

Fine and Ultrafine Particle Concentrations in a Cannabis Consumption Lounge

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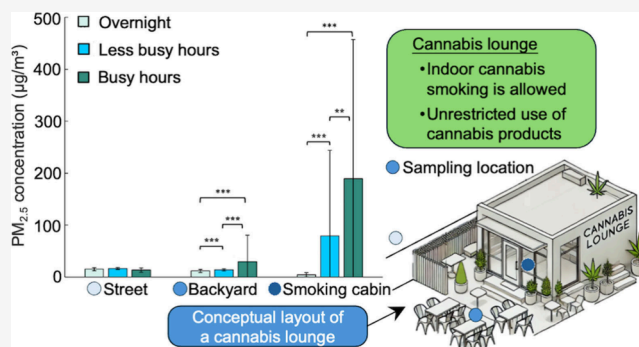
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Supporting Information

ABSTRACT: With widespread adult-use cannabis legalization in the United States, cannabis consumption lounges have rapidly emerged. However, studies of indoor cannabis exposure are still lacking, particularly in public spaces. We measured fine particle ($PM_{2.5}$) mass concentrations and particle number concentrations at a cannabis consumption lounge in Los Angeles, California. We compared particle concentrations at the street front, backyard, and two smoking cabins and identified three busyness levels to investigate concentration differences in the smoking cabin. The results showed that $PM_{2.5}$ concentrations in the smoking cabin exceeded $1600 \mu\text{g}/\text{m}^3$. During busy hours (12:00 p.m. to 10:00 p.m.), the median (IQR) $PM_{2.5}$ concentration [31.2 (317.3) $\mu\text{g}/\text{m}^3$] was >10 times higher than overnight (10:00 p.m. to 9:00 a.m.) concentrations [3.0 (1.3) $\mu\text{g}/\text{m}^3$] and >3 times higher than concentrations [8.5 (13.8) $\mu\text{g}/\text{m}^3$] during less busy hours (9:00 a.m. to 12:00 p.m.). The particle number concentration during active cannabis use [median of 1.9×10^4 , interquartile range (IQR) of 1.3×10^4 particles/ cm^3] was significantly higher than the baseline (median of 0.9×10^4 , IQR of 0.3×10^4 particles/ cm^3). Our research shows high fine and ultrafine particle concentrations in a cannabis consumption lounge, which could facilitate future studies of related health effects and the development of targeted regulations.

KEYWORDS: cannabis consumption lounge, fine particulate matter, indoor aerosols, secondhand exposure, ultrafine particles



INTRODUCTION

As of October 20, 2024, 24 states and the District of Columbia have legalized recreational cannabis use.¹ The progression of procannabis laws and policies has led to an increase in the number of cannabis users in the United States, especially among adolescents. A meta-analysis of adolescents at all school grades found a 5-fold increase in the 30-day prevalence of cannabis vaping from 1.6% (2013) to 8.4% (2020).² The estimated total number of cannabis users was 55 million in 2023.³ Various forms of cannabis businesses are rapidly growing,⁴ among which cannabis consumption lounges have emerged as a unique public space for customers to use cannabis.^{5,6} A cannabis consumption lounge usually consists of an indoor cannabis retail area and designated smoking areas. Unlike a cannabis dispensary where cannabis smoking is legally prohibited, customers can freely use cannabis at smoking areas in cannabis consumption lounges, including smoking cabins and outdoor spaces such as patios and backyards, where frequent particle emissions are observed due to active use.⁷ The city of West Hollywood received 313 applications for cannabis business licenses, with 81 of them applying for consumption lounge licenses,⁸ highlighting the urgency of assessing particle exposure levels in these unique public settings.

