Title
Assessing Ultrafine Particles Exposure in Electronic Cigarette Vape Shops

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Publication Date
2016

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA

Los Angeles

Assessing Ultrafine Particles Exposure in Electronic Cigarette Vape Shops

A thesis submitted in partial satisfaction

of the requirements for the degree Master of Science

in Environmental Health Sciences

By

Chanbopha Sen

2016

ABSTRACT OF THE THESIS

Assessing Ultrafine Particles Exposure in Electronic Cigarette Vape Shops

By

Chanbopha Sen

Master of Science in Environmental Health Sciences

University of California, Los Angeles, 2016

Professor Yifang Zhu, Chair

Introduction: Vape shops have grown in popularity among adults and youth. The increased popularity of electronic cigarettes has triggered many new businesses to open within the last three years to sell electronic cigarettes devices, flavor liquids and provide a place for lounging. High levels of ultrafine particles (UFP) are generated when active vaping is occurring.

Objectives: 1. Quantify and understand the spatial distribution of ultrafine particles in vape shops. 2. Identify factors that generate elevated levels of ultrafine particle concentrations.

Methods: Two vape shops in Southern California were recruited to participate in the study. There were six testing days for vape shop A and four testing days for vape shop B. Ultrafine particles were collected using two TSI Condensation Particle Counters. Carbon dioxide, relative humidity and temperature were also measured using a TSI Q-Trak Plus. CPC A was placed in a high activity area and was kept there for subsequent sessions. CPC B rotated around the store and outside. The Q-Trak was placed with CPC A during the sampling sessions. The air exchange rate (AER) was calculated using one overnight CO_2 trend data using the TSI Q-trak.

Results: A temporal profile of UFP showed that high spikes of UFP were observed during vaping. The CPC placed in a low activity area, showed similar up and down fluctuations of UFP as shown in CPC A, even when no activity was occurring near the instrument. The UFP increased significantly when 1-2 and 3+ individuals were vaping compared to when no vaping was occurring. The UFP differed significantly ($P<0.001$) in both vape shops even when averaging the UFP concentration when zero, 1-2 and 3+ people were smoking. This is likely due to differences in the ventilation of the shops. The AER for Vape Shop A was 3.8$hour^{-1}$ and for Vape Shop B is 4.8$hour^{-1}$. The indoor-outdoor ratio is 10:1 and 1.4:1 for Vape Shop A and Vape Shop B respectively. Data also showed when CO_2 levels are increased the UFP levels also increased.

Conclusions: This research shows that e-cigarettes are a major source of UFP in the vape shops. Also, higher levels of UFP is seen when 1-2 and 3+ individuals are smoking and the indoor UFP levels are significantly reduced in the more ventilated shop.

The thesis of Chanbopha Sen is approved.

Shane Que Hee

Wendie Robbins

Yifang Zhu, Committee Chair

University of California, Los Angeles

2016

Table of Contents **Pages**

Table of Contents for Figures and Tables

Acknowledgments

Special thank you to the employees in the two vape shop locations, especially Clifford T. and Boris K. This research would not have been possible without your participation. Also special thank you to Dr. Zhu and team for providing guidance and expertise. Lastly to my parents and Eberth Q for moral support.

1. **Introduction**

Over recent years electronic cigarettes (e-cigarettes) have steadily increased in popularity among adults and children (King et al. 2015, Arrazola et al. 2015). Traditional tobacco smokers are now moving towards using e-cigarettes as cessation aids or as an alternative (Cobb et al 2013, Tan et al 2014). Using the 2011, 2012, 2013 National Youth Tobacco Surveys of students in grades 6-12, Bunnell et al. (2015) found e-cigarette use increased from 79,000 to greater than 263,000 among those who reported never having used tobacco cigarettes. In 2014, e-cigarettes were the most commonly used smoking product in middle and high school students in the US (CDC, 2013) and was second most popular smoking method in Southern California schools (CDC, 2013). Young adults age 18-24 were more likely to try e-cigarettes than older adults (Schoenborn et al. 2015). E-liquid, the liquid in e-cigarettes that contains flavor and nicotine, come in a variety of flavors which can attract younger audiences (Zhu et al. 2014).

