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Original Article

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Occupational Exposure and Ventilation Assessment in New York City Nail Salons

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Abstract

In 2015, New York State enacted new ventilation regulations to protect employees and clients from exposure to chemicals used in nail salons. This study measured common air pollutants found in nail salons and assessed compliance with ventilation requirements. Area sampling was conducted in 12 nail salons located in New York City for three consecutive days (Thursday, Friday, and Saturday) to measure total volatile organic compounds (TVOCs), methyl methacrylate, toluene, and ethyl acetate concentrations and estimate ventilation rates. Salon characteristics were determined through a walkthrough inspection and survey administered to the manager. The average daily concentration of carbon dioxide and TVOCs across all salons was 1070 ppm [standard deviation (SD) = 440 ppm] and 29 ppm (SD = 25 ppm), respectively. Chemical-specific air sampling showed low to non-detectable levels of the three measured chemicals. Seventy-five percent of the nail salons did not meet general minimum outdoor airflow requirements. Little temporal variation was observed in day-to-day average concentrations of contaminants within salons, indicating uniform exposure during high customer count days. Salons that met the outdoor airflow requirements had twice the average daily customers (83 versus 42) and half the TVOC concentrations compared with salons that did not (33 versus 16 ppm). Nail salons not meeting ventilation requirements tended to have fewer customers and managers that did not understand the essential components of the ventilation system. Data from this study can be used as evidence of reduction in exposure due to compliance with the ventilation requirements.

Keywords: indoor air quality; nail salons; occupational exposure; VOC exposure; volatile organic compounds

Introduction

No longer a niche industry in the USA, in 2015, revenue from nail services surpassed $4 billion and the employment rate is expected to increase by over 10% in the next decade (US Department of Labor, Bureau of Labor Statistics, 2016; Sharma *et al*., 2018). The New York City (NYC) metropolitan area has the highest number of nail salon workers in the USA with 27 000 (US Department of Labor, 2019). This number is likely underestimated due to high rates of job misclassification, unlicensed nail technicians, and undocumented workers in this employment sector (Sharma *et al.*, 2018). Approximately 30% of nail salon workers are self-employed or independent contractors and have fewer workplace protections compared with full-time employees (Sharma *et al.*, 2018). In NYC, there are approximately 2000 nail salons with the majority owned and operated by Korean and Chinese immigrants (Nir, 2015a).

Over the past two decades, investigators have documented exposures to low levels of volatile organic compounds (VOCs) (Table 1) in nail salons (Gjølstad *et al.*, 2006; Quach *et al.*, 2011; Alaves *et al.*, 2013; Lamplugh *et al.*, 2019; Ma *et al.*, 2019) and adverse health effects among nail salon technicians (Roelofs *et al.*, 2008; Reutman *et al.*, 2009). Exposure to chemicals used in nail salons may cause headaches, lightheadedness, fatigue, and irritation of the eyes, skin, and respiratory system, and allergic sensitization (Occupational Safety and Health Administration, n.d.). Although the concentrations of chemical contaminants in nail salons are generally below occupational exposure limits, including the Threshold Limit Value (TLV) issued by the American Conference of Industrial Hygienists (ACGIH), many of the health effects experienced by nail technicians, such as sensitization, are not considered in setting these standards (American Conference of Governmental Industrial Hygienist, 2019). Additionally, the additive or synergistic effects of these chemical compounds, that are almost always present as mixtures in nail salons, are not known (Carpenter *et al.*, 2002). Thus, it is challenging to promote worker and client health through a chemical-by-chemical risk assessment and standard setting protocol that could be relevant to the nail salon environment.

In May 2015, the New York Times published a series of investigative reports on nail salon workers including negative health effects among nail technicians and poor workplace conditions, along with reports of harassment, wage theft, labor violations, worker exploitation, and lack of investigation and intervention from the state Labor Department (Nir, 2015a,b). Following the reporting in the New York Times, the Governor of New York announced that nail salons throughout New York State (NYS) would have to comply with new ventilation regulations (Section 160.16) to protect employees and clients from exposure to chemicals used in the salons (Office of the Governor, New York State, 2016). All salons licensed before October 2016 have 5 years to come into compliance, while those licensed after must meet the ventilation requirements upon the establishment of the business (Office of the Governor, New York State, 2016). The new ventilation requirements incorporate the 2015 International Mechanical Code (2015 IMC), which specifies general exhaust ventilation (GEV) and local exhaust ventilation (LEV) standards for nail salons and hair salons that provide nail services (NYS Department of State, 2016). The GEV requirement is a function of occupant density and area of the salon with a minimum of 0.0094 $m^3 s^{-1}$ (cubic meters per second) of outdoor airflow per person, plus an additional 0.000057 $m^3 s^{-1}$ per 0.093 m^2. When the occupant density is unknown, a default value of 25 people per 93 m^2 is required. The LEV requirements are for a source capture hood placed within 30.5 cm of manicure and pedicure task areas and exhausted directly outside at a rate no less than 0.024 $m^3 s^{-1}$ per nail station (NYS Department of State, 2016). No recirculation of salon air is permitted.