Currently, studies of indoor cannabis exposures are limited. Previous research investigated $PM_{2.5}$ (particulate matter with aerodynamic diameters of $\leq 2.5 \mu\text{m}$) concentrations in indoor residences due to cannabis aerosols and reported concentrations reaching high hundreds of micrograms per cubic meter or even exceeding $1000 \mu\text{g}/\text{m}^3$.^{9–11} Secondhand cannabis smoke in a car cabin was measured in another study, and the reported $PM_{2.5}$ concentration range was from 500 to $2500 \mu\text{g}/\text{m}^3$.¹¹ However, these studies applied prescribed consumption protocols and did not characterize exposures from unrestricted use in public settings. Recently, findings were published on indoor $PM_{2.5}$ concentrations in cannabis dispensaries where active use of cannabis was observed, with one reporting a mean $PM_{2.5}$ concentration of $84 \mu\text{g}/\text{m}^3$,¹² and another reporting a value of $840 \mu\text{g}/\text{m}^3$.¹³ Another study quantified $PM_{2.5}$ concentrations at an indoor cannabis event for cannabis dabbing and vaping and found mean $PM_{2.5}$ values of 564 and

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354 $\mu\text{g}/\text{m}^3$ for dabbing and vaping, respectively.¹⁴ To date, studies of particle exposures due to cannabis smoking in cannabis consumption lounge settings are still missing, thus leaving a knowledge gap about the exposure risks in these unique businesses.

Previous studies have reported $\text{PM}_{2.5}$ concentrations in various other indoor settings, where smoking is allowed. Existing evidence on indoor $\text{PM}_{2.5}$ concentrations from vape shops and hookah bars reported high $\text{PM}_{2.5}$ concentrations during active use of tobacco products, with peak $\text{PM}_{2.5}$ concentrations reaching $>1000 \mu\text{g}/\text{m}^3$.^{15–17} One study measuring indoor respirable suspended particles from cigar emissions observed concentrations of $>400 \mu\text{g}/\text{m}^3$.¹⁸ Given that cannabis consumption lounges are the only form of cannabis businesses where indoor cannabis use is legally permitted, assessment on indoor cannabis exposures is needed.

Compared to $\text{PM}_{2.5}$, ultrafine particles (UFPs) are more likely to deposit deeper into the respiratory system and potentially to pose increased toxicity given the larger surface area to mass ratio.¹⁹ However, no study has evaluated the UFP concentrations of indoor cannabis use. In this study, particle concentrations due to cannabis use are assessed in a cannabis consumption lounge in Los Angeles, California. $\text{PM}_{2.5}$ concentrations were measured and compared at different store locations. Particle number concentrations (PNCs) were measured during periods with and without active cannabis use.

METHODS AND MATERIALS

Study Location. The study was conducted in a cannabis consumption lounge in Los Angeles, California. The lounge is a street-front business with an entrance on the sidewalk. The lounge consists of three different microenvironments: (1) a cannabis retail area at the entrance, (2) a backyard, and (3) four cannabis smoking cabins in the backyard (Figure 1).

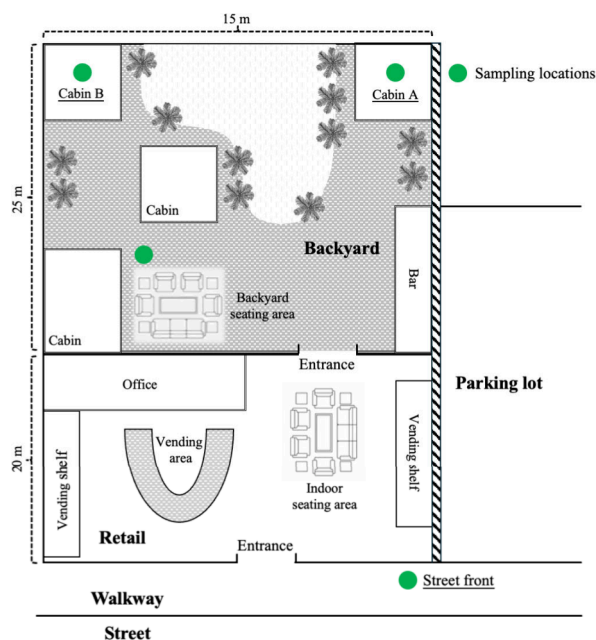


Figure 1. Schematic layout of the studied cannabis consumption lounge and sampling locations. A top view of the cannabis consumption lounge is shown. The green dots represent sampling locations at the street front, the backyard outdoor seating area, and inside two smoking cabins (cabins A and B).