E-cigarettes are battery-powered devices that deliver nicotine, propylene glycol or glycerol and flavoring via vaporization (Bullen et al. 2010; Goniewicz et al. 2014). There are two types of e-cigarettes: disposable e-cigarettes and refillable e-cigarettes (Grana et al. 2014). The puffing of these e-cigarettes results in the formation of aerosols and vapors or “vape”. Nicotine concentration is variable and typically ranges from 0 mg - 24 mg per cigarette or in e-liquid fluid (Chen et al. 2013). Independent testing of e-cigarettes found that nicotine varied between batches and brands. Certain metals have been detected in the e-liquids which can be dangerous to users and by-standers (Wolfgang et al 2014; Goniewicz et al. 2014; Williams et al. 2014).

In 2014, there were 8,500 vape shops in the United States that generated about 900 million dollars in sales (USA Today, 2015). In California, there were 1836 vape shops in 2015, most of which opened in the last three years (LA Times, 2015). In Los Angeles alone there were 103 vapes shops in 2014 (Sussman et al. 2014). With the increase of sales and use of e-cigarettes, the activities taking place inside the vape shops are important parameters to investigate. Despite the electronic smoking devices growing in popularity internationally and domestically, research data are limited on active and passive exposures to e-cigarettes in particularly in vape shops. Some local store vape shop owners believe that vaping is a safer alternative to smoking and compare them to food products ingredients (Cheney et al. 2015). Up until recently e-cigarettes were not monitored by the Food Drug Administration (FDA), however they recently announced to expand their authority to regulate e-cigarettes (FDA, 2016).

There is limited research that explores the parameters of the impact of indoor air quality from e-cigarettes. Despite few studies available, researchers have found metals, volatile organic compounds (VOC), nicotine, propylene glycol, and glycerol in exhaled e-cigarette emissions (Schripp et al. 2013, McAuley et al. 2012, Schober et al 2014). With the increased use of e-cigarettes in the United States and the number of vape shops opening, parameters such as bystander exposure, occupant exposure, worker exposure, and air quality trends are important to investigate. To our awareness, no indoor air quality studies have been conducted in vape shops.

People who work in poor indoor air quality run the risk to experience health symptoms such as headaches, eyes, nose and lungs irritation (OSHA, 2012). Parameters such as poor ventilation, high carbon dioxide levels, humidity, and particulate matter are important to consider in an indoor air quality assessment (OSHA, 2012).

The Occupational Health and Safety Administration (OSHA) has set limits on fine particles allowed in the workplace in terms of inhalable and respirable sizes (OSHA, 2012). Exposure to fine, particulate matter (PM) with an aerodynamic diameter of 2.5μm, often termed PM2.5, and ultrafine particles (diameter <100nm), have been identified to cause adverse health effects (Donaldson et al. 1998, Donaldson et al. 2001, Oderdorster et al. 1990). Soule et al. (2016) investigated fine particle concentrations in a two day E-cigarette event and found that concentrations ranged 311.7-818.9 $\mu g/m^3$ above a baseline level of 1.92-3.20 $\mu g/m^3$.

In our study we investigated two vape shops in Southern California and monitored their ultrafine particle concentrations. E-cigarettes have been shown to have elevated levels of UFP (Laugesen et al. 2009, Schripp et al., 2012, Fuoco et al. 2013, Zhao et al. 2016). UFP have been linked to several different health symptoms (Pekkanen et al, 1997; Peters et al 1997). Ultrafine particles can penetrate deeper into the respiratory system than $PM_{2.5}$ and PM_{10} and can even go into the bloodstream (Terzano et al. 2010).

The two objectives of this study were to understand the spatial distribution of ultrafine particles in the vape shops and to identify factors that generate elevated levels of ultrafine particles concentrations.

2. Experimental Methods:

2.1 Recruitment:

The geographic regions of the shops were in Southern California. Recruitment was conducted by walk-ins and phone calls. Three shops were initially recruited. However, one shop went out of business and was no longer able to participate. Therefore, only two shops participated.

2.2 Characteristics of the Vape Shops:

Vape Shop A is located in the San Gabriel Valley in California. The shop is located in the corner of a major street. Adjacent to the shop is a glass supply store. The inner dimensions of the shop are 6.44 m x 8.63 m x 5.72 m. with a volume of 317.90 m^3. The backroom was not taken into account since the doors leading to this room were always kept closed. Inside the shops there are four major sections: a glass counter, a liquid sampling area, a lounge, and a back storage area. There are usually three employees working. The store lacks a ventilation system but instead uses an air conditioner which recirculates the air but does not replenish it with the outside air. The front door of the store is usually kept open providing outside air. The back storage area door is kept closed for the majority of the store hours. The store opens Mondays to Sundays from 11:00 am to 12:00 am.