In a 2017 study conducted by the authors of this study, total volatile organic compounds (TVOCs) and

Table 1. Exposure ranges, occupational exposure limits, ionizing potentials (IP), and PID correction factors for common compounds found in nail salon products.

Chemical	Exposure ranges (ppm)	2019 ACGIH TLV (ppm)	IP <10.6 eV	PID correction factor
Acetone	0.05–45	250	Yes	1.1
Benzene	0.00018–0.0015	0.5	Yes	0.53
Butyl acetate	0.001–0.67	150	Yes	2.6
Ethyl acetate	0.01–5.50	400	Yes	3.49
Formaldehyde	0.011–0.032	0.1	No	—
Isopropyl alcohol	0.06–5.9	200	Yes	6.0
Methyl ethyl ketone	ND–0.13	200	Yes	0.9
MMA	0.02–39.45	50	Yes	1.5
Toluene	0.04–1.0	20	Yes	0.50

ND, non-detectable level and LOD was not provided.

carbon dioxide (CO_2) concentrations were measured in ten nail salons located in NYC to establish baseline indoor air quality (IAQ) levels prior to the new regulations taking effect (Pavilonis *et al.*, 2018). The study showed a strong positive correlation (ρ = 0.81; $P < 0.01$) between TVOC and CO_2 concentrations and an almost 10-fold increase in TVOC levels when CO_2 concentrations exceeded 850 ppm. While this study was the first IAQ assessment conducted in NYS, it suffered from several limitations, including IAQ measurements collected over a single weekday in each salon and a lack of chemical-specific air sampling. The current study aims to expand upon the previous study and address the prior limitations by measuring the concentrations of methyl methacrylate (MMA), toluene, ethyl acetate, and TVOCs generated in nail salons across three consecutive sampling days and to estimate outdoor airflow rates in advance of the new ventilation requirements.

Methodology

Recruitment

We approached managers of nail salons in three boroughs within NYC (Queens, Manhattan, and Brooklyn) from July to September 2018. Areas within NYC with a high density of nail salons were identified each recruitment day using Google Maps, and a recruiter visited salons within that area. Salon managers were presented with a flyer that explained the goals of the study and expected time commitment from the manager. The recruiter would then answer any logistical and/or technical questions the manager had. If the manager agreed to participate, the technician would schedule a date and time to return with an informed consent form, questionnaire, and sampling equipment. A total of 307 salons were approached to participate in the study. Twelve salons refused to participate, 30 salons did not have a manager present, five salons had managers that did not speak English (a participation requirement), and at 248 salons a recruitment flyer was left with the manager, but the salon did not contact the investigators. Four salons were recruited from the authors' 2017 study, and eight new salons consented to participate in the current study. Seven of the participating salons were located in Manhattan, and five were in Brooklyn. The City University of New York Institutional Review Board approved all recruitment materials, consent processes, and the study protocol and instruments.

Walkthrough survey

The survey began with a short questionnaire administered to the manager regarding the characteristics of the nail salon. The survey assessed the characteristics of the ventilation system in the salon, whether the air was exhausted directly outside or recirculated, number and type of services typically provided, and type of personal protective equipment used by salon workers (survey available upon request). We documented the brand of nail products used in the salon. Some salons declined to allow us to record this information. We then sketched the layout of the nail salon, including the location of the diffusers, intakes, and any LEV ducts, as well as the approximate location of manicure and pedicure stations, waiting area, and other rooms in the salon (massage, waxing, etc.). Salon dimensions were determined using a laser distance measurer (GLM 30, Bosch, Gerlingen, Germany) with a maximum distance of 30.5 m. Due to the ceiling configuration and location of the air-handling units, we were unable to measure exhaust rates directly. Consequently, as described below, we used average daily CO_2 concentrations to estimate outdoor airflow per person.

Air sampling

Measurements were collected in each salon over a period of three consecutive days (Thursday, Friday, and Saturday). We selected these days to capture IAQ and ventilation measurements during high customer volume days. Instrumentation was deployed on Wednesday or Thursday morning/afternoon, depending on the manager's schedule. Equipment and sampling sheets were retrieved by technicians and data were downloaded from the instruments by the technicians. In the prior study conducted by the authors, it was determined that concentrations of CO_2 and TVOCs in salons showed little spatial variability, indicating that salon air was well mixed and area exposure was similar throughout the salon regardless of the task being performed (Pavilonis *et al.*, 2018). For this study, direct reading and passive monitors were colocated in one central location within the salon for the duration of the assessment in order to evaluate day-to-day variability in ventilation and IAQ within the salon.

Direct reading instruments

In each salon, we deployed a device to measure CO_2, temperature, and relative humidity (IAQ-Calc model #7545, TSI, Shoreview, MN, USA) and a photoionization detector (PID), calibrated with isobutylene, with a 10.6 eV lamp (UltraRAE 3000, Honeywell, Morris Plains, NJ, USA) to measure TVOC concentrations. The IAQ-Calc has a CO_2 range of 0–5000 ppm, an accuracy of ±3% of the reading or ±50 ppm, whichever is greater, and a resolution of 1 ppm. The PID has a range of

0.05–10 000 ppm and a resolution between 0.025 and 0.1 ppm depending on the concentration. Table 1 shows chemicals that have been previously identified in nail salons, whether the ionizing potential is <10.6 eV and thus detectable by the PID, and the correction factors for this PID model. High humidity can affect the PID's response resulting in underestimating concentrations (LeBouf *et al.*, 2013). The average daily relative humidity measured inside nail salons was 55% with a range of 45–69%. This was within the PID's operating specifications and any bias would be uniform across all salons, since the measurements were collected within the same season. The majority of common VOCs found in nail salons such as acetone, ethyl acetate, isopropyl alcohol, MMA, and toluene are detectable with a PID. All direct reading instruments were calibrated according to the manufacturer's instructions and programmed to datalog concentrations every minute. Direct reading instruments datalogged continuously and data were excluded when the salon was not open for business. Depending on the analyses, direct reading data were averaged by day or over the three consecutive days.