Cannabis smoking is allowed at the backyard and in the smoking cabins but is forbidden in the retail area. The backyard covers an area of $\sim 375 \text{ m}^2$. Two of the four cabins (A and B) were tested. Both cabins are 25 m^3 in volume and have windows for ventilation. An air conditioner (A/C) is mounted on the wall, and an air purifier is imbedded in the wall next to the fireplace as mandated by city law.⁸ The air purifier runs for 24 h and has an estimated air exchange rate of $0.9\text{--}2.2 \text{ h}^{-1}$. For the purpose of comparison, a cannabis dispensary was also recruited. This dispensary is a street-front business located in the city of West Hollywood, 2.4 km from the cannabis consumption lounge.

Study Design. We obtained permission from the store manager to conduct experiments using air sensors and portable instruments over two test periods. During the first test period (August 28 to September 1, 2023), $\text{PM}_{2.5}$ concentrations were measured simultaneously inside smoking cabin A, in the backyard, and at the street front directly outside of the lounge. Three PurpleAir PA-II sensors (PurpleAir Inc., Draper, UT) were used for $\text{PM}_{2.5}$ sampling. One sensor was hung on the TV stand (1.5 m above the ground) in the smoking cabin. Another sensor was fixed to a support pole of the overhead shade in the backyard, 2.5 m above ground, and 10 m from cabin A. A third sensor was attached to the lamppost closest to the lounge entrance at the street front (2.5 m above the ground and 5 m from the store entrance). In the second test period (March 26 to April 3, 2024), particle concentrations in cabin A, cabin B, and a dispensary were continuously monitored using a PurpleAir PA-II sensor. This week-long measurement presents day-to-day variations and facilitates the identification of high exposure periods during the day. The PurpleAir sensor was placed on the side table inside the smoking cabins and on the vendor shelf in the dispensary throughout the test period.

To assess UFP concentrations, a 50 min session containing baseline and active use of cannabis was designed and conducted in cabin A. A 10 min baseline was first measured, followed by a 40 min test, in which four cannabis puffs were created by a cannabis user every 10 min. Particle number concentrations (PNCs) were measured using a condensation particle counter (CPC 3007, TSI Inc., St. Paul, MN). The CPC device was placed 1 m in front of the smoker on a coffee table. See the Supporting Information for more details about the sampling protocols and quality assurance/quality control (QA/QC).

Statistical Analysis. Summary statistics, including the mean, standard deviation (SD), median, and interquartile range (IQR), were calculated for each sampling day. Time series plots, bar charts, and box plots were created to visualize the distribution of the exposure levels. The *alt* algorithm (also known as ALT cf=3 or ALT CF3) was used for the analysis of indoor cannabis particles collected by PurpleAir PA-II sensors (see the Supporting Information for more details).^{20,21} A Granger causality test²² and linear regression analysis were used to test the correlation between store busyness level and $\text{PM}_{2.5}$ concentrations (see the Supporting Information for more details). All data collected were tested for normality using the Shapiro–Wilk test. A Mann–Whitney U test was conducted to compare $\text{PM}_{2.5}$ concentrations between locations and busyness levels and between PNCs during baseline and active cannabis use. A cutoff value of 10^5 particles/ cm^3 for PNC was used for comparisons between the baseline and active cannabis-use periods.

