AERs) were calculated and translated to per-person ventilation rates to assess the ventilation of the salons with respect to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) ventilation standard for acceptable indoor air quality in nail salons. VOC levels were measured below occupational exposure limits in all salons, but isopropyl alcohol and toluene concentrations exceeded environmental exposure limits in 4 and 1 salon(s), respectively. Individual and total VOC concentrations measured in this study were 4 to 6 times higher than concentrations measured in other nail salon indoor air quality studies. Formaldehyde was not detected during most salon visits. PM2.5 emissions from nail grinding and hand filing can increase exposures above EPA PM2.5 standards. Nail activities were not a

source of UFP emissions. The average AER across the salons was 2.65 ± 2.16 h^{-1}. Pearson correlation and univariate statistical analyses were performed to assess occupancy, number and type of nail services, and ventilation as predictors of pollutant exposures. Occupancy, related to the number of nail services, strongly and significantly predicted VOC exposure levels. Acrylic nail, regular manicure, and pedicure services, but not gel nail services, showed significant positive correlations with total VOC concentrations. Ventilation was a weak predictor of VOC and particulate exposure levels. Furthermore, the ASHRAE ventilation standard does not ensure acceptable indoor air quality in nail salons with respect to VOC and PM exposure limits. This study demonstrates that nail salon workers in the greater Los Angeles area are exposed to high levels of VOCs, and a holistic approach to ventilation standards is needed to protect workers from harmful pollutant exposures.

The thesis of Charlene Minh Chau Nguyen is approved.

Dr. Shane Que Hee

Dr. Niklas Krause

Dr. Yifang Zhu, Committee Chair

University of California, Los Angeles

2016

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1. INTRODUCTION

Recently, the nail salon industry has drawn notable public attention for its working conditions and for the health and safety concerns faced by nail salon workers. Although various statements from those in the industry declare that the concerns are exaggerated, the increase in attention is not unjustified. In 2015, there was reported to be close to 130,000 nail salons in the U.S., and more than 15,000 located in California (Nails Magazine, 2016). In the same year, there were estimated over 400,000 nail technicians, with the majority of technicians licensed in California (Nails Magazine, 2016). The nail salon workforce is largely female with a significant percentage being Vietnamese immigrants, putting this particular group at higher occupational risk (Federman et al., 2006). The nail salon business continues to thrive, and has been identified by the National Occupational Research Agenda of NIOSH (National Institute of Occupational Safety and Health) as a service industry subsector in need of research and intervention to reduce occupational illness and injury (NORA, 2015).

Products used in the nail salons include solvents, glues, polishes, hardeners, and other supplies that may release volatile organic compounds in the indoor environment. These products may contain formaldehyde, toluene, dibutyl phthalate, methyl ethyl ketone, ethyl acetate, acetate, methyl methacrylate, methacrylic acid, and/or acetonitrile (Roelofs & Do, 2012; Su et al., 2004; Kwapkniewski et al., 2008). The wide range of chemicals is known or suspected to cause adverse health effects like skin and eye irritation, respiratory damage, and musculoskeletal, neurologic, and reproductive effects (ATSDR, 2000; Aydin et al., 2002; Hiipakka & Samimi, 1987; Roelofs & Do, 2012; U.S. EPA, 2007; Aalto-Korte et al., 2010). In addition to chemical agents, dusts and particulate matter are also emitted during nail salon activities such as nail grinding and application of acrylic powders (Goldin et al., 2014; Hiipakka & Samimi, 1987; Maxfield & Howe, 1997). Health effects of inhalable dusts and particulate matter include respiratory and cardiovascular diseases (WHO, 2013).

Nail workers have expressed concern for their health, and numerous studies have documented their work-related health problems (Quach et al., 2008). In one study, half of patients who developed occupationally related allergic contact dermatitis were beauticians specializing in nail sculpturing (Lazarov, 2007). Nasal symptoms and respiratory irritation including occupational asthma due to methacrylate exposures have been observed in nail workers as well (Harris-Roberts et al., 2011; Sauni et al., 2008). Researchers found that decreased lung function and increased airway inflammation were associated with the number of years a nail technician was employed and the number of hours exposed to acrylic gel (Reutman et al., 2009). Neurocognitive effects were observed in nail technicians after exposure to low levels of toluene, acetone, formaldehyde, and methacrylates, which have known neurotoxic properties. On neurocognitive assessments and tests of attention, processing speed, executive functioning, and memory, nail technicians performed more poorly than did demographically-similar controls who did not have any toxic chemical exposure and were matched with the study subjects using the Neuropsychological Impairment Scale (LoSasso et al., 2002; LoSasso et al., 2001).

Reproductive effects and cancer are the more controversial adverse health effects suspected to be caused by exposure to the chemical agents used in nail salons. Associations between spontaneous abortions and the numbers of hours worked per day, the number of chemical services performed with the use of formaldehyde-containing disinfectants, and nail sculpturing were found in a survey of salon workers in North Carolina (John et al., 1994). Only one study has looked at cancer incidence among salon workers. Authors of a retrospective cohort study linked California cosmetology licensee and cancer surveillance files to identify incident cases of invasive cancers among female workers during 1988-2005. No cancer excess was found among manicurists except for moderately elevated proportional incidence ratios for thyroid cancer among all licensees and for lung cancer among manicurists (Quach et al., 2010). The authors stated that these findings may be artificially influenced by limitations in demographic information available from the licensee files. Still, studies about nail technicians continue to show the adverse health impacts due to occupational exposures. Even at VOC exposure levels below threshold limit values, nail technicians presented increased levels of oxidative stress biomarkers, including increased activity of glutathione peroxidase I (GPx1), plasma ceruloplasmin, and GPx1/superoxide dismutase 1 ratio (Gresner et al., 2015). Significant correlations between the oxidative stress biomarkers, DNA damage, and VOC levels were found.

A few studies have measured volatile organic compounds, notably formaldehyde, toluene, and methyl methacrylate, in the indoor nail salon environment at levels above recommended occupational and environmental guidelines (Alaves et al., 2013; Quach et al., 2011). Levels of PM2.5 were measured in a number of Boston, MA nail salons and linked to indoor emission sources (Goldin et al., 2014). Number and type of nail care services, salon size, and ventilation characteristics have been suggested as predictors of exposure for VOCs and PM2.5 (Goldin et al 2014; Quach et al., 2011; Tsigonia et al., 2010). However, exposure to ultrafine particles (UFP) has not been studied in nail salons. Secondary organic aerosol formation in indoor environments can occur from photochemical reactions of volatile organic compounds released from the use of consumer products with reactive gases like ozone and NO_x (Nazaroff & Weschler, 2004; Adeniran et al., 2014; Raupp & Junio, 1993). Ozone-initiated indoor chemical reactions can generate substantial amounts of UFP and cause much higher exposure to UFP to occupants in indoor environments (Weschler et al., 1999). The indoor environment of nail salons can contain high levels of reactive VOCs as well as ultraviolet (UV) light penetrating through window glass and being generated by different lamps (Quill et al., 2004). It may be possible that UV light can initiate chemical reactions among reactive compounds and generate UFP, which can induce oxidative stress and mitochondrial damage in nail salon workers (Li et al., 2002).

The objectives of this study are (1) to conduct a cross-sectional indoor air quality assessment of nail salons in the greater Los Angeles area measuring VOCs, formaldehyde, PM2.5, and UFP concentrations as well as the air exchange rate, and (2) to investigate the relationships between these four pollutants and the type and number of nail services, number of occupants, and ventilation in the nail salon. This study may help inform community members on the occupational exposures and factors that increase occupational risk among nail salon workers. This study can also help advise policymakers to make future improvements in workplace standards of the nail salon industry and reduce the negative health outcomes afflicting the particular demographic dominating this industry in the greater Los Angeles area.

2. EXPERIMENTAL METHODS

2.1 Recruitment of Nail Salons

Eight nail salons from the greater Los Angeles area were recruited for this study through convenience sampling. Since access into the workplace is quite difficult for this occupation, in which the vast majority of workers in Southern California are of Vietnamese-descent, are of immigrant status, speak limited amount of English, and are fearful of state or government inspection, convenience sampling was the most effective option for recruitment. **Figure 1** shows the salon locations on a map. The study objectives and methods were communicated to salon owners/managers during recruitment, and written agreement to participate in the study was obtained for each salon. This study was reviewed and considered exempt by UCLA IRB. All study procedures were conducted to the comfort and authorization of the salon owner/manager.