Passive monitors and daily salon information

Radiello 130 samplers (Millipore-Sigma, St. Louis, MO, USA) were used to measure daily concentrations of ethyl acetate, toluene, and MMA and colocated with the direct reading instruments. The monitors were positioned in a central location in the nail salon with air movement to prevent starvation which can cause a negative bias (US EPA, 2014). A coordinator instructed salon owners on how to open and insert the adsorbing cartridge into the diffusive body and owners were asked to change out the cartridge daily and record exposure duration. Early in the project, two salons were unable to comply with the passive monitoring protocol (salons 3 and 4). Subsequently, the protocol was updated and a coordinator sent out multiple daily reminders (morning and afternoon) via text message to remind salon managers to change out the cartridges. After we updated the protocol, only one salon for one sampling day did not adhere to the sampling methodology. Passive monitor exposure time ranged from 220 to 692 min with a mean of 525 min. Monitors were stored according to the manufacturer's instructions until analyses.

Salon owners were asked to record the number of manicures, pedicures, and artificial nails performed daily. In addition, the survey asked if the air conditioner was used and if windows and doors were kept open each day. Managers were not asked to record the duration of natural ventilation and/or air conditioner use throughout the day.

Laboratory analysis

Laboratory analyses of the Radiello 130 samplers were conducted at an American Industrial Hygiene Accredited (AIHA) laboratory (EMSL Analytical, Inc., Cinnaminson, NJ, USA). Gas chromatography with a flame ionization detector was used to detect all analytes. Ethyl acetate, toluene, and MMA were desorbed with 2 ml of CS_2 and samples were extracted using a rotary table shaker at 180 rpm for 30 min. A 1 µl aliquot was analyzed using a 30 m Restek VGC capillary column (Part number 10971, Restek, Bellefonte, PA, USA). The temperature program was 50–200°C at 10°C min^{-1}. The injector was programmed at 200°C and the detector was at 225°C. The average concentration over the sampling time was calculated from the mass of analyte found on the cartridge and the exposure time without introducing a temperature corrective factor. The laboratory reporting limits for the contaminants quantified in the study were 9.4 µg (0.048–0.152 ppm) for MMA, 8.7 µg (0.044–0.139 ppm) for toluene, and 8.9 µg (0.045–0.142 ppm) for ethyl acetate. Airborne concentrations were calculated using equation (1). Since airborne concentration is a function of exposure time, each sampling period in the study had a unique limit of detection (LOD).

$$C = (m/Q \times t) \times 10^6 \quad (1)$$

where C = airborne concentration (µg m^{-3}), m = mass of contaminant (µg), Q = chemical-specific uptake rate (ml min^{-1}), and t = exposure time (min).

Estimated outdoor airflow rate per person

We were unable to directly measure outdoor airflow rates. Therefore, we estimated outdoor airflow rates per person using equation (6) from ASTM standard D6245-18 and shown as equation (2). The CO_2 generation rate was selected for a female aged 21 to <30 years performing light work and 410 ppm was the average measured outdoor CO_2 concentration (ASTM International, 2018).

$$V_O = [N/(C_S - C_O)] \times 10^6 \quad (2)$$

where V_O = outdoor airflow rate per person (m^3 s^{-1}), N = CO_2 generation rate per person (0.0000052 m^3 s^{-1}), C_S = CO_2 concentration in the space (ppm), and C_O = CO_2 concentration in outdoor air (410 ppm).

The amount of outdoor airflow is a function of the number of occupants, season (heating versus cooling), and the square footage of the nail salon (NYS Department of State, 2016). Since the number of occupants is not uniform throughout the day, we calculated the minimum required amount of outdoor airflow based on the cooling season and the default values of 93 m^2

and 25 occupants, which equals 0.012 $m^3 s^{-1}$ of outdoor airflow rate per person.

Statistical analysis

SAS Statistical software (version 9.4, SAS Institute, Cary, NC, USA) was used to conduct all statistical analyses. Normality of average daily exposure data was assessed using the Univariate procedure and determined to be not normally distributed even after being log-transformed; therefore, non-parametric statistical analyses were performed. Descriptive statistics, including arithmetic means, standard deviations, and medians were calculated. Spearman rank-order correlations were calculated to determine correlations between average daily TVOC and ethyl acetate concentrations and salon characteristics. Kruskal–Wallis *H* tests were used to evaluate differences in CO_2 and TVOC concentrations between days. Imputation for data below the LOD was performed for the results of the passive monitors and TVOC concentrations. The LOD was divided by the square root of 2 to derive replacement values for censored data (Succop *et al.*, 2004). Salon 4 did not record the number of daily nail services provided, so the median number of services was imputed for the missing values.