The statistical significance for all tests was set at a two-sided α level of 0.05. Data were analyzed using R Studio, version 1.2.5019.²³

RESULTS AND DISCUSSION

PM_{2.5} Concentrations at Different Sampling Locations. Figure 2 presents PM_{2.5} concentrations for a typical 6 h

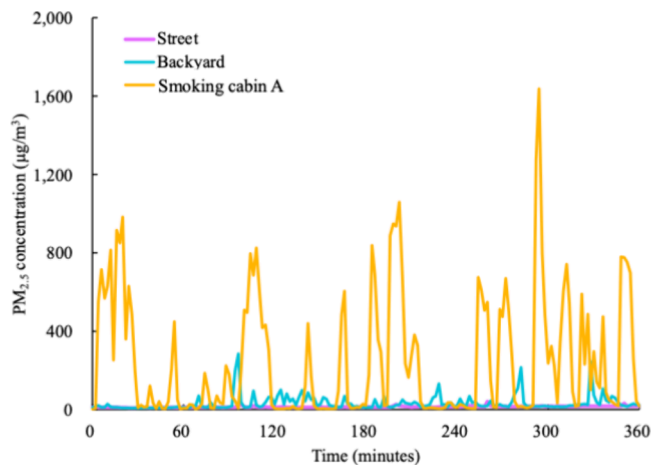


Figure 2. Time series of PM_{2.5} concentrations at different locations of a cannabis consumption lounge. Purple, blue, and orange lines represent the PM_{2.5} concentrations in the street, backyard, and smoking cabin A, respectively.

period (from 3:00 to 9:00 p.m.) at each sampling location (i.e., street, backyard, and cabin A). Throughout the 6 h sampling period, the PM_{2.5} concentrations on the street directly outside the front entrance to the lounge ranged from 7.9 to 40.7 $\mu\text{g}/\text{m}^3$. In comparison, PM_{2.5} concentrations for both cabin A and the backyard exhibited frequent larger spikes, with the peaks exceeding 1600 and 200 $\mu\text{g}/\text{m}^3$, respectively. Compared to previous studies on indoor cannabis exposure, we found that the PM_{2.5} concentration in cabin A is higher than those in residences^{9,24} and dispensaries,^{12,13} potentially due to more frequent smoking activities. Similar to cannabis consumption lounges, vape shops allow customers to freely vape electronic cigarettes (e-cigs) where high particle exposures are found.^{14,15} Our result showed that the observed PM_{2.5} concentrations in the smoking cabin exceed those from previous vape shop studies,^{16,25} suggesting that the smoking cabin is a hot spot with high exposure risks to customers and staff. Exposure to secondhand indoor tobacco smoke has been associated with chronic obstructive pulmonary disease, decreased lung function, and asthma.^{26–28} Recent research investigated short-term effects of daily PM_{2.5} exposures and identified significant increases in all-cause mortalities for all concentration ranges tested (ranges of 0–35, 35–75, and 115–150 $\mu\text{g}/\text{m}^3$), suggesting a nonthreshold relationship between PM_{2.5} exposure and health effects.²⁹ Although the chemical composition of particles from cannabis smoke is different from that of tobacco smoke,³⁰ high concentrations of particles still present a health concern. Thus, future regulatory controls are needed to mitigate particle exposures in cannabis consumption lounges.

We then conducted a week-long sampling in the second test period to study day-to-day variation and identify high exposure hours. As shown in Figure S1A, spikes in PM_{2.5} concentrations in cabin A were observed across all sampling days except

Monday, likely because no customers were smoking cannabis on that day. Wednesday and Thursday had lower-magnitude spikes ($<100 \mu\text{g}/\text{m}^3$) than did Friday, Saturday, Sunday, and Tuesday. The peak PM_{2.5} concentration across the sampling week was observed on Saturday (580.3 $\mu\text{g}/\text{m}^3$). Higher PM_{2.5} concentrations were more likely observed in the afternoon hours across all days, indicating increased smoking activities. Cabin B showed patterns similar to those of cabin A (Figure S1B), with higher PM_{2.5} spikes observed on Friday, Saturday, and Sunday and no spikes or smaller spikes observed from Monday through Thursday. The peak PM_{2.5} concentration across the sampling week was observed on Saturday (982.4 $\mu\text{g}/\text{m}^3$). The week-long time series suggested that the PM_{2.5} concentration in the smoking cabin varied across days, possibly suggesting more cannabis use during weekends than during weekdays. This observation agrees with the smoking pattern previously reported in adolescent tobacco smokers, which suggested more smoking on weekends than on weekdays.³¹ In comparison, inside the dispensary, the most prominent PM_{2.5} spike occurred on Tuesday, with the peak concentration reaching only 23 $\mu\text{g}/\text{m}^3$ (Figure S1C). We did not observe busy weekdays or times of day affecting the overall concentration, as smoking is not permitted in the dispensary, resulting in consistently low concentrations.