Vape Shop B is located in the San Fernando Valley in California. It is in a small shop strip adjacent to two ethnic sit-in food restaurants. The inside dimensions of the shop are 4.40 m x 22.81 m x 2.61 m with a volume of 262.01 m^3. There are three major sections: the lounge, a liquid sampling area, and a display glass case area. The store has two doors which are kept open for the majority of the day. There are several vents inside the store as well. There is usually only one employee working the full operating hours. The store is opens from Monday to Sunday from 10:00 am to 10:00 pm.

2.3 Sampling days and hours:

There were six sampling days for Vape Shop A and four sampling days for Vape Shop B. Differences in sampling sessions were due to the availability of the store. Sampling occurred during business hours. Morning samples were conducted approximately at 12:00 pm to 5:00 pm. Night samples are defined as 5:00 pm to 10:00 pm. There were four night samples and four day samples collected for Vape Shop A. There were three night samples and two morning samples for Vape Shop B. For Vape A there were four weekends and two weekday samples. For Vape

Shop B there were two weekdays and two weekend samples. **Table 1** summarizes the characteristics of the shops.

Table 1 Summary of sampling schedule and characteristics of the shops.

Descriptions	Vape Shop A	Vape Shop B
Vape Shop Location	San Gabriel Valley, CA, US	San Fernando Valley, CA, US
Number of Days Sampled	6	4
Number of Weekends	4	2
Number of Weekdays	2	2
Dimensions	6.44 m x 8.63 m x 5.72 m.	4.40 m x 22.81 m x 2.61 m
Volume	317.90 m^3.	261.95 m^3
Ventilation System	Air Conditioner Unit/ Prop Door Open	Central Ventilation System, Two doors prop open (One located in the rear of the store; one in front of the store.)
Building Type	Corner Shop with an adjacent building	Shop strip
Stores Nearby Shop	Glass Supply Store	Sit-in Restaurants on either side of the shop
Number of Employees	2 Employees, 1 Manager	1 Employee
Store Capacity	N/A	59

2.4 Vape Shop A Sampling Protocol:

The instruments used for sampling ultrafine particles and carbon dioxide levels were two TSI Condensation Particle Counters (CPC 3007, TSI Inc., St. Paul., MN, USA) and a TSI Q-Trak Plus (Model 8554, TSI Inc., St. Paul, MN), respectively. The first day of sampling, CPC A was moved to determine the most impacted area (See Figure S1). Once a high exposure area was determined, CPC A was placed in that area for all other sessions, and CPC B rotated within the store. CPC B was moved to the lounge, behind the counters and outside of the store. Sampling Session 1 was conducted on a Friday 12:00 to 17:00 and was considered the preliminary sampling session and was used to determine areas of high to low levels of UFP concentration. During sampling Session 2 the CPC B was placed in the lounge area. For sampling Session 3 the CPC B was placed behind the counter where there is low customer traffic to simulate cashier worker exposure. For sampling Session 4 the CPC B was placed outside for half the day and only

CPC B continued to record for the rest of the day. In sampling Session 5 the CPC B was placed again in the lounge area. Finally, for Session 6 CPC B was placed behind the employee's counter where there is low customer traffic (see **Table 2** for a summary).

2.5 Vape Shop B Sampling Protocol:

Similar protocols to those for Vape Shop A were conducted for Vape Shop B. CPC A was located behind the counter of the worker. CPC B was located above the vending machine for the first test day. During the second and third sessions of testing CPC B was moved to the liquid sampling area. On the fourth session of sampling CPC B was placed outside to determine the indoor-outdoor ratio of ultrafine particles. The Q-trak was placed next to CPC A for the duration of the sampling sessions (See Figure S2).

Table 2 Sessions summaries of Vape Shop A and Vape Shop B.

Sessions	Vape Shop A Location of CPC B[1]	Vape Shop B Location of CPC B[2]
1	Preliminary Session	Left Side of Employees counter
2	Lounge	Left Side of Employees counter
3	Behind Employee's Counter Left Side	Left Side of Employees counter
4	Outside-Inside Ratio	Outside-Inside
5	Lounge	NA
6	Behind Employee's Counter Left Side	NA

[1]Vape Shop A CPC A was always located on the right side of the employee's counter.
[2]Vape Shop B, CPC A was located on top of a vending machine on session one and moved to liquid sampling location for the subsequent sessions.

2.6 Air Exchange Rate (AER):

The air exchange rate was calculated by CO_2 decay method using the TSI Q-trak. The Q-trak was left overnight for one night when no employees were in the store to determine the decay rate.