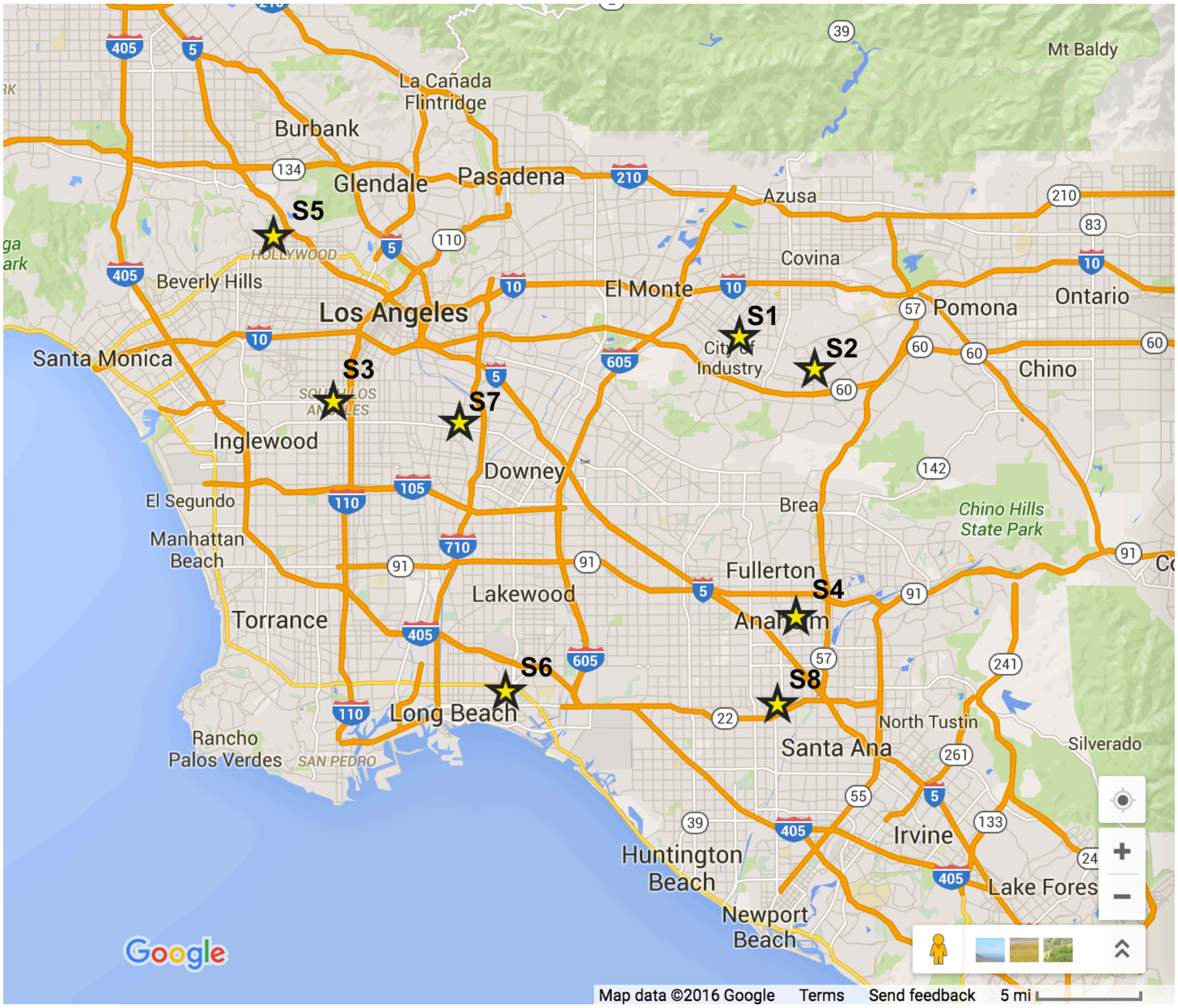

Figure 1. Map of salons that participated in study. Yellow star and salon ID mark location of salon.

2.2 Sampling Schedule

Eleven sampling sessions were conducted from January – July 2016. Each sampling session was 4 hours long. Sampling sessions for salons S1 – S4, S6, and S7 were done on a busy business day (Friday or Saturday) except for salons S5 and S8, which were done on a Wednesday. Salons S1 – S3, S5, S6, and S8 were sampled beginning at the time the salon opened (~9:30 am – 10:30 am). Salons S4 and S7 were sampled in the middle of business hours (~1:30 pm – 2:30 pm). These two salons requested that sampling occur in the afternoon.

2.3 VOCs, PM2.5, and UFP

VOCs, PM2.5, and UFP were sampled concurrently in salons S1 – S7. Salon S8 was only sampled for VOCs, and salons S3 and S4 were sampled for VOCs in two and three separate sampling sessions, respectively. Inside a salon, one 6-liter Summa canister (Entech Instruments Inc.) was used to collect an air sample for VOC analysis. Since all salons allowed only one canister to be placed inside, intra-run variation could not be obtained. Canisters were placed in the general area where services were being conducted. One 6-liter canister was used to collect an outdoor air sample to serve as a comparison. After a sampling session, the canister was delivered to an AIHA (American Industrial Hygiene Association)-accredited laboratory for VOC analysis using EPA Method TO-15 (EPA, 1999). The EPA Method TO-15 includes quantification of 75 target compounds and tentatively identified compounds (TIC) from a library search. Formaldehyde, PM2.5, and UFP were measured using real-time instruments. The real-time instruments were also placed in the general area where services were being conducted. Formaldehyde was monitored at 30-minute intervals using the Formaldehyde Multimode Meter (FM-801, Graywolf Sensing Solutions, Shelton, CT). PM2.5 was monitored at 1-minute intervals using DustTrak (DustTrak II Aerosol Monitor 8532, TSI Inc., St. Paul, MN). UFP was monitored at 1-second intervals using Condensation Particle Counter (CPC 3007, TSI Inc., St. Paul, MN). Another set of DustTrak (DustTrak Aerosol Monitor 8520, TSI Inc., St. Paul, MN) and CPC was placed outside of the salon to measure outdoor PM2.5 and UFP in order to compare indoor and outdoor PM concentrations. It should be noted that DustTrak Aerosol Monitor 8520 has been shown to overestimate PM2.5 readings by 2 to 3 times, after calibration with gravimetric PM2.5 sampling (Chung et al., 2001; Wallace et al., 2011). Thus, actual outdoor PM2.5 concentrations, and subsequent indoor-to-outdoor comparisons, may be 2 to 3 times lower than the readings given by the instrument. Background concentration of formaldehyde was assumed to be 3 – 5 ppb, which is the average concentration in outdoor air in California and is below the detection limit (10 ppb) of the formaldehyde meter (SCAQMD, 2015).

2.4 Nail Services and Occupancy Data

Type of nail service, number of nail service, and occupancy were recorded every 30 minutes from the start to the end of the sampling session. Types of nail services were identified as: 1) regular manicure (nail polish only); 2) gel manicure (gel nail polish cured with a UV or LED lamp); 3) acrylic nails (polymer powder and liquid monomer mixture applied to nails); and 4) pedicure. Occupancy included customers, employees, and people waiting inside. Correlations between the indoor air pollutant concentrations, type and number of nail services, and occupancy were investigated. To confirm whether or not the nail activities produced PM2.5 and UFP emission peaks, one set of DustTrak and CPC instruments was placed at the nail station and another set was placed at the location of the first sampling session for 3 salons. For 4 hours, nail activities were observed and recorded at the nail station and at the other location. The activity data was then compared with the emission data.

2.5 Air Exchange Rate

Air exchange rate (AER) was measured in salons S1 – S7 using the concentration decay method with CO2 as the tracer gas. AER was not allowed to be measured in salon S8. CO2 gas from a cylinder was injected into the salon during non-business hours until the concentration reached ~2000 ppm. Fans were used to mix the air contents of the room in order to attain a well-mixed condition. QTrak (QTrak Plus Model 8554, TSI Inc., St. Paul, MN) was used to read the CO2 concentration as it decayed to ~500 ppm. The CO2 readings were plotted versus time to obtain a decay curve. The following relationship was used, followed by linear regression analysis, to determine AER (λ):

$$\ln(C(t) - C_a) = \ln(C_0 - C_a) - \lambda t \quad (1)$$

Where:

C(t) = CO2 concentration as a function of time;

C_a = outdoor CO2 concentration (assumed to be 380 ppm);

C_0 = initial CO2 concentration;

λ = air exchange rate [h^{-1}]; and

t = time [h].

Using the AER, the ventilation rate (scfm, standard cubic feet per minute) was calculated for each salon using the following equation:

$$\text{Ventilation Rate} = \lambda V / O * (1\ \text{hr}/60\ \text{minutes}) \quad (2)$$

Where:

λ = air exchange rate [h^{-1}];

V = volume of salon in ft^3; and

O = occupancy (number of people in salon).

Ventilation rate was calculated using maximum occupancy of the salon and the occupancy observed in the salon during the sampling session. Ventilation rates were compared to 25 cfm (cubic feet per minute)/person, the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) ventilation standard for acceptable indoor air quality in beauty and nail salons (ASHRAE, 2010).

2.6 Data Analysis

Geometric means of PM2.5 and UFP data points were calculated. Contribution of indoor emission sources to indoor PM was assessed using indoor-to-outdoor (I/O) ratios of PM concentrations. Pearson correlation was used to assess correlations between indoor air pollutant concentrations (including PM I/O ratios averaged over the interval of 5 minutes before and after the time nail services and occupancy data were recorded), type and number of nail services, and occupancy. Pearson correlation was also used to assess ventilation (AER) as a predictor for indoor air pollutant levels. Mann-Whitney rank sum tests were performed to assess whether or not ASHRAE compliance reduces indoor air pollutant levels.

3. RESULTS

3.1 Physical Descriptors of Nail Salon

Table 1 shows a summary of the physical characteristics of the 8 salons, including temperature (temp) and relative humidity (RH). Salon volume ranged from 136 to 311 m^3, number of nail stations ranged from 4 to 12, and number of pedicure stations ranged from 0 to 16. All but one salon, S7, kept the entrance door open during the sampling session. Salon S3's entrance was opened and closed intermittently during the sampling session. Mechanical ventilation was not in use during the sampling sessions in all participating salons. In addition to manicure and pedicure services, some salons offered waxing, facial, and tanning services.