PM_{2.5} Concentrations at Different Busyness Levels.

To investigate the impact of cannabis smoking activities on observed PM_{2.5} concentrations, we calculated store busyness levels as defined by the ratio of the hourly foot traffic to the maximum foot traffic for each weekday. Hourly foot traffic is derived from historical data of the business. The PM_{2.5} concentration ratio is calculated by dividing hourly PM_{2.5} concentrations by the maximum PM_{2.5} concentration for each weekday observed in cabin A (see the Supporting Information for more details). Using a linear regression model, we found a moderately high positive relationship ($R^2 = 0.64$) between busyness levels and hourly PM_{2.5} concentration ratios (Figure S2), suggesting that increased busyness is associated with higher PM_{2.5} concentrations. The Granger causality test also suggested that the busyness level Granger-caused the changes in hourly PM_{2.5} ratios²² [see the Supporting Information, Granger causality test (Table S1)]. Previously, we reported store occupancy (number of customers vaping per 30 min) as a predictor for e-cig particle concentrations in vape shops,¹⁵ and a similar pattern was found in the smoking cabin (cabin A) of the cannabis consumption lounge in this study.

We then categorized each day into three time periods [i.e., overnight (10:00 p.m. to 9:00 a.m.), less busy hours (9:00 a.m. to 12:00 p.m.), and busy hours (12:00 p.m. to 10:00 p.m.)] (see the Supporting Information for classification methods). PM_{2.5} concentrations in the street front, backyard, and smoking cabin A were analyzed and compared between these time periods. During busy hours, the mean $\pm$ SD and median (IQR) PM_{2.5} concentrations were $189.5 \pm 267.9 \mu\text{g}/\text{m}^3$ and 31.2 (317.3) $\mu\text{g}/\text{m}^3$, respectively, in cabin A, with means being >40 times higher than those during the overnight hours ($4.4 \pm 4.1 \mu\text{g}/\text{m}^3$) and medians being 10 times higher than overnight levels [3.0 (1.3) $\mu\text{g}/\text{m}^3$] (Figure 3). The air purifier possibly reduced the PM_{2.5} concentrations in cabin A during the overnight hours compared to those on the street front and in the backyard as lower concentrations were observed. The PM_{2.5} concentration in the street front showed no significant difference across all hours. Published vape shop studies have noted the transport of particles from inside the shop to the

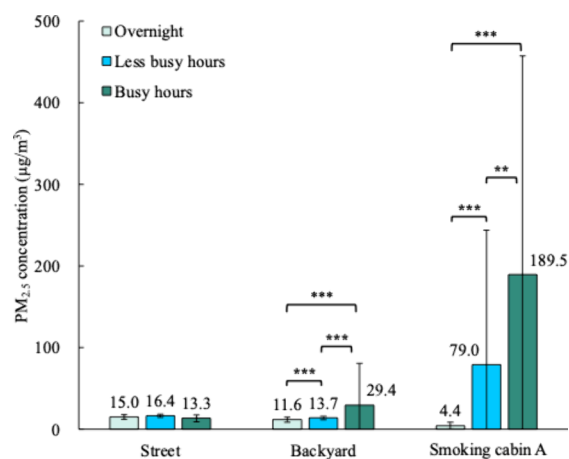


Figure 3. PM_{2.5} concentrations at three locations during different times of the day at a cannabis consumption lounge. Error brackets representing the standard deviation are shown. Differences in the mean PM_{2.5} during three time periods (overnight, less busy hours, and busy hours) were compared using the Mann–Whitney U test. Different levels of statistical significance are shown using asterisks (** $p < 0.01$; *** $p < 0.001$).

ambient and adjacent businesses.¹⁶ However, our results showed no apparent increase in PM_{2.5} concentrations in the street front. As shown in Figure 1, the cannabis retail building may act as a barrier that blocked particle transport from the smoking cabin and backyard to the street. Local meteorological conditions, such as the direction of the wind, may also affect particle transport. Future studies on cannabis tracer chemicals³² are needed to determine the transport of cannabis aerosols by comparing the chemical constituents of collected samples inside and outside the facility.

Summary statistics on PM_{2.5} concentrations at different busyness levels (i.e., overnight, less busy, and busy hours) for cabin A during all seven weekdays are presented in Table S2.

PNC during Active Cannabis Use. UFP concentrations were tested during a 50 min session: a 10 min baseline and a 40 min active-use period with four puffs generated every 10 min. A significantly higher PNC was detected when the customer was actively using cannabis [median (IQR) of 1.9×10^4 (1.3×10^4) particles/cm³] compared to the baseline [median (IQR) of 0.9×10^4 (0.3×10^4) particles/cm³] (Figure S3). The initial PNC spikes after cannabis puffs were created reached $>100\,000$ particles/cm³, which is >10 times higher than the baseline concentration. The PNCs in cabin A were comparable to but slightly lower than those previously reported in vape shop environments possibly due to the different consumption method used.^{15,16,33} A previous study on cannabis vaping also suggested higher particle concentrations from vaping than from smoking.¹⁰ Long-term and short-term health effects due to UFP exposures have both been associated with oxidative stress and cardiovascular outcomes.³⁴ As such, studies focusing on mitigating UFPs in cannabis consumption lounges are needed to contain exposure risks.

Limitations. This study has a few limitations. First, to avoid disrupting normal business operations and unnecessary overexposure, no researchers were on site to record the store occupancy in terms of the number of customers and their smoking frequency. Nevertheless, we were able to discover a positive relationship between store busyness levels and PM_{2.5} concentrations using linear regression and the Granger

causality test. Second, only low-cost sensors were used for longer-term measurements, as we were permitted to bring only small instruments to avoid affecting normal business. As this experiment is one of the first studies conducted in a cannabis consumption lounge setting, future experiments can be improved by selecting more representative sampling locations, extending sampling durations, and including more information about on-site cannabis usage and store foot traffic. Due to the high particle concentrations observed in the cabin indoor area, future studies should explore effective ventilation strategies and identify appropriate ventilation rates for mitigating secondhand exposure and informing future regulatory controls for cannabis consumption lounges.

In summary, our study showed high particle concentrations in a cannabis consumption lounge, especially the smoking cabin, which has large day-to-day variations and variations within a day depending on the busyness level. UFP concentrations are significantly higher during active cannabis use and 10 times the concentration of the baseline. This study provides a better understanding of the exposures within the rapidly growing cannabis consumption lounge segment and facilitates future studies on cannabis-related health effects as well as the development of regulations to control indoor cannabis exposure.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at <https://pubs.acs.org/doi/10.1021/acs.estlett.4c01019>.

Additional experimental details, including sampling protocols and QA/QC, store busyness level calculation and categorization, and the Granger causality test, and additional results for Granger causality test p values for different lags, week-long PM_{2.5} time series, summary statistics for cabin A, relationship between store busyness ratio and background-subtracted PM_{2.5} ratio, and PNC comparisons between baseline and active cannabis use (PDF)

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Author Contributions

^VM.N. and Y.Y. contributed equally to this work.

Notes

The authors declare no competing financial interest.

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■ ABBREVIATIONS

e-cig electronic cigarette
PM_{2.5} particulate matter with aerodynamic diameters of ≤ 2.5 μm
PNC particle number concentration
UFP ultrafine particle, particle diameter of ≤ 0.1 μm

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