The equation used to calculate the AER is:

$$-\ln\left(\frac{C(t)-Co}{C(t=0)-Co}\right) = \lambda * t$$

where C(t) is concentration as a function of time t, C_o is the outdoor CO_2 concentration (380-400ppm), C(t=0) is the initial CO_2 room concentration, λ is the number of volumetric air changes per hour.

3. Results and Discussion:

3.1 Temporal profile of UFP concentration inside Vape Shop A

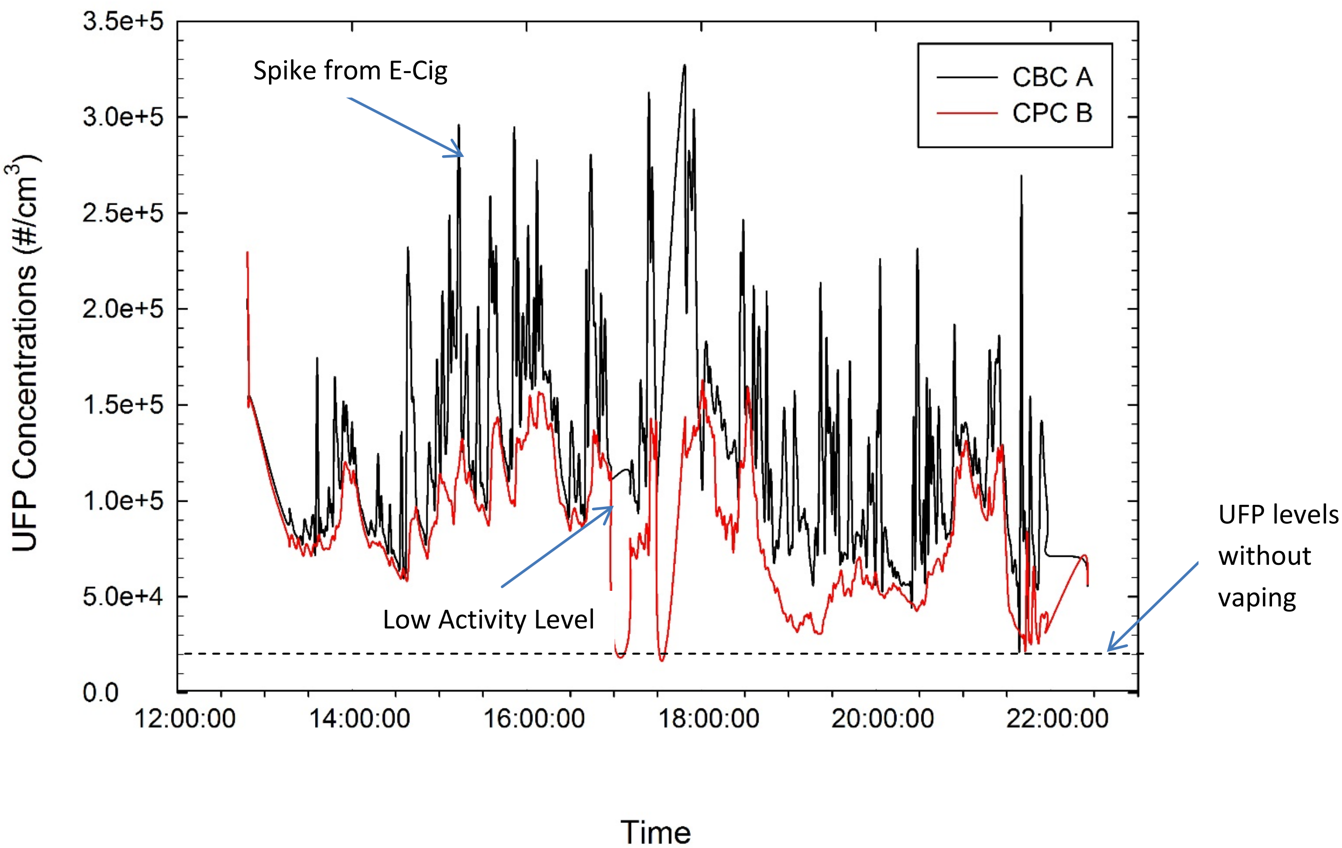


Figure 1 Temporal profile of UFP concentrations of two CPCs in Vape Shop A. CPC A was located 0.61 m from active smoking and CPC B is located approximately 3.7 m diagonally.