Table 1. Nail salon physical description

Salon ID	Meters from freeway	Salon Volume (m^3)	Nail Stations† (#)	Occupancy (#/30 min)	Services Delivered (#/30 min)	Temp (°C/30 min)	RH (%/30 min)
S1	3,219	248	7M, 0P^{+}	17	8	20.6	49.5
S2	2,032	243	8M, 8P	12	7	25.4	34.0
S3	914	310	12M, 16P	72	29	24.4	43.5
S4	1,676	235	4M, 4P	10	4	26.4	36.0
S5	1,219	311	6M, 7P	8	2	27.7	34.9
S6	2,414	188	4M, 5P	18	9	24.1	47.5
S7	1,829	136	6M, 0P^{+}	6	2	22.6	40.5
S8	792	148	10M, 5P	7	3	20.6	41.5

* Front entrance kept open (O), closed (C), or open and closed (O/C) intermittently during 4-hour sampling duration

† Manicure (M) services were also performed at pedicure stations

$^{+}$ Pedicure (P) services were given at the nail stations

3.2 VOC, PM2.5, and UFP Concentrations

Figure 2 shows the 4-hour time-weighted average (TWA) concentrations of select and total VOCs identified by EPA Method TO-15 in each sampling session as percentages of current occupational and environmental exposure limits. **Table S1** shows a summary of all the VOCs identified in the study and their 4-hour TWA concentrations in parts-per-million (ppm). All identified compounds were found below occupational exposure limits. Acetone, isopropyl alcohol, and methyl methacrylate were VOCs commonly found in all participating salons at

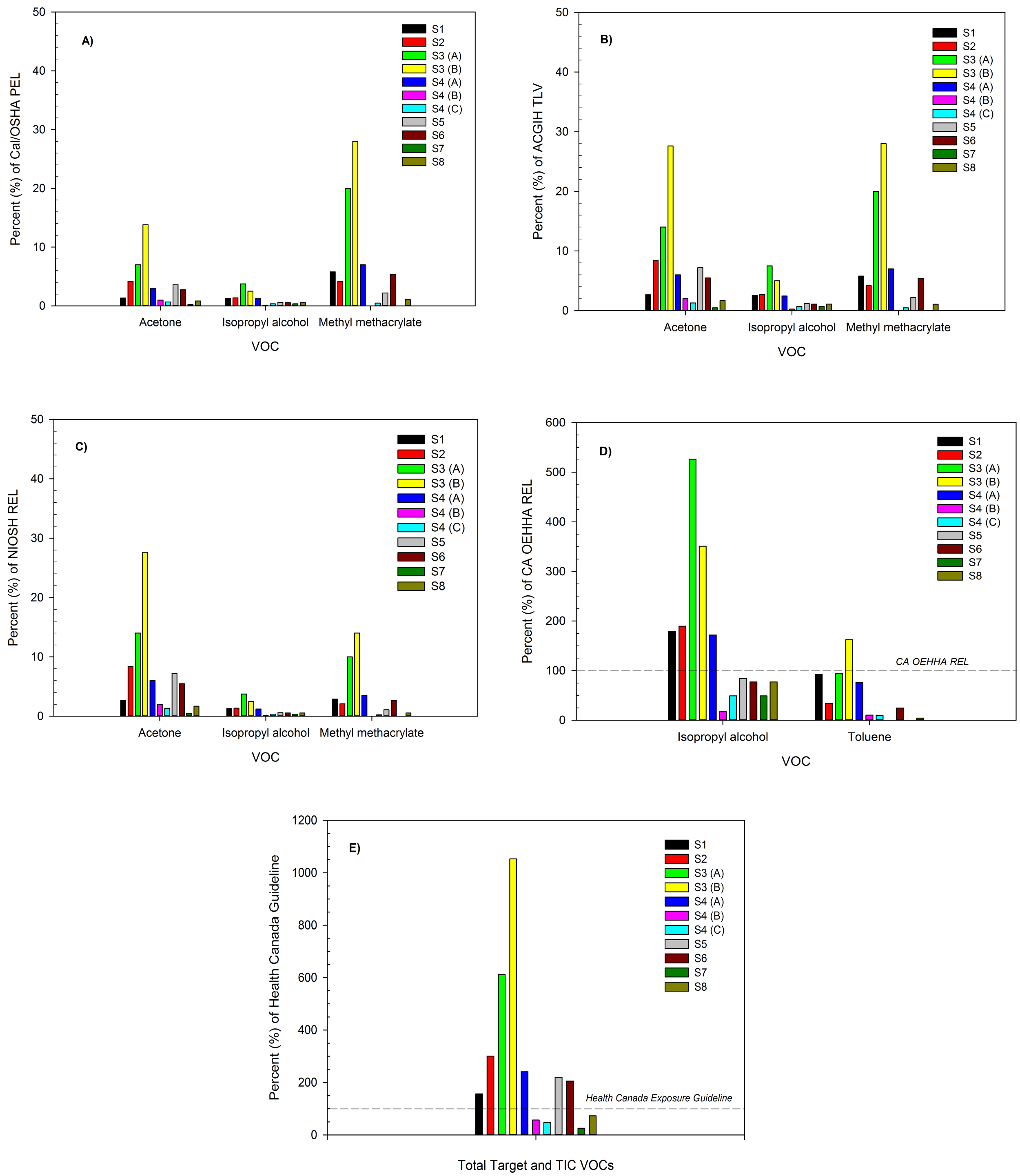

Figure 2. Four-hour TWA concentrations of select and total VOCs as percentages of occupational and environmental exposure limits. Cal/OSHA PELs (A) and ACGIH TLVs (B) are 8-hour TWA occupational exposures limits. NIOSH RELs (C) are 10-hour occupational exposure limits. CA OEHHA RELs (D) refer to chronic (annual) inhalation in the ambient environment. The Health Canada TVOC exposure guideline (E) is intended for office buildings.

higher levels relative to other VOCs identified when assessed against the lowest occupational exposure limit for the particular chemical. Ethanol and ethyl acetate, VOCs that were also commonly identified in all participating salons, were found at less than 1% of their lowest occupational exposure limit. Modest concentrations of 2-butanone (methyl ethyl ketone), acetic acid, and n-butane were found in 50%, 75%, and 63% of the salons, respectively. All of the identified compounds were also found below environmental exposure limits except isopropyl alcohol, which was found above the CA OEHHA chronic inhalation REL in half of the salons. Toluene was found in 75% of the salons, with the highest concentration measured above the CA OEHHA chronic inhalation REL by 63%. Most of the 30-minute formaldehyde readings were below the limit of detection (10 ppb). When formaldehyde was detected, the readings ranged between 11 and 16 ppb. Styrene, xylenes, and ethyl methacrylate were also found in this study, but they were detectable in only one salon. The combined concentrations of all identified VOCs exceeded the Health Canada toxic exposure guideline of 10 ppm for total VOCs (TVOC) in 7 out of 11 salon visits (Health Canada, 1995). The highest 4-hour TWA TVOC level recorded in this study was more than 10 times this guideline.

Figure 3 shows the distributions of indoor and outdoor PM2.5 and UFP concentrations measured during the sampling sessions for salons S1 – S7. The summary statistics of the particles measured during the sampling sessions are given in **Table S2**. Indoor and outdoor PM2.5 concentrations ranged from 6.0 to 139.0 $\mu g/m^3$ and 5.5 to 101.0 $\mu g/m^3$, respectively. The geometric means of indoor and outdoor PM2.5 concentrations were 8.5 to 108.6 $\mu g/m^3$ and 10.1 to 68.2 $\mu g/m^3$, respectively. Indoor and outdoor UFP concentrations ranged from 2.3×10^3 to 1.2×10^5 $\#/cm^3$ and 2.6×10^3 to 7.8×10^4 $\#/cm^3$, respectively. The geometric means of indoor and outdoor UFP concentrations were 8.3×10^3 to 2.3×10^4 $\#/cm^3$ and 6.5×10^3 to $2.5\ 10^4$ $\#/cm^3$, respectively. The maximum indoor PM2.5 concentration, 139.0 $\mu g/m^3$, was found in salon S2, and the maximum indoor UFP concentration, 1.2×10^5 $\#/cm^3$, was found in salon S7. Salon S2 has the largest within-salon variance of indoor PM2.5, and salon S7 has the largest within-salon variance of indoor UFP.

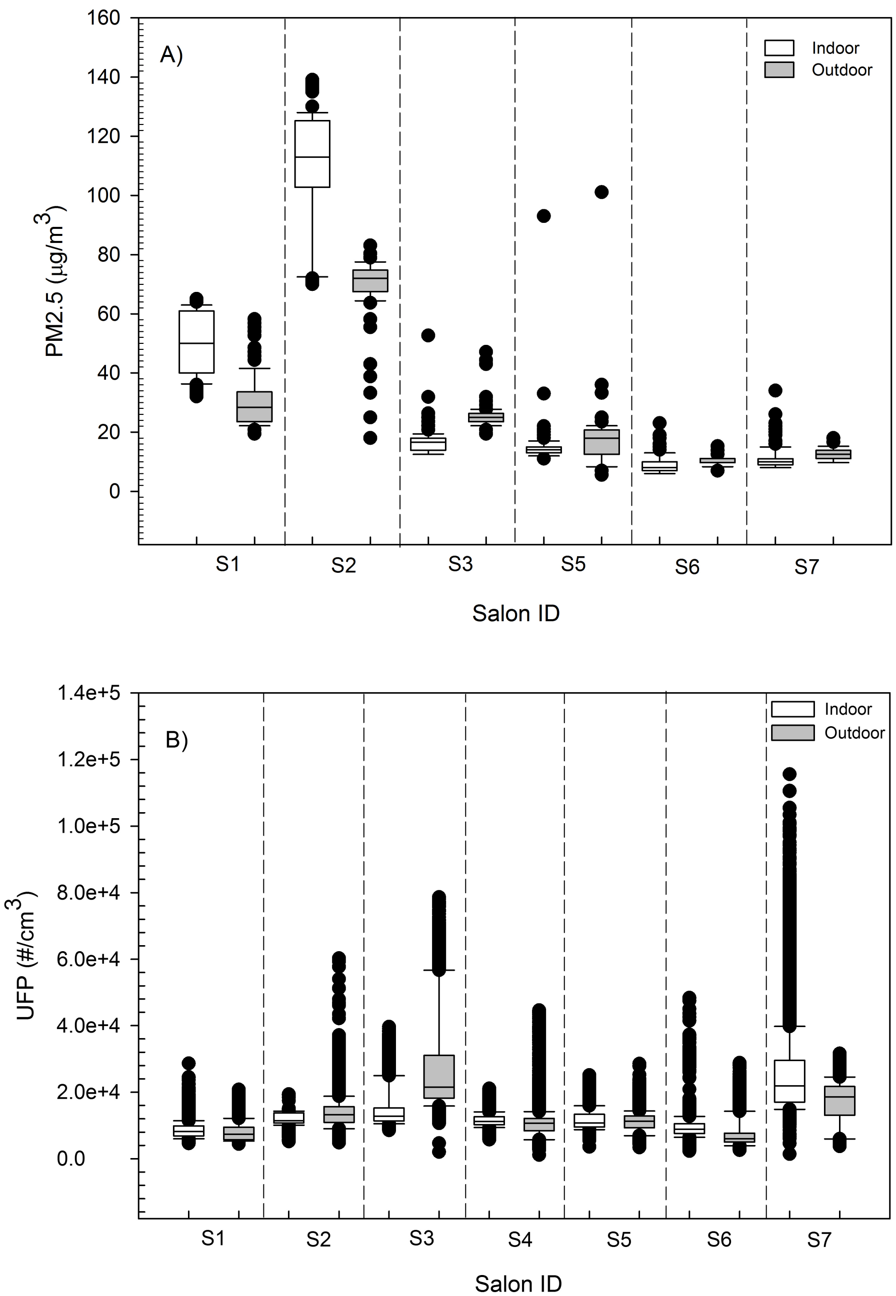

Figure 3. Distribution of indoor and outdoor PM2.5 and UFP concentrations for salons S1 – S7. Mean PM2.5 (A) concentrations in salons S1 and S2 exceeded the 35 µg/m^3 24-hour outdoor EPA standard. There are no exposure standards for UFP (B).

3.3 Indoor Sources

Indoor-to-outdoor (I/O) ratios for PM2.5 and UFP concentrations were calculated for the 7 salons, ranging from 2.00 to 16.79 and 0.15 to 5.40, respectively. **Table S3** presents the summary statistics of the I/O ratios determined for each salon. The geometric means of PM2.5 and UFP I/O ratios were 0.65 to 1.65 and 0.55 to 1.53, respectively. Besides VOCs, nail activities, specifically manicure and pedicure services, were sources of PM2.5 indoors. Across all salons, real-time indoor and outdoor PM2.5 levels did not trace each other, indicating that there are PM2.5 emission sources related to nail activities inside the salon. Emission peaks of PM2.5 inside the salons were observed during nail grinding and filing. The matching of emission peaks between area and at-station time-series data confirms this. The average PM2.5 I/O ratio was 1.70 during grinding activity compared to 0.90 during non-grinding activity. However, real-time indoor and outdoor UFP levels generally followed each other regardless of nail activity and occupancy. Large UFP emission peaks were observed though, notably in salons S1 and S7. At these salons, the CPC was placed near the back area, where microwaves and electric warmers were used to heat facial treatments, towels, and even food, and was able to pick up UFP emissions from those sources. These results indicate that nail activities did not emit UFP in the salons, but rather, other services that are not nail-related. Time series of indoor and outdoor PM2.5 and UFP for salon S7 is shown in **Figure 4**.

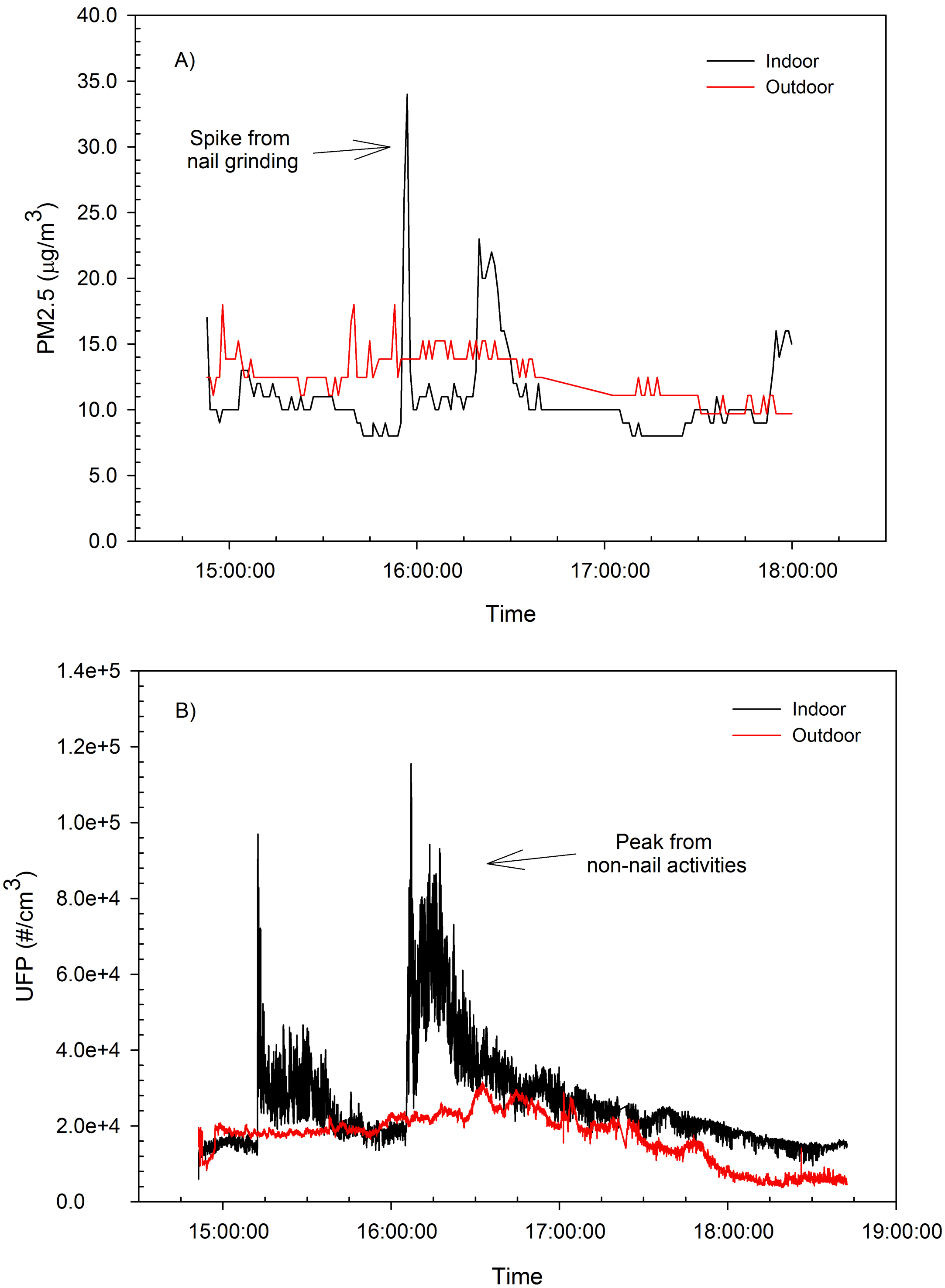

Figure 4. Time series of indoor and outdoor PM2.5 and UFP concentrations for salon S7. PM2.5 (A) was measured in the general area where nail services took place, about 1.5 m away from the nearest nail station. UFP (B) was measured less than 0.5 m away from the section where waxing and facials took place.

3.4 Correlations between Pollutant Concentrations, Nail Services and Occupancy

In addition to looking at time-series data to distinguish PM emission sources, Pearson correlation analyses of PM I/O ratios, averaged over 10 minutes, with the number of each nail service, the total number of nail services, and occupancy present at 30-minute intervals were performed. Between PM2.5 and UFP I/O ratios and the number of nail services being performed and occupancy, the Pearson correlation coefficients R ranged from 0.17 to 0.20 (n=48, CI 95%: -0.10 – 0.44) and from 0.01 to 0.045 (n=56, CI 95%: -0.27 – 0.32), respectively. These results indicate that PM I/O ratios were weakly associated with the number of nail services and occupants, but 95% confidence intervals suggest a possible trend toward moderate association. Statistical significance tests showed no correlations between PM I/O ratios and the number of nail services being performed and occupancy (p>0.05), but these measures may be confounded by small sample size.

Among the chemical compounds investigated, Pearson correlation analyses showed that the concentrations of almost all of the compounds of concern, mainly acetone, ethanol, isopropyl alcohol, methyl methacrylate, and toluene, strongly and significantly correlated with the total VOC concentrations except for ethyl acetate (R≥0.80, p<0.01). Acetone and methyl methacrylate, in particular, had the strongest correlations with total VOCs (R>0.97, p<0.0001). There was also statistically significant correlation between total VOC concentrations and individual and total nail services (# of services delivered per 30 minutes) except with gel nail services (R≥0.87, p<0.01). When reviewing the relationships between number of nail services and individual compound concentrations, the number of gel nail services significantly correlated with isopropyl alcohol, methyl methacrylate, and toluene concentrations (R>0.70, p<0.05). In **Figure 5**, total VOC concentrations significantly correlated with nail services delivered and occupancy (# of people per 30 minutes) during the salon visits (R>0.90, p<0.0001).

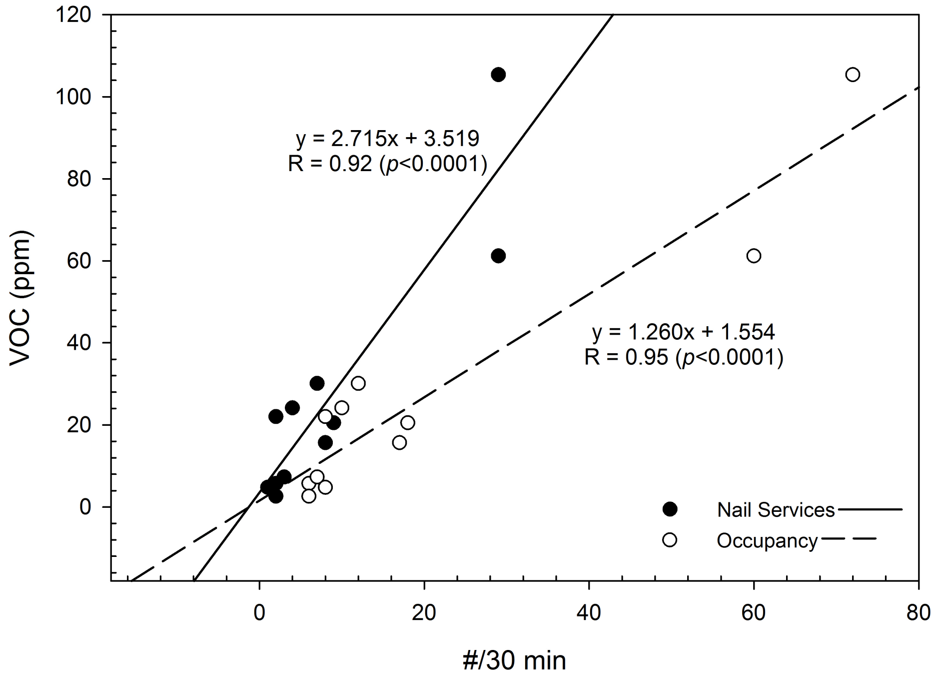

Figure 5. Correlation of nail services delivered and occupancy vs. total VOC concentrations. VOC concentrations are 4-hour TWA. Occupancy is related to the number of nail services being delivered. Ratio of employee to nail service is 1:1.

Table 2. Air exchange rate (AER) and ventilation rate measured in salons. Salons S3, S4, S6, and S7 did not meet the ASHRAE minimum ventilation rate of 25 cfm/person for nail salons. AER was not measured for salon S8.

Salon ID	Occupant Density (# of people/1000 ft^2)	AER (h^{-1})	Ventilation Rate (cfm/person)
S1	17.55	5.11	43.84
S2	13.94	5.67	67.62
S3	58.68	0.22	0.57
S4	11.91	1.33	18.36
S5	6.41	3.74	85.67
S6	25.73	1.48	9.12
S7	12.67	1.00	13.30
Average ± SD	20.98 ± 17.65	2.65 ± 2.16	34.07 ± 32.42

3.5 Air Exchange Rate

Four out of the 7 salons had per-person ventilation rates that did not meet the ASHRAE minimum ventilation standard for acceptable indoor air quality for nail salons. **Table 2** shows the air exchange rates (AERs) and per-person ventilation rates determined for salons S1 – S7.

Using Pearson correlation tests, there were no correlations found between AERs, mean indoor pollutant concentrations, and mean UFP I/O ratios. PM2.5 I/O ratios significantly correlated with AER ($R=0.88$, $p<0.05$). Univariate Mann-Whitney rank sum tests and Student t-tests were performed to see the effect of the ASHRAE standard on reducing pollutant exposures from nail activities. As presented in **Figure 6**, non-ASHRAE-compliant salons had higher VOC levels than ASHRAE-compliant salons. The mean difference in VOC levels, however, was not statistically significant. In contrast, non-ASHRAE-compliant salons had much lower levels of PM2.5 and PM2.5 I/O ratios than ASHRAE-compliant salons.

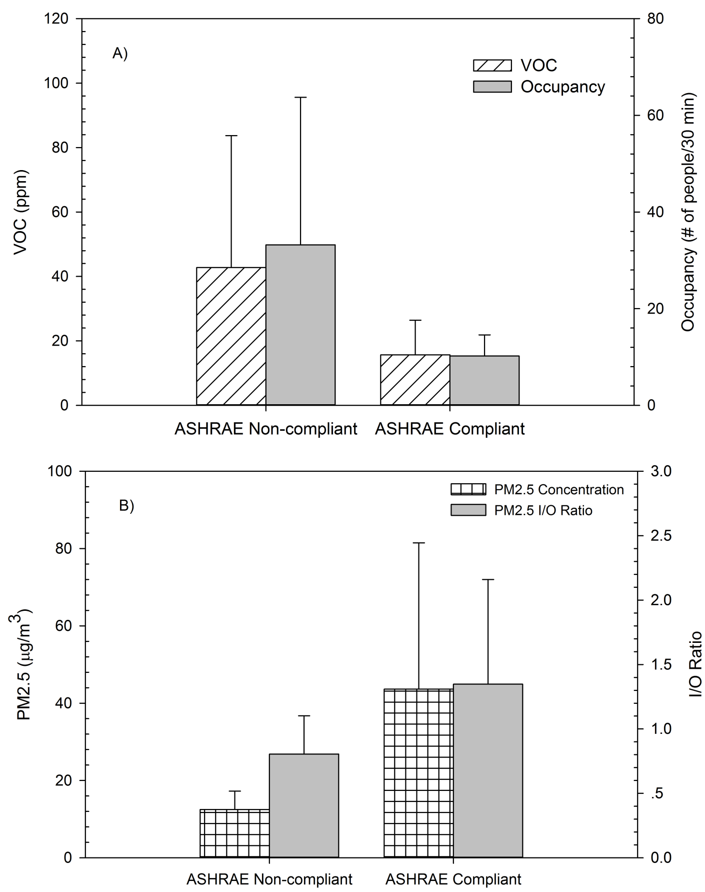

Figure 6. VOC and PM2.5 levels in ASHRAE-compliant and non-ASHRAE-compliant salons. VOC (A) concentrations in ASHRAE-compliant salons were lower than those in non-ASHRAE-compliant salons, but the difference is not statistically significant (Student t-test, $p=0.19$). This is likely due to ASHRAE-compliant salons having lower occupancy. The opposite is observed for PM2.5 (B) concentrations and I/O ratios (Mann-Whitney rank sum test, $p<0.001$).

4. DISCUSSION

4.1 Pollutant Exposures and Sources

From the indoor air quality surveys conducted in 8 nail salons located in and near Los Angeles, high levels of VOCs and particulate matter were observed in the nail activity areas. Although air sampling was conducted for half of a typical 8-hour work shift, the 4-hour TWA pollutant concentrations measured in the salons were sufficient for estimating the severity of the occupational exposures Southern California nail salon workers are regularly exposed to. In regard to strictly nail activities in this study, VOCs and PM2.5 are the main pollutants of concern.

4.1.1 Volatile Organic Compounds

All the EPA Method TO-15-identified compounds in the nail salons were emitted from nail product applications except for n-butane, which has an outdoor origin considering that its indoor and outdoor concentrations are about the same. Acetone and isopropyl alcohol, the highest-emitted VOCs that make up at least 65% of the total VOC concentrations measured per salon, are used to remove nail polish, dehydrate the nail, and to clean the nail surface. Isopropyl alcohol is also a solvent ingredient in nail polishes. Methyl methacrylate, banned in nail products by the Food and Drug Administration (FDA), is found in the liquid monomer that binds the acrylic powders to create acrylic nails. The rest of the identified VOCs come from nail polishes and coatings. Ethyl acetate, the main solvent ingredient in nail and gel polishes, breaks down into ethanol and acetic acid, which were detected in the indoor air samples.

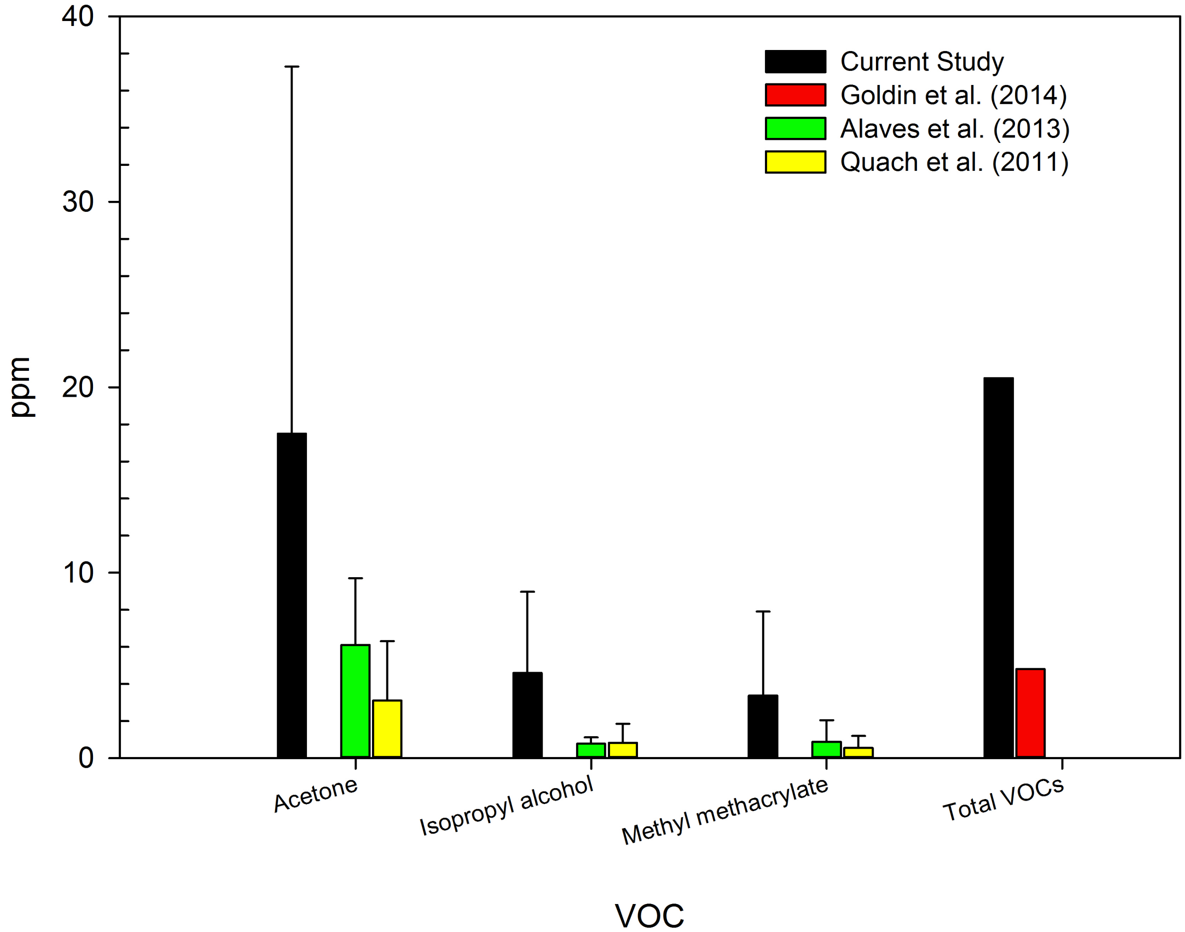

Figure 7. Average VOC concentrations reported in previous indoor air quality studies in nail salons compared to current study. Goldin et al. (2014) reported a median TVOC concentration from point sampling, Alaves et al. (2013) reported mean 8-hour TWA concentrations, and Quach et al. (2011) reported mean 6-hour TWA concentrations.

The average measurements of the major VOCs identified in this study greatly exceed those reported in previous nail salon studies, which measured worker chemical exposures over a 6- to 8-hour duration. **Figure 7** compares this study's average VOC concentrations with the relevant concentrations found in the other studies. The mean concentrations of acetone, isopropyl alcohol, and methyl methacrylate measured in this study went as high as 6 times the mean stationary concentrations of these compounds measured in Alameda County, CA and Salt Lake City, UT nail salons by Quach et al. (2011) and Alaves et al. (2013), respectively. Plus, the median cumulative VOC concentration measured among this study's 8 salons is more than 4 times the median TVOC concentration measured among 21 Boston, MA nail salons (Goldin et al., 2014). Only the concentrations of ethyl acetate and toluene are comparable to those found in previous studies. Furthermore, the maximum concentration of formaldehyde observed in this study is half of the formaldehyde concentration observed in the Alaves et al. study, which suggested that the elevated formaldehyde levels could be attributed to off-gassing of construction materials inside the salons instead of nail activities. Since formaldehyde was not detectable throughout most of this study's salon visits even during high occupancy periods, the instrument must have detected formaldehyde coming inside through the open salon entrances from outdoor activities. These activities were most likely smoking and fuel combustion from mobile sources.

This study suggests that nail salon workers in the greater Los Angeles area are exposed to higher area concentrations of VOCs, except for ethyl acetate, toluene, and formaldehyde, than nail salon workers in other U.S. locations that have been studied thus far. This may be due to a higher population density in the South Coast Basin, leading to more patrons frequenting nail salons in this area. However, the salon sample sizes studied in these different locations vary from 3 salons to 21 salons, so there is a wide range of uncertainty associated with the data's representativeness of the occupational exposures experienced by nail workers in their respective cities or counties. Compared to other retail stores and commercial buildings, where individual and TVOC concentrations average up to 3 ppm, nail salons are sites of considerably high indoor VOC concentrations (Seigel et al., 2012; Chan et al., 2012; Wu et al., 2011; Eklund et al., 2008).

Although the 4-hour TWA concentrations of individual VOCs identified in the salons, even when assuming that the concentrations double for an 8-hour workday, are below their Cal/OSHA, NIOSH, and ACGIH exposure limits, there is still reason to suspect that nail salon workers are chemically exposed at levels that pose adverse health risks. In fact, this study observed, in a number of salons, isopropyl alcohol, toluene, and formaldehyde concentrations exceeding CA ambient exposure reference levels, which are much lower than the occupational exposure limits. CA OEHHA cites adverse effects to the kidney, respiratory and nervous systems, and development at exposure levels above the chronic RELs for these compounds (OEHHA, 2016). Knowledge about the cumulative effects from VOC mixture exposures is few, and currently, there are no U.S. exposure limits or guidelines for TVOCs. Health Canada has recommended an indoor TVOC guideline for toxicity at ≥10 ppm, a level that 6 out of 8 salons in this study exceed. Since this study captured concentrations at the stationary level, personal VOC concentrations may be significantly higher, increasing the potential health implications of the salon workers' chemical exposures. Studies have been conducted measuring personal chemical exposures from nail salon activities at concentrations at least 3 times more than stationary exposures (Quach et al., 2011; Hiipakka & Samimi, 1987). More studies looking at possible interactive effects from exposure to chemical mixtures in nail and beauty salons are needed.

4.1.2 Particulate Matter

No indoor PM2.5 exposure limits have been established, but mean indoor PM2.5 levels were observed up to 3 times above the 35 $\mu g/m^3$ 24-hour outdoor EPA standard in two salons (NAAQS, 2012). Furthermore, the mean I/O PM2.5 ratios for these two salons were 1.35 and 1.65, demonstrating that PM2.5 could be generated indoors at levels up to 65% higher than outdoor concentrations on average. Meanwhile, the mean PM2.5 levels found in the remaining salons, ranging from 8.5 to 16.2 $\mu g/m^3$, are consistent with the levels generally found in other retail stores and small- and medium-sized commercial buildings (Seigel et al., 2012; Wu et al., 2012). Time-series data confirms that the increased PM2.5 exposures are a result of mechanical processes in nail services, particularly nail grinding and removal of callouses using electric tools. Margalho et al. found that a single technician can generate an average 79.92

μg/m^3 PM2.5 concentration from electric drilling and 22.85 μg/m^3 from hand filing (2014). Among 21 Boston, MA nail salons, the range of PM2.5 concentrations observed was 6.1 to 56 μg/m^3, about half the range of PM2.5 concentrations observed in this study (Goldin et al., 2014). Discrepancy in the PM2.5 levels observed in this study may be due to the two salons having elevated outdoor PM2.5 entering the indoor environment and contributing to the PM2.5 measure inside, and possibly the intensity of grinding or filing activities in these two salons is greater than in the other salons. Although not apparent in all salons sampled in this study, nail salon workers can potentially be occupationally exposed to much higher PM2.5 concentrations than other retail workers.

This is the first study that investigates nail salon workers' exposure to UFP. Unlike PM2.5, UFP exposures in nail salons are not due to nail activities, but to outdoor particles entering the indoor environment and non-nail-related sources like heating chambers and microwaves. Despite the frequent use of UV lamps in curing gel nail applications, no significant UFP emissions were detected, even when monitoring was done at the nail station. The UV frequency of the curing lamps was not high enough to initiate particle generation among reactive VOCs. Without indoor sources, the mean UFP levels in the nail salons, ranging from 8.3 x 10^3 to 14 x 10^3 #/cm^3, are similar to the mean levels found in California hair salons, grocery stores, office buildings, and other retail and miscellaneous buildings (Wu et al., 2012). These levels, however, are about four times lower than levels observed in restaurants, where heating and combustion sources are much more prominent (Wu et al., 2012). Considering that the nail salons studied, excluding salon S7, had their entrances open during sampling, the indoor UFP concentrations were reflective of the outdoor UFP concentrations. Zhang & Zhu (2012) observed the highest average indoor particle concentration of 47.0 x 10^3 #/cm^3 in rooms with vented gas fan heaters, followed by rooms with food-related activities and use of a microwave oven, with I/O ratios of 6.6 to 10.3. These findings correspond with UFP concentrations observed in salon S7, where the highest average indoor particle concentration of 23 x 10^3 #/cm^3 and I/O ratio of 5.40 were observed when facial, waxing, and other heat-required services were being performed near the nail services. In the presence of microwaves and heating chambers used for the non-nail-related services, the indoor UFP concentration increased to 120 x 10^3 #/cm^3. This level is close to the elevated UFP levels reported in classrooms, up to 140 x 10^3 #/cm^3, due to art activities such as painting, gluing, and drawing (Morawska et al., 2009). Large UFP concentrations were not measured in the presence of nail services, which was not expected since the art activities reported in the Morawska et al. study are similar activities that nail salon workers perform. There are currently no indoor or outdoor UFP exposure standards, but workers should be aware of potential exposures to UFP in nail salons.

4.2 Predictors of Pollutant Exposure Levels

Previous nail salon studies have proposed a few predictors of indoor pollutant exposures, namely number and type of nail services, salon size, and ventilation characteristics. This study investigated occupancy and ventilation as predictors of workers' pollutant exposures in nail salons. Using multivariate analyses, Alaves et al. found that "number of customers" was nonsignificant to predicting acetone and benzene concentrations with other physical/chemical descriptors in nail salons, but there was possible trending toward significance (p=0.13 and p=0.08, respectively) (2013). This study, however, asserts that occupancy is an acceptable predictor of VOC exposure levels. In another study, Goldin et al. evaluated the indoor air quality and effect of ventilation on indoor pollutant exposures in nail salons by measuring CO2 as a surrogate for ventilation (2014). In contrast, this study assesses ventilation by determining salon air exchange rates (AERs).

4.2.1 Occupancy

As seen in Figure 5, the two regression lines, one representing the independent variable of number of nail services and the other occupancy, show positive correlation between these two predictor variables and total VOC concentrations. The linear regression slope of the nail services correlation, however, is greater than that of the occupancy correlation. This shows that occupancy can serve as a general estimator of VOC exposure levels in nail salons even though the number of nail services is a more sensitive indicator of VOC levels by 50%. Thus, according to Figure 5, seven occupants, which roughly corresponds to 3 nail services or 3 employees delivering nail services, would be the starting point for TVOC exposures above 10 ppm, the Health Canada toxicity guideline for TVOCs. However, the conclusion that there is definite linear relationships between number of services, occupancy, and VOC concentrations may be tentative, considering that most of the VOC concentrations plotted in Figure 5 are clustered below 40 ppm. Still, this study demonstrates that higher occupancy, which relates to the number of customers and nail services being delivered, leads to higher chemical exposures in nail salons.

Since UFP emissions from nail activities were not evident compared to PM2.5 emissions, occupancy and number of nail services are irrelevant to predicting UFP exposure levels in nail salons. The statistically insignificant correlations found between occupancy, number of nail services, and PM I/O ratios confirms that. Despite electric drilling and hand filing being capable of generating PM2.5, neither occupancy nor number of nail services was a significant predictor of indoor PM2.5 exposures in this study. This observation could be due to the lack of air mixing in the salons sampled, so the indoor PM2.5 concentrations recorded during the sampling sessions may be of emissions from nearby nail stations instead of all nail activity-related emissions occurring in the salon. These findings are inconsistent with previous studies that show occupancy is related to indoor air pollutant levels (Wierzbicka et al., 2015; Zhang & Zhu, 2012). More research is warranted to measure emission rates of single nail services and activities in order to fully quantify and assess individual worker exposures.

4.2.2 Ventilation

As seen in Table 2, AERs among the participating salons averaged 2.65 ± 2.16 h^{-1}. This is higher than the mean AERs found across small- and medium-sized commercial buildings in California (1.6 ± 1.7 h^{-1}) and retail stores in Texas and Pennsylvania (0.63 ± 0.37 h^{-1}) (Wu et al., 2012; Seigel et al., 2012). Peculiarly, the range of indoor particulate concentrations observed in commercial and retail buildings by Wu et al. and Seigel et al. are similar to that of the nail salons in this study even though AERs differ. The sample size of this study is less than those of the other studies, which may explain the greater variation in AER observed in this study. Furthermore, all but one salon kept the doors open during business hours, thus increasing the AER by at least 2 times but also introducing the indoor environment to outdoor pollutants (Howard-Reed et al., 2002).

So far, indoor air quality surveys of nail salons have assessed ventilation by measuring indoor CO2 concentrations, using the steady state concentration of 700 – 800 ppm, which approximately translates to the recommended ventilation rate of 25 cfm/person for nail salons, as the threshold for inadequate ventilation (Goldin et al, 2014; Roelofs & Do, 2012). This is the first study to characterize the ventilation of nail salons by measuring AERs and translating them to per-person ventilation rates for review against the ASHRAE standard. In this study, 57% of the sampled salons did not meet the ASHRAE recommended ventilation rate. Considering that this study takes into account typical occupancy in each salon when translating the AERs to ventilation rates, the assessment of ventilation in nail salons in this study is more accurate than those of other studies, which found a higher percentage of salons in their respective samples were inadequately ventilated based on indoor CO2 concentrations.

Despite AER correlating with PM2.5 I/O ratios, higher ventilation did not lead to lower VOC or particulate exposure levels inside the salons. This contradicts the finding of Goldin et al. (2014) that salons with poorer ventilation, indicated by higher CO2 levels, had significantly higher

TVOC concentrations. The positive correlation observed between AER and PM2.5 I/O ratio is most likely due to the addition of outdoor PM2.5 into the indoor environment as the air exchange increases from opening doors. The results of the univariate statistical analyses, seen in Figure 6, indicate that the ASHRAE ventilation standard for nail salons is an unsteady benchmark for ensuring suitable indoor air quality for workers with respect to pollutant exposures distinct to nail work. VOC levels were lower in ASHRAE-compliant salons than in non-ASHRAE-compliant salons, but the difference was not statistically significant. As previously established in this study, occupancy is most likely the predictor of this difference instead of ventilation because the occupancy in ASHRAE-compliant salons was also lower than the occupancy in non-ASHRAE-compliant salons. In contrast, PM2.5 concentrations and I/O ratios observed in ASHRAE-compliant salons were higher than in non-ASHRAE-compliant salons. Among the three ASHRAE-compliant salons, two that had the highest mean indoor PM2.5 concentrations also had the highest mean outdoor PM2.5 concentrations. Thus, the entry of PM2.5 from outside to inside likely contributed more to the indoor PM2.5 levels in these salons than in non-ASHRAE-compliant salons, which had much lower mean outdoor PM2.5 concentrations.

When applied to specific chemicals of health concern for nail salon workers, the ASHRAE ventilation standard is incongruent with health exposure limits. To illustrate, assuming the rate of nail service delivery is constant and the 4-hour TWA concentrations double for an 8-hour work day, all the AER-measured salons in this study would have isopropyl alcohol concentrations exceeding the CA OEHHA chronic REL. Likewise for toluene concentrations, 3 out of the 7 salons would exceed the CA OEHHA chronic REL. Expecting that the salons with supposed 8-hour TWA concentrations exceeding the respective RELs would all be non-ASHRAE-compliant, instead only a little more than half are deemed non-compliant with the ASHRAE standard. Overall, these findings strongly suggest that ASHRAE-compliance is an unreliable and even ineffective strategy for indoor air mitigation in nail salons with respect to reducing adverse health effects. Ventilation is a weak predictor of pollutant exposures. Local exhaust ventilation, which was not found in any of the participating salons, may be more effective in reducing worker exposures to VOCs and PM2.5 in nail salons.

Some limitations of this study are the small sample size and unequal distribution of nail salon types. More nail salons of wider variety need to be studied in the greater Los Angeles area to increase the statistical power and to have a better understanding of pollutant exposures and ventilation characteristics in salons with larger area and occupant density. Another limitation is the lack of replicate or repeated pollutant and air exchange rate measurements, which was challenging to overcome due to salon owner objections to further sampling. These parameters can fluctuate at different locations in the salon, so this study may not have captured the full range of exposures salon workers potentially face. Furthermore, personal air sampling was not conducted in this study. Hiipakka & Samimi (1987) and Quach et al. (2011) measured higher VOC concentrations from personal sampling in nail salons than the VOC concentrations measured in this study from stationary sampling.

5. CONCLUSIONS

Nail salon workers in the greater Los Angeles area are exposed to higher levels of VOCs than other nail salon workers and workers in other retail industries. They can be exposed to toxic levels of toluene, isopropyl alcohol, and PM2.5 from nail activities. Nail salon workers can also be exposed to significant levels of ultrafine particles from non-nail-related activities. Occupancy is a stronger predictor of VOC exposure levels than ventilation. Instead of CO2, VOCs and PM2.5 levels can be more effective indicators of good indoor air quality in nail salons. The ASHRAE ventilation standard for acceptable indoor air quality in nail salons should be revised to incorporate these indicators. More work is needed to study the potential interactive effects and health impacts from exposures to chemical mixtures unique to nail salons.

SUPPLEMENTAL INFORMATION

Table S1. Summary of 4-hour TWA VOC concentrations (in ppm) measured during sampling sessions (N=11). Measured air concentrations are compared to exposure limits set by various U.S. agencies.

VOC	25th Pctile	Median	75th Pctile	Mean ± SD	Range	Cal/OSHA PEL*	ACGIH TLV#	NIOSH REL†	CA OEHHA REL+
Acetone	4.20	13.7	21.0	17.5 ± 19.8	1.20 – 69.0	500	250	250	NA
Ethanol	0.027	0.15	0.87	1.29 ± 3.25	0.008 – 11.0	1,000	1,000 STEL	1,000	NA
Ethyl acetate	0.037	0.31	0.63	0.345 ± 0.332	0.016 – 1.02	400	400	400	NA
Isopropyl alcohol	1.40	2.40	5.40	4.59 ± 4.38	0.493 – 15.0	400	200	400	1.30 (A) 2.85 (C)
Methyl methacrylate	0.237	2.10	3.50	3.37 ± 4.53	0.0079 – 14.0	50	50	100	NA
2-Butanone (Methyl ethyl ketone)	0	0	0.079	0.0386 ± 0.0671	0 – 0.21	200	200	200	4.41 (A)
Acetic acid	0	0.073	0.165	0.092 ± 0.092	0 – 0.27	10	10	10	NA
Toluene	0.0034	0.0197	0.074	0.0369 ± 0.0424	0 – 0.13	10	20	100	9.82 (A) 0.08 (C)
Ethyl methacrylate	0	0	0	0.00873 ± 0.029	0 – 0.096	NA	NA	NA	NA
n-Butane	0	0	0.014	0.0125 ± 0.0243	0 – 0.079	NA	1000 STEL	800	NA
Styrene	0	0	0	0.00054 ± 0.00178	0 – 0.0059	50	20	50	4.93 (A) 0.21 (C)
Xylenes	0	0	0	0.00145 ± 0.00482	0 – 0.016	100	100	100	5.07 (A) 0.16 (C)
Total Target and TIC	5.71	20.5	30.1	27.2 ± 30.7	2.60 – 105	NA	NA	NA	NA

* California Occupational Safety and Health Administration (Cal/OSHA) Permissible Exposure Limit (8-hr TWA PEL) in ppm

American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (8-hr TWA TLV) in ppm

† National Institute of Occupational Safety and Health (NIOSH) Recommended Exposure Limit (10-hr TWA REL) in ppm

+ California Office of Environmental Health Hazard Assessment (CA OEHHA) Reference Exposure Level (1-hr acute (A) inhalation and annual chronic (C) inhalation REL) in ppm

STEL = Short Term Exposure Limit

NA = Not Available (Agency does not have an exposure limit for particular chemical(s))

Table S2. Summary of PM2.5 and UFP concentrations measured in salons

Salon ID		PM2.5 (μg/m^3)			UFP (#/cm^3)		
		GM	GSD	Median	GM	GSD	Median
S1	Indoor	49.0	1.2	50.0	8,300	1.3	8,100
	Outdoor	29.7	1.3	28.4	7,600	1.4	7,400
S2	Indoor	108.6	1.2	113.0	12,000	1.2	11,000
	Outdoor	68.2	1.2	72.0	13,000	1.3	13,000
S3	Indoor	16.2	1.2	16.6	14,000	1.4	13,000
	Outdoor	25.0	1.1	24.9	25,000	1.6	22,000
S4	Indoor	NA	NA	NA	11,000	1.2	11,000
	Outdoor	NA	NA	NA	9,900	1.4	11,000
S5	Indoor	14.4	1.2	14.0	11,000	1.3	11,000
	Outdoor	15.5	1.5	18.0	11,000	1.3	11,000
S6	Indoor	8.5	1.3	8.0	9,000	1.3	8,900
	Outdoor	10.1	1.1	9.7	6,500	1.6	6,000
S7	Indoor	10.6	1.3	10.0	23,000	1.5	22,000
	Outdoor	12.3	1.2	12.5	15,000	1.7	19,000

Table S3. Summary of indoor-to-outdoor (I/O) ratios of PM2.5 and UFP concentrations

Salon ID	PM2.5 I/O					UFP I/O				
	GM	GSD	Min	Median	Max	GM	GSD	Min	Median	Max
S1	1.65	1.21	0.81	1.71	2.24	1.08	1.30	0.43	1.12	4.61
S2	1.35	1.38	0.68	1.59	4.44	0.90	1.30	0.21	0.94	2.25
S3	0.65	1.26	0.26	0.67	2.00	0.55	1.23	0.21	0.57	0.94
S4	NA	NA	NA	NA	NA	1.00	1.30	0.22	1.00	3.77
S5	0.92	1.63	0.17	0.78	16.79	1.03	1.40	0.37	0.98	4.02
S6	0.85	1.41	0.43	0.83	3.32	1.38	1.49	0.15	1.40	4.15
S7	0.86	1.30	0.44	0.81	2.45	1.53	1.52	0.27	1.67	5.40

REFERENCES

Aalto-Korte K, Henriks-Eckerman M-L, Kuuliala O, Jolanki R. 2010. Occupational methacrylate and acrylate allergy--cross-reactions and possible screening allergens. Contact Derm 63:301–312.

Adeniran JA, Jimoda LA, Sonibare JA. 2014. A review of household products induced secondary organic aerosols formation in indoor environment. Br J Appl Sci Technol 4:3813–3839.

Alaves VM, Sleeth DK, Thiese MS, Larson RR. 2013. Characterization of indoor air contaminants in a randomly selected set of commercial nail salons in Salt Lake County, Utah, USA. Int J Environ Heal Res 25:419–433.

ASHRAE. 2010. ANSI/ASHRAE Standard 62.1-2010, Ventilation for Acceptable Indoor Air Quality. Atlanta, GA:American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ATSDR. 2000. Toxicological Profile for Toluene. Department of Health and Human Services.

Aydin O, Attila G, Dogan A, Volkan Aydin M, Canacankatan N, Kanik A. 2002. The effects of methyl methacrylate on nasal cavity, lung, and antioxidant system (an experimental inhalation study). Toxicol Pathol 30:350–356.

CA OEHHA. 2015. Air Toxics Hot Spots Program Guidance Manual for the Preparation of Health Risk Assessment 2015. Sacramento, CA:California Environmental Protection Agency.

Chan W, Sidheswaran M, Sullivan D, Cohn S, Fisk W. 2012. Contaminant levels and source strengths in U.S. retail stores – a pilot study. Berkeley, CA:Lawrence Berkeley National Laboratory.

Eklund BM, Burkes S, Morris P, Mosconi L. 2008. Spatial and temporal variability in VOC levels within a commercial retail building. Indoor Air 18:365–374.

EPA. 1999. Method TO-15: Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS). EPA/625/R-96/010b. Cincinatti, OH:U.S. Environmental Protection Agency.

EPA. 2012. National Ambient Air Quality Standards (NAAQS). Office of Air and Radiation. EPA 40 CFR part 50. Research Triangle Park, NC:U.S. Environmental Protection Agency.

Federman MN, Harrington DE, Krynski KJ. 2006. Vietnamese manicurists: displacing natives or finding new nails to polish? Ind Labor Rel Rev 59:302–318.

Goldin LJ, Ansher L, Berlin A, Cheng J, Kanopkin D, Khazan A, et al. 2014. Indoor air quality survey of nail salons in Boston. J Immigr Minor Health 16:508–514.

Gresner P, Stepnik M, Król MB, Swiercz R, Smok-Pieniazek A, Twardowska E, et al. 2015. Dysregulation of markers of oxidative stress and DNA damage among nail technicians despite low exposure to volatile organic compounds. Scand J Work Environ Health 41:579–593.

Harris-Roberts J, Bowen J, Sumner J, Stocks-Greaves M, Bradshaw L, Fishwick D, et al. 2011. Work-related symptoms in nail salon technicians. Occup Med (Lond) 61:335–340.

Health Canada. 1995. Indoor Air Quality in Office Buildings: A Technical Guide. 93-EHD-166. Ottawa, ONT:Minister of National Health and Welfare.

Hiipakka D, Samimi B. 1987. Exposure of acrylic fingernail sculptors to organic vapors and methacrylate dusts. Am Ind Hyg Assoc J 48:230–237.

Howard-Reed C, Wallace LA, Ott WR. 2002. The effect of opening windows on air change rates in two homes. J Air Waste Manag Assoc 52:147–159.

John EM, Savitz DA, Shy CM. 1994. Spontaneous abortions among cosmetologists. Epidemiology 5:147–55.

Kwapniewski R, Kozaczka S, Hauser R, Silva MJ, Calafat AM, Duty SM. 2008. Occupational exposure to dibutyl phthalate among manicurists. J Occup Environ Med 50:705–711.

Lazarov A. 2007. Sensitization to acrylates is a common adverse reaction to artificial fingernails. J Eur Acad Dermatol Venereol 21:169–174.

Li N, Sioutas C, Cho A, Schmitz D, Misra C, Sempf J, et al. 2002. Ultrafine particulate pollutants induce oxidative stress and mitochondrial damage. Environ Health Perspect 111:455–460.

LoSasso GL, Rapport LJ, Axelrod BN, Whitman RD. 2002. Neurocognitive sequelae of exposure to organic solvents and (meth)acrylates among nail-studio technicians. Neuropsychiatry Neuropsychol Behav Neurol 15:44–55.

LoSasso GL, Rapport LJ, Axelrod BN. 2001. Neuropsychological symptoms associated with low-level exposure to solvents and (meth)acrylates among nail technicians. Neuropsychiatry Neuropsychol Behav Neurol 14:183–189.

Margalho T, Ferreira A, Figueiredo JP, Silva F. Assessment levels of dustiness – case study applied to technicians of gel nails. In: Occupational Safety and Hygiene II (Arezes et al., eds). London:Taylor & Francis Group, 375–380.

Maxfield R, Howe HL. 1997. Silica exposure in artificial nail application salons. Available: http://www.idph.state.il.us/about/epi/pdf/epi97-8.pdf

Morawska L, He C, Johnson G, Guo H, Uhde E, Ayoko G. 2009. Ultrafine particles in indoor air of a school: possible role of secondary organic aerosols. Environ Sci Technol 43:9103–9109.

Nails Magazine. 2016. 2015–2016 Industry Statistics. Torrance, California: NAILS.

Nazaroff WW, Weschler CJ. 2004. Cleaning products and air fresheners: exposure to primary and secondary air pollutants. Atmospheric Environment 38:2841–2865.

NORA. 2015. National services agenda: for occupational safety and health research and practice in the U.S. services industries. NORA Services Sector Council.

Quach T, Doan-Billing PA, Layefsky M, Nelson D, Nguyen KD, Okahara L, et al. 2010. Cancer incidence in female cosmetologists and manicurists in California, 1988–2005. Am J Epidemiol 172:691–699.

Quach T, Gunier R, Tran A, Von Behren J, Doan-Billings P-A, Nguyen K-D, et al. 2011. Characterizing workplace exposures in Vietnamese women working in California nail salons. Am J Public Health 101 Suppl 1:S271–276.

Quach T, Nguyen K-D, Doan-Billings P-A, Okahara L, Fan C, Reynolds P. 2008. A preliminary survey of Vietnamese nail salon workers in Alameda County, California. J Community Health 33:336–343.

Quill J, Fedor G, Brennan P, Everett E. 2004. Quantifying the indoor light environment: testing for light stability in retail and residential environments. Final Program and Proceedings of IS&T's NIP20: International Conference on Digital Printing Technologies 689–698.

Raupp GB, Junio CT. 1993. Photocatalytic oxidation of oxygenated air toxics. Applied Surface Science 72:321–327.

Reutman SR, Rohs AM, Clark JC, Johnson BC, Sammons DL, Toennis CA, Robertson SA, MacKenzie BA, Lockey JE. 2009. A pilot respiratory health assessment of nail technicians: symptoms, lung function, and airway inflammation. Am J Ind Med 52:868–875.

Roelofs C, Do T. 2012. Exposure assessment in nail salons: an indoor air approach. International Scholarly Research Network Public Health.

Sauni R, Kauppi P, Alanko K, Henriks-Eckerman M-L, Tuppurainen M, Hannu T. 2008. Occupational asthma caused by sculptured nails containing methacrylates. Am. J. Ind. Med. 51:968–974.

SCAQMD. 2015. Multiple Air Toxics Exposure Study in the South Coast Air Basin: MATES IV Final Report. Diamond Bar, CA:South Coast Air Quality Management District.

Seigel JA, Srebric JS. 2012. ASHRAE Research Project 1596-RP: Ventilation and indoor air quality in retail stores. Atlanta, GA:American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Su FC, Mukherjee B, Batterman S. 2011. Trends of VOC exposures among a nationally representative sample: analysis of the NHANES 1988 through 2004 data sets. Atmos Environ 45:4858–4867.

Tsigonia A, Lagoudi A, Chandrinou S, Linos A, Evlogias N, Alexopoulos EC. 2010. Indoor air in beauty salons and occupational health exposure of cosmetologists to chemical substances. Int J Environ Res Public Health 7:314–324.

U.S. EPA. 2007. Protecting the Health of Nail Salon Workers. Office of Pollution Prevention and and Toxics and Office of Administration and Resource Management. EPA 744-07-001. 1–21.

Weschler CJ, Shields HC. 1999. Indoor ozone/terpene reactions as a source of indoor particles. Atmospheric Environment 33:2301–2312.

WHO. 2013. Health effects of particulate matter: policy implications for countries in eastern Europe, Caucasus and central Asia. Available: http://www.euro.who.int/__data/assets/pdf_file/0006/189051/Health-effects-of-particulate-matter-final-Eng.pdf

Wierzbicka A, Bohgard M, Pagels JH, Dahl A, Löndahl J, Hussein T, et al. 2015. Quantification of differences between occupancy and total monitoring periods for better assessment of exposure to particles in indoor environments. Atmospheric Environment 106:419–428.

Wu XM, Apte MG, Bennett DH. 2012. Indoor particle levels in small- and medium-sized commercial buildings in California. Environ Sci Technol 46:12355–12363.

Wu XM, Apte MG, Maddalena R, Bennett DH. 2011. Volatile organic compounds in small- and medium-sized commercial buildings in California. Environ Sci Technol 45:9075–9083.

Zhang Q, Zhu Y. 2012. Characterizing ultrafine particles and other air pollutants at five schools in South Texas. Indoor Air 22:33–42.