Results

Descriptive data collected from the walkthrough surveys and questionnaires are presented in Table 2. The salons ranged in volume (85.5–427.6 m^3) and in the number of nail tables and pedicure stations within salons ranging from 2 to 10 and 1 to 10, respectively. Although the largest salon had five times greater volume compared with the smallest, it performed fewer average daily nail services (39 versus 62), suggesting a salon's physical size is a poor predictor of the number of customers. Salons also differed in the type of services provided. Only six salons in the study performed artificial nail services and one salon primarily specialized in spa services, such as massages, and had only three nail stations. Across all salons, the daily average customer count was relatively uniform with Friday having the highest average number of services provided compared with Thursday and Saturday. The majority of salon managers (58%) either did not have a GEV system or did not operate their system continuously while the salon was open. Of the salons that had a ventilation system installed, only 50% indicated that salon air was exhausted directly outside as mandated by the requirements. None of the salons surveyed had LEV ventilation installed.

The results from the direct reading instruments and passive monitors are shown in Table 3. Mean daily

Table 2. Nail salon characteristics.

Characteristics	Mean (range)
Location of salon (no.)	
Brooklyn	5
Manhattan	7
Volume (ft^3)	8100 (3020–15100)
No. of nail tables	6 (2–10)
No. of pedicure stations	6 (1–10)
Exhaust use (no.)	
All day	5
None	2
Periodic	4
Unsure	1
Ventilation ducted outside (no.)	
Yes	5
Recirculate	1
Unsure	4
Manicures[a]	
Thursday	23 (6–41)
Friday	30 (5–57)
Saturday	26 (7–66)
Pedicures[a]	
Thursday	21 (4–45)
Friday	26 (6–51)
Saturday	23 (6–36)
Artificial nail services[b]	
Thursday	5 (2–10)
Friday	6 (2–10)
Saturday	6 (2–12)

[a]Does not include salon 4.
[b]Only 6 salons performed this service.

indoor summer temperatures across all salons was 76°F (range: 68–82°F) with an average humidity level of approximately 55%. Fridays had the highest average daily TVOC concentrations (34 ppm); however, the day of the week was not a significant predictor of TVOC and CO_2 concentrations (P = 0.65 for TVOC; P = 0.75 for CO_2) when analyzed with a Kruskal–Wallis test. The majority of MMA and toluene samples were below the LOD. MMA was only detected in three salons with airborne concentrations ranging from 0.04 to 1.3 ppm. Ethyl acetate was most commonly detected, with 27 samples being above the LOD and an average concentration of 0.69 ppm.

Spearman rank-order correlations were calculated to determine associations between salon characteristics and average daily ethyl acetate and TVOC concentrations (Table 4). The number of daily services was not

Table 3. Daily IAQ characteristics for all nail salons.

Variable	Mean	SD (range)
Temperature (°C)	24	1.6 (20–28)
Relative humidity (%)	55	6.4 (45–69)
TVOCs (ppm)	29	25 (0.09–85)
Thursday	31	23 (0.60–66)
Friday[b]	34	30 (2.0–85)
Saturday	23	25 (0.09–74)
CO_2 (ppm)	1070	440 (460–2200)
Thursday	1120	490 (430–2200)
Friday[b]	970	310 (450–1600)
Saturday	1120	500 (450–2100)
Toluene (ppm)[a]	0.06	0.04 (0.03–0.18)
No. above LOD	5	
No. below LOD	24	
MMA (ppm)[a]	0.12	0.24 (0.04–1.3)
No. above LOD	6	
No. below LOD	23	
Ethyl acetate (ppm)[a]	0.69	0.69 (0.03–2.8)
No. above LOD	27	
No. below LOD	2	

[a]Excludes salons 3 and 4 (all days) and salon 6 (Saturday) due to lack of compliance with the sampling protocol.
[b]Excludes salon 1 due to equipment malfunction.

Table 4. Spearman rank-order correlations between select variables and average daily TVOC and ethyl acetate concentrations.

Variables	TVOC	Ethyl acetate
	r (*P*-value)	*r* (*P*-value)
Daily services	−0.10 (0.58)	0.02 (0.91)
Salon volume	−0.31 (0.07)	−0.38 (0.05)
# of services per day/salon volume	0.16 (0.36)	0.36 (0.06)
# of nail stations/salon volume	0.25 (0.13)	0.37 (0.05)
Estimated outdoor airflow rate per person	−0.69 (<0.01)	−0.80 (<0.01)
Ethyl acetate concentrations	0.92 (<0.01)	—

significantly correlated with either pollutant. A negative association was observed between larger salon volume and higher ethyl acetate ($r = -0.38$; $P = 0.05$) and TVOC ($r = -0.31$; $P = 0.07$) concentrations. A moderate positive correlation was observed between both pollutant concentrations and salon density as approximated by either the total number of daily services or total number of nail stations divided by salon volume. There was a statistically significant negative correlation between mean daily ethyl acetate ($r = -0.80$; $P < 0.01$) and TVOCs ($r = -0.69$; $P < 0.01$) concentrations and estimated outdoor airflow rate per person. TVOC and ethyl acetate concentrations were highly correlated with one another ($r = -0.92$; $P < 0.01$). Fig. 1 shows a plot of average daily CO_2 and TVOC concentrations. Overall, the correlation between TVOC concentrations was highly significant, but did vary within and between salons.

Daily estimated outdoor airflow rate per person was averaged over the three consecutive sampling days for each salon and presented in Table 5. Only three salons (1, 8, and 9) in the study met the requirements of at least 0.012 $m^3\ s^{-1}$ of outdoor airflow during the cooling season, air exhausted directly outdoors, and exhaust used all day. These three salons had no detectable amounts of MMA or toluene and had roughly half the concentrations of TVOC (16 versus 33 ppm) compared with salons that did not meet these requirements. Additionally, salons that met these criteria performed double the number of average daily nail services compared with salons that did not meet these criteria (83 versus 42). Two salons without mechanical ventilation also met the minimum guidelines of outdoor airflow (0.015 and 0.15 $m^3\ s^{-1}$) by utilizing open windows. These salons did not have a ventilation system or a dedicated exhaust installed in the salon. One of these two salons had detectable levels of MMA and the other had detectable levels of toluene. None of the five salons where managers indicated that air was recirculated or they were unsure about recirculated air met the 0.012 $m^3\ s^{-1}$ per person of outdoor airflow requirement.

Figs. 2 and 3 show CO_2 and TVOC concentrations in two different nail salons, 6 and 9, respectively. A salon achieving the recommended outdoor airflow would not exceed 850 ppm of CO_2, which is indicated by the solid line plotted on the figures. Measurements for both salons were collected on Fridays with salon 6 recording 40 customers and salon 9 logging 65 customers. Salon 6 had an average CO_2 concentration of 1760 ppm (0.0038 $m^3\ s^{-1}$ of outdoor airflow/person) and TVOC concentration of 67 ppm. The manager indicated that the salon used their exhaust all day, but was unsure if it was ducted outside or recirculated. Concentrations of both contaminants increased quickly after the salon opened and achieved a steady state around midday, with concentrations fluctuating slightly throughout the day. In salon 9, average CO_2 concentration was 870 ppm (0.011 $m^3\ s^{-1}$ of outdoor airflow/person) and TVOC concentration was 24 ppm. Concentrations of CO_2 increased throughout the day and reached a maximum concentration (1230 ppm) around closing time. TVOC

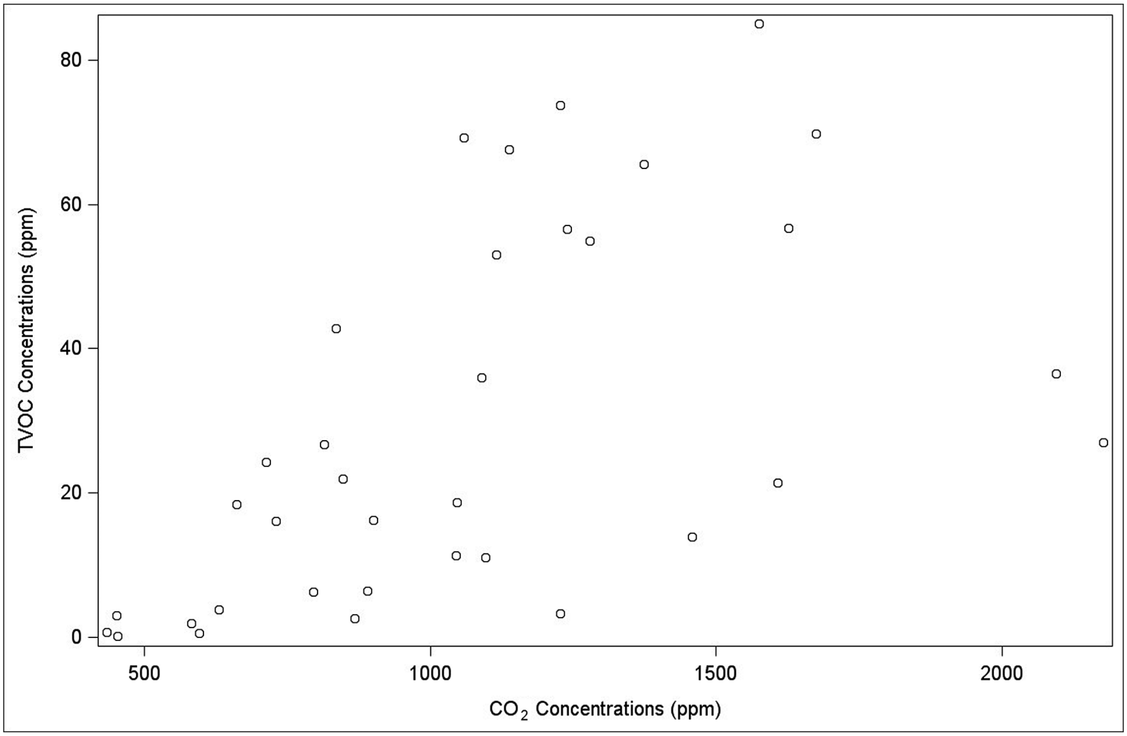

Figure 1. Plot of average daily CO_2 and TVOC concentrations (ppm) by nail salon.

Table 5. Mean estimated outdoor airflow and select salon characteristics.

ID	Mean services	Salon volume (m^3)	Mean TVOC (ppm)	Mean outdoor estimated airflow ($m^3\ s^{-1}$)	Exhaust use	Exhaust ducted outside	Windows open
1	106	227.5	17.4	0.012	All day	Yes	No
2	45	108.5	70.5	0.0060	Unsure	Yes	No
3	10	143.9	28.3	0.0034	Periodic	Unsure	Yes
4	50	153.4	44.3	0.0064	Periodic	Unsure	No
5	20	155.5	6.6	0.0076	All day	Unsure	No
6	39	427.6	67.4	0.0068	All day	Unsure	No
7	62	85.5	22.4	0.015	None	None	Yes
8	71	399.0	2.1	0.027	All day	Yes	No
9	79	282.4	27.7	0.013	All day	Yes	No
10	50	209.1	49.1	0.0066	Periodic	Yes	No
11	52	274.2	9.5	0.0097	All day	Recirculate	No
12	46	289.0	1.3	0.15	None	None	Yes

concentrations varied throughout the day and appeared to be influenced by localized sources. Although salon 9 had an estimated outdoor airflow greater than 0.012 $m^3\ s^{-1}$ per person, when averaged over 3 days, there were time periods when this threshold was not met, especially toward the end of the day.

Discussion

The objectives of this study were to measure the concentrations of key air pollutants generated in nail salons located in NYC across three consecutive days and to estimate outdoor airflow rates in advance of the new ventilation requirements. Although the implementation date

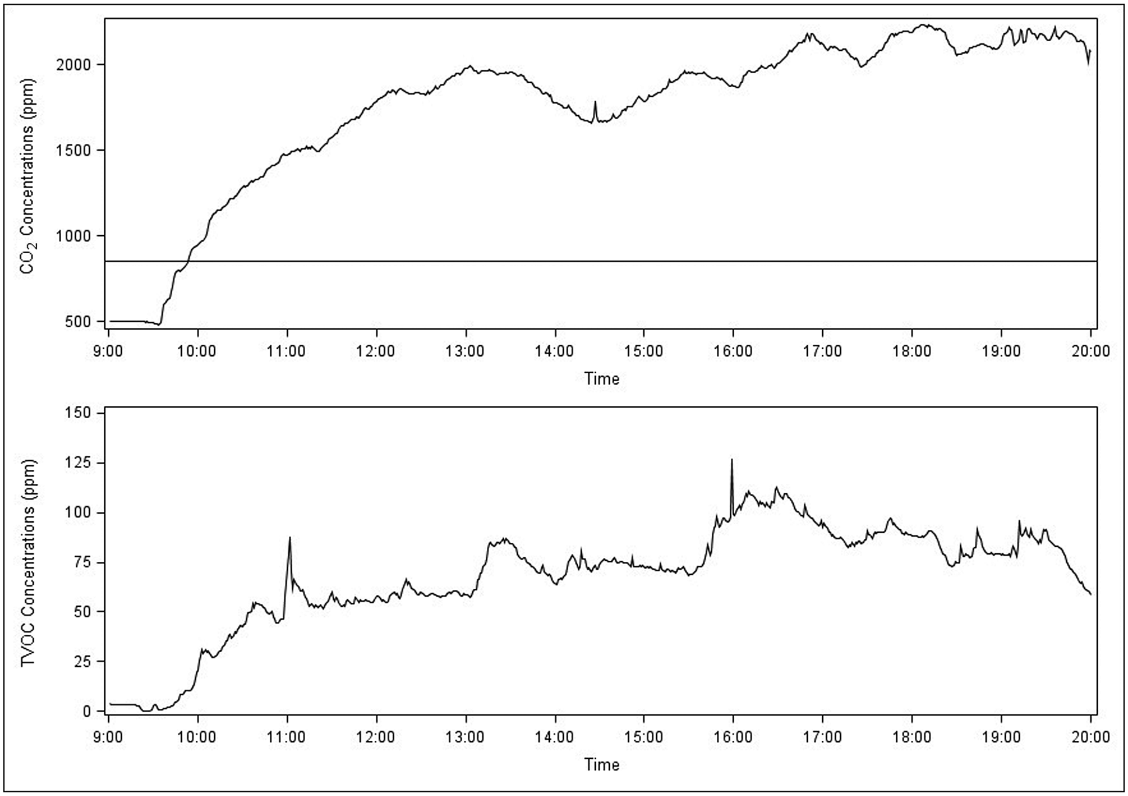

Figure 2. Time series plot of CO_2 and TVOC concentrations (ppm) in salon 6.

of the NYS regulations is rapidly approaching, none of salons surveyed in this study were in full compliance with the requirements. Only 25% of the salons met the newly established GEV requirements and none met the LEV provision of the standard. Two salons did meet the minimum outdoor airflow rate of 0.012 m^3 s^{-1} per person, but relied on natural ventilation for compliance. This strategy is only feasible during seasonable outdoor temperatures. The results of this study support the use of the IMC 2015 GEV requirements as a means for reducing workers and clients' exposures in nail salons. Because no salon had LEV, we were not able to determine what additional benefit would be provided by LEV systems in salons that met the GEV requirements.

Despite new regulations implemented by the state, results from this study indicate salon managers still have limited knowledge regarding their ventilation systems. Numerous managers were unaware if indoor air was exhausted directly outside or recirculated within the salon. Recirculated air is not permitted according to the NYS ventilation requirements and salons must have a dedicated exhaust that is in operation throughout the day. Additionally, some managers indicated that the exhaust system was used only periodically throughout the day or they were unsure about the use of the exhaust system at all. While guidelines published by the state advises salon owners to engage qualified mechanical engineers to design compliant systems, there is also the need for specific health and safety training among salon workers and managers regarding the operation and maintenance of the ventilation system (International Code Council, 2016). Salons in our study with higher daily customer counts were more likely to meet the 0.012 m^3 s^{-1} of outdoor airflow per person threshold. Public health officials might target smaller customer volume salons for health and safety training and technical assistance in order to enhance salon managers' ability to comply with the regulation. A recent report from Boston, MA found that a combination of technical assistance and enforcement ensured compliance with similar nail salon ventilation requirements (Seller *et al.*, 2019).

One of the challenges with the new regulation is determining compliance beyond the approval of a ventilation design. NYC has approximately 2000 nail salons and ventilation measurements need to be performed quickly and efficiently without the interruption of business. Ventilation assessments may be especially

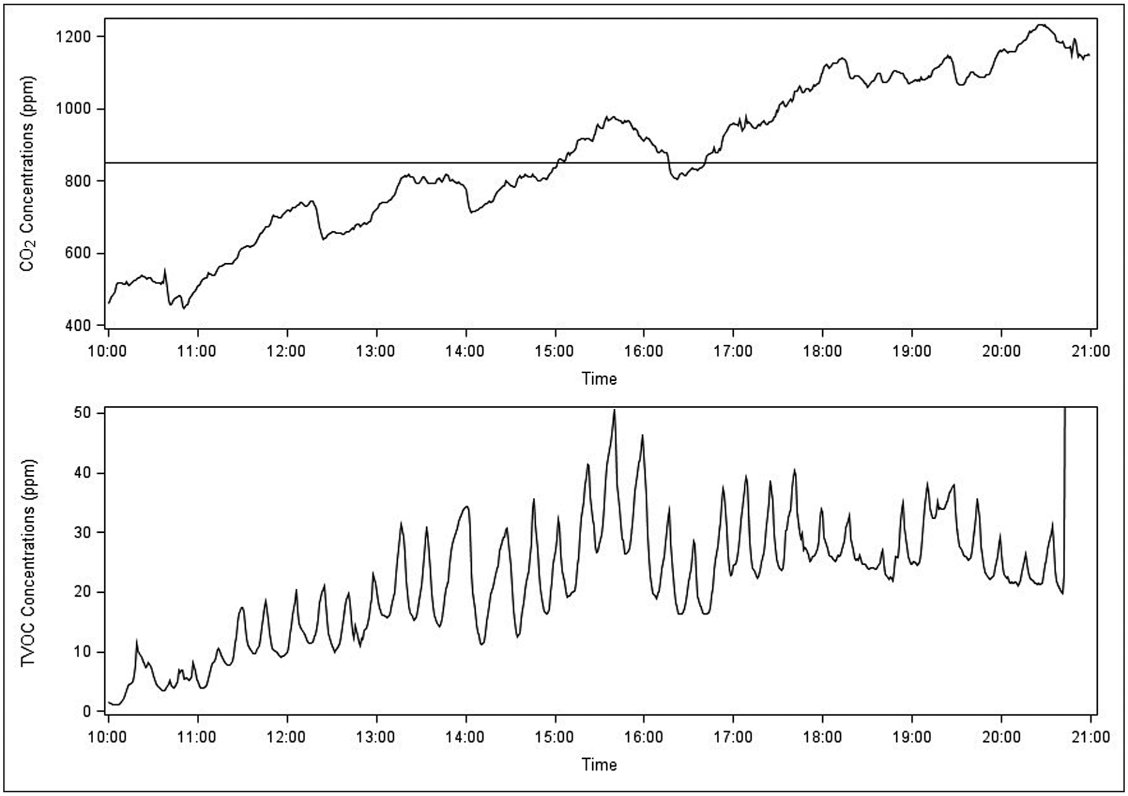

Figure 3. Time series plot of CO_2 and TVOC concentrations (ppm) in salon 9.

problematic in salons located in high-rise buildings if the salon owner does not have direct access to the system. Future studies need to be conducted to validate the ASTM method for assessing compliance with outdoor airflow requirements in nail salons as this method can be conducted by public health inspectors efficiently. Day of the week was not significantly associated with ventilation and exposure measurements and representative measurements can be performed on high customer volume days for purposes of determining compliance. Salon owners can also install low-cost CO_2 monitors in conjunction with their ventilation systems to verify and augment compliance to assure adequate IAQ despite changes in outdoor temperatures or customer counts.

Chemical-specific air sampling showed a substantial number of non-detects for toluene and MMA, while ethyl acetate was readily detected in salons. This is consistent with previous exposure studies that found similar airborne concentrations of these three chemicals in nail salons (Gjølstad *et al.*, 2006; Quach *et al.*, 2011; Alaves *et al.*, 2013; Park *et al.*, 2014; Pavilonis *et al.*, 2018; Lamplugh *et al.*, 2019; Ma *et al.*, 2019). Given the high TVOC concentrations relative to the quantified chemicals, the majority of exposures to nail salon workers are likely from alcohols and acetone, which were not quantified individually and are underestimated by the PID. Toluene is part of a group of chemicals known as the 'toxic trio' (toluene, dibutyl phthalate, and formaldehyde) and there has been an ongoing effort to substitute these chemicals out of nail products (Breskey, 2013; Occupational Safety and Health Administration, n.d.). In this study, three salons had detectable levels of toluene and used the same brands of nail products. A review of available safety data sheets showed toluene presently and formerly used in certain products manufactured by these brands. The lack of detectable concentrations toluene in the majority of nail salons may be due to the movement away from using this chemical in nail polish and fingernail glue. MMA was only detected in three salons and while monomeric MMA use is prohibited in New York (CDC NIOSH, 2018) it may continue to be used as a component of acrylic nail preparations, or it may be a contaminant or byproduct of other acrylates. The levels of MMA detected in this study are comparable to a Norwegian nail salon study and two studies conducted in the USA (Gjølstad *et al.*, 2006; Quach *et al.*, 2011; Lamplugh *et al.*, 2019). Ethyl acetate, used in nail polish, nail polish remover, and fingernail glue, was detected frequently in the salons (93%), albeit at concentrations well below the TLV, with concentrations ranging from 0.03 to 2.8 ppm and comparable to previous exposure assessments conducted in nail salons (0.001–5.5 ppm) (Gjølstad *et al.*, 2006; Quach *et al.*, 2011; Alaves *et al.*, 2013; Lamplugh *et al.*, 2019; Occupational Safety and Health Administration, n.d.).

Compared with the 2017 study conducted by the authors, salons included in the present study were smaller (229 versus 402 m^3) and had approximately 2.5 times greater TVOC concentrations. Salons in the previous study were less representative of NYC salons and tended to be more upscale, spacious, and had multiple locations throughout the area. While both studies demonstrated that an increase in outdoor airflow was effective in reducing TVOC concentrations, this study specifically addressed NYS ventilation regulations, which stipulates salons must have dedicated exhaust directed outside and cannot rely on natural ventilation to achieve compliance. This study further demonstrates the correlation between CO_2 and TVOCs and that CO_2 can be used as an indicator of IAQ in nail salons (Pavilonis *et al.*, 2018).

This study, like previous exposure assessments conducted in nail salons, was limited by relying on a convenience sample of a few salons. We visited over 300 nail salons for this study, but only 12 agreed to participate. Participating salons shared many similar features with regard to design, service types and products, and business hours as salons that refused. We relied on a participatory approach for measuring chemical-specific concentrations in nail salons and recording the number of daily services provided. Although we trained the managers how to use the passive monitors and record daily services and sent daily reminders, we were unable to assess the accuracy of this approach. In addition, area samples were collected as opposed to personal samples which generally underestimates exposure in nail salons due to proximity to the source (Quach *et al.*, 2011). Natural and mechanical ventilation use was self-reported and categorized dichotomously (Yes/No). This could cause misclassification of predictor variables, since natural and mechanical ventilation can vary throughout the day. Despite a relatively small sample size, we believe that the findings can be generalized because the salons that participated have characteristics that are similar to other salons in the general NYC region. Another strength of this study is the novel use of multiday sampling to investigate temporal variability in air quality in nail salons. Additionally, the results of this study can inform specific training programs for salon staff when the ventilation systems are installed.

Conclusions

Reducing nail technicians' exposure requires a multifaceted approach including increasing ventilation in nail salons, substitution and elimination of high toxicity chemicals, and proper usage of personal protective equipment. This study demonstrated the effectiveness of GEV to reduce occupants' TVOC exposure, which was one component of the NYS regulations. Salon should base occupancy on the maximum number of customers and technicians to ensure proper outdoor airflow. Further reduction would be likely be achieved by installing LEV systems which would improve IAQ by capturing contaminants released near workers and customers during nail services; however, in the over 300 nail salons we visited during recruitment, none had implemented this requirement. Contrary to our initial hypothesis, the number of daily nail services was not associated with increased TVOC concentrations, and salons with greater numbers of customers were more likely to meet the requirements. Many of the salon managers were unable to answer questions regarding the use and operation of their ventilation system. It is expected that many other salons, sharing similar characteristics to the ones in this study, may not be in compliance with the new ventilation regulations. More outreach to nail salons is needed by the state in preparation for the new requirements going into effect in October 2021. There are currently no published protocols for assessing compliance with the regulations postinstallation of required ventilation systems. We have established in two studies that CO_2 concentrations are a significant predictor of TVOC concentrations. Establishing baseline metrics for IAQ in nail salons can facilitate evaluation of progress toward public health goals of eliminating harmful exposures to salon personnel and their customers.

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Conflict of interest

The authors declare no conflict of interest.

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