In Vape Shop A the high peaks shown in **Figure 1** were likely from evaporation of a single puff of e-cigarette with a maximum of 4.81E+05 #/cm. Once the e-cigarette was evaporated the UFP concentration reduced back down to background levels. CPC A logged the UFP particle trends near the high activity area was able to capture most of the e-cigarette emissions that was occurring. Personnel were usually located about 0.60 m from CPC A. However, the red trend line in figure 1 logged the UFP concentration in the low activity area (CPC B). CPC B was placed in the lounge area approximately 3.7 m from the instrument placed in the high activity area. As shown in Figure 1, the concentrations near CPC A were consistently higher than the concentration in the low activity area. The visual air clarity decreased causing a foggy atmosphere in the room when high rates of smoking occurred at times 14:00 to 16:00. The low activity area did not show high spikes of e-cigarette emission due to no one smoking near the instrument. When comparing the UFP trends against the low activity trends the UFP concentration follows the same trends as the concentration in the high activity area, suggesting that there are some ingredients that linger~~s~~ inside the room and do not fully volatilize.

3.2 UFP Concentrations compared to number of people that were actively smoking

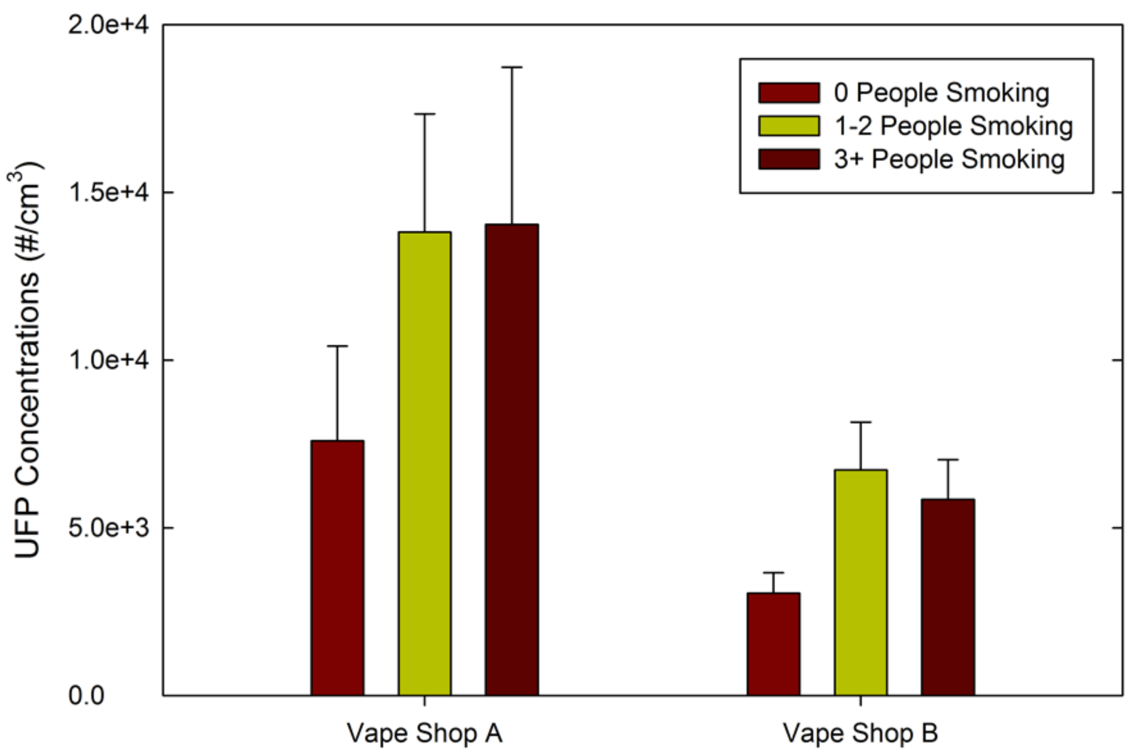


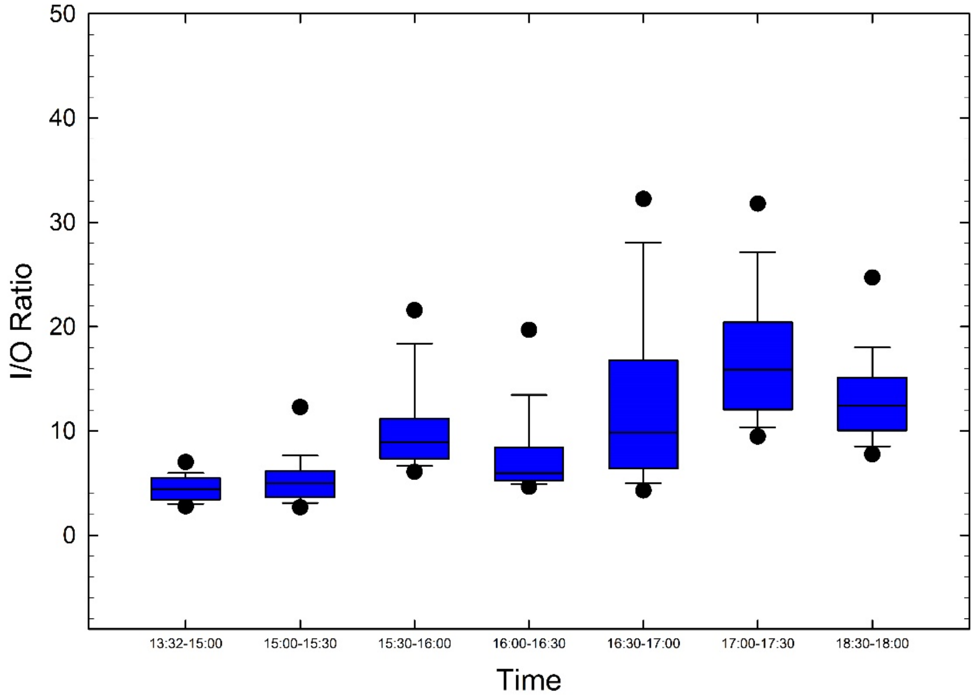
Figure 2 UFP Concentrations when zero, 1-2, 3+ people are smoking e-cigarettes.

Figure 2 shows there is a significant difference (P=<0.001) using the Mann-Whitney Rank Sum Test at in the average of the UFP concentrations between the two shops. In Vape Shop A the UFP concentrations averaged for the CPC located in the high-impacted area were 7.59E+04 ± 3.1E+04 #/cm^3, 2.8E+04 ± 6.1E+03 #/cm^3, 1.4E+05 ± 6.7E+04 #/cm^3, when zero, 1-2, and 3+ people were smoking respectively. In Vape Shop B the UFP concentrations averaged 2.83E+04 ± 6.1E+03 #/cm^3, 6.72E+04 ± 1.4E+04 #/cm^3, 5.85E+04 ± 1.2E+04 #/cm^3 when zero, 1-2 and 3+ people were smoking respectively. The UFP concentrations were significantly lower when no vaping was occurring. There were no differences when 1-2 and 3+ people were vaping. This could be explained relative to individual smokers' vaping habits. Behar et al. (2015) found that smokers who were more experienced had puff durations of 2.65± 0.5s and similarly Farsalinos et al. (2013) found that experienced EC smokers had higher puff durations than unexperienced smokers. UFP levels variabilities could be caused by doors propped open to aid in venting foggy atmospheres when vaping activities increase~~s~~.

3.3 Indoor-Outdoor (I/O) UFP Ratio Differences between Vape Shop A and Vape Shop B

The indoor and outdoor UFP ratios of the stores are significantly different at $p \leq 0.001$ using the Mann Whitney Rank Sum Test. In Vape Shop A and Vape Shop B the ratios are 10.4:1 and 1.4:1, respectively. This could explain the significant differences in UFP readings in Figure 2. Even when the same number of people was smoking in both of the vape shops the UFP were very different, as were their e-cigarette types vaped. In Figure 3, the I/O ratio was calculated in 30 minute intervals throughout the morning shift. Vape Shop A I/O ratio was high for indoors because of poor ventilation (AER= 3.8hr^{-1}) and high UFP concentrations. As shown in Figure 1, the UFP concentration consistently stayed high throughout the measurement days, causing the inside air quality to be very stuffy. In Vape Shop B the ratio was also consistent throughout the day; partly because there was a constant air flow (AER= 4.8hr^{-1}). In Vape Shop B, the back door and front door was open throughout most of operating hours of the store thus the store rarely become foggy from smoking activities. In Vape Shop A the inside concentration of UFP ranged from 4.01E+04 #/cm^3 to 4.94E+05 #/cm^3. The outside UFP ranged from 7.98E+03 #/cm^3 to 4.89E+04 #/cm^3. The indoor-outdoor ratio average was 10.4 ± 6.9. In Vape Shop B the inside concentration of UFP ranged from 1.32E+04 #/cm^3 to 2.48E+05 #/cm^3 and the outside UFP ranged from 2.26E+04 #/cm^3 to 1.51E+05 #/cm^3. The indoor-outdoor ratio averaged 1.41 ± 0.406.

A



B

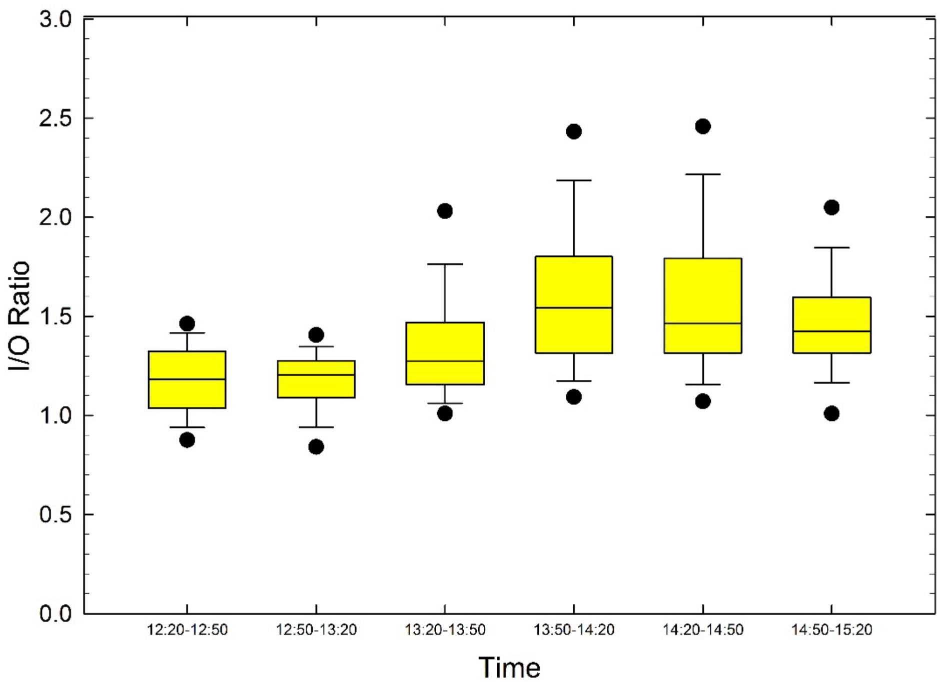


Figure 3 (A) Indoor and Outdoor UFP ratio for (A) Vape Shop A and (B) Vape Shop (B)

3.4 Carbon Dioxide and UFP Correlations

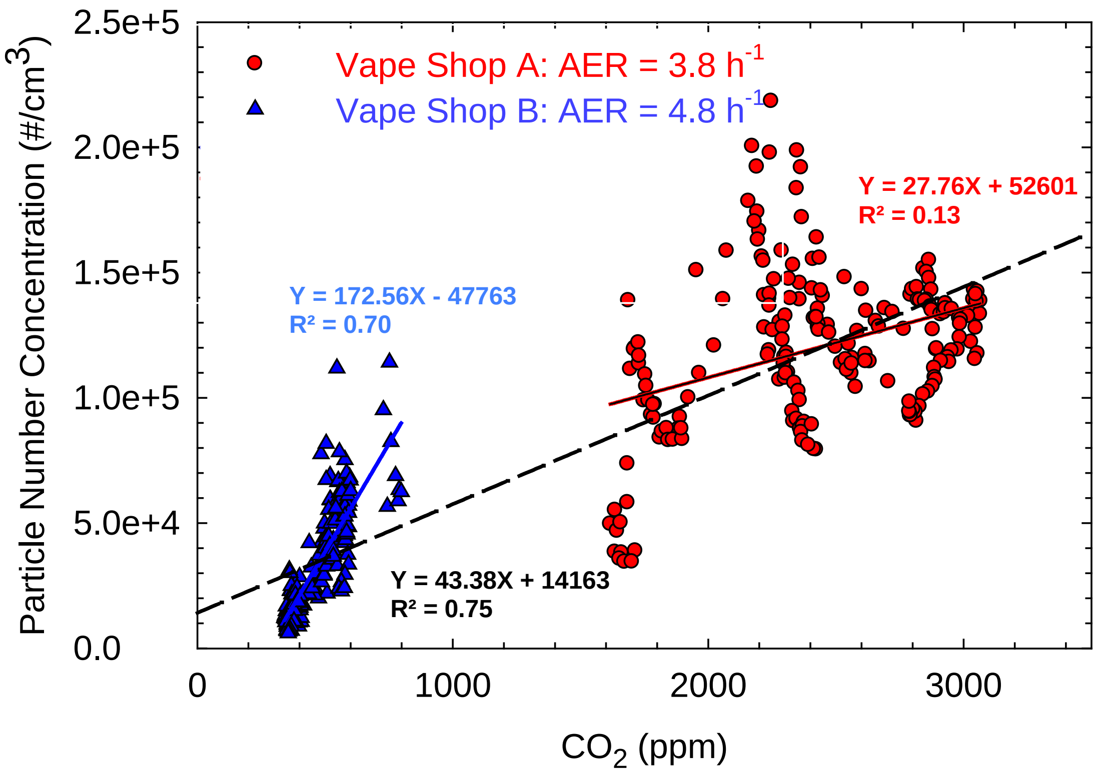


Figure 4 CO2 Levels versus UFP (#/cm^3) in Vape Shop A and Vape Shop B. Vape Shop A has significantly larger levels of UFP and CO2 levels compared to Vape Shop B.

The air exchange rate for Vape Shop A and B is 3.8 hour^{-1} and 4.8 hour^{-1}, respectively. In a website tool called Engineering Toolbox, the website suggest a bar environment should have an AER of 20-30hr^{-1}. In Vape Shop A the CO_2 concentrations averaged 1326.2 ± 686.9 ppm over all the sampling days, clearly being non-normal distribution in nature. The relative humidity in Vape Shop A ranged from 29.5% to 47.2% and the temperature ranged 71.4 F to 76. 7 F. In Vape Shop B the CO_2 averaged 430 ± 38.76 ppm over all the sampling days, the distribution being clearly normal since the coefficient of variation was 9.0%. The relative humidity in Vape Shop B ranged from 13.6% to 26.8% and the temperature ranged from 69.3 F to 73.9 F. **Figure 4** shows session 2 for Vape Shop A and session 4 for Vape Shop B. As shown in Figure 4, Vape Shop A has higher CO_2 and UFP levels than Vape Shop B. The person time weighted average for Vape Shop A and Vape Shop B are 5.42 people and 6.32 people respectively. Therefore, we can conclude that the CO_2 differences between Vape Shop A and B are not caused by the human traffic but rather the differing ventilation inside of the store. The correlation for CO_2 to UFP concentrations in Vape Shop B is R=0.70 ($P<0.001$, Pearson Product Moment Correlation). The data is Humans produce CO_2 through normal exhalation which can indicate the more people in the vape shop the higher CO_2 levels. Figure 4 shows that increased CO_2 levels correlated with increased UFP concentrations. Vape Shop A had a correlation of R=0.13 ($P<.001$) which is a much weaker correlation. Poor ventilation causes the UFP to continue to stay in the shop. However there is a strong correlation between the two trends, with R=0.75 indicating that higher CO_2 concentrations have higher UFP concentrations.

To our knowledge, no air quality studies have been done in vape shops. This research highlights the strikingly high numbers of UFP inside these types of stores. A study by Neuberger et al. (2013) showed that ultrafine particles from tobacco cigarettes averaged 3.25E+04 $\#/cm^3$ for rooms adjacent to smoking rooms and 1.29E+05 $\#/cm^3$ in smoking rooms. Other studies have also shown that UFPs are seen in high concentration during frying bacon on gas rings with a maximum reading of 5.90E+05 $\#/cm^3$ (Dennekamp et al. 2001). The present research highlights the importance of the occupational hazards of working inside a vape shop for long periods of time and how important it is to monitor nearby shops that might have elevated levels of UFP due to activities inside the stores. Employees in both vape shops have approximately 12 hour shifts and are consistently exposed to high levels of UFP. This research also highlights the importance of proper ventilation in these types of shops and how necessary it is to improve the air quality indoors.

Some limitations of this study are that we only investigated two shops. More shops need to be studied to increase the statistical power and have a wider representation of the different types of vape shops. Soule et al. (2016) found high levels of fine particles $PM_{2.5}$ in a study conducted in a two day E-Cigarette convention and fine particles are important parameters to consider. Another limitation is this study is based on real-world settings and doors being propped open could vastly affect the results. The AER for Vape Shop B was taken when the door was closed, however during business hours the doors are open.

4. Conclusions:

In this pilot study we were able to determine that vaping is a major source of UFP emission inside the vape shops. When there is no vaping the UFP concentrations are much lower than when there is active vaping. Ventilation inside these shops can play an important role in maintaining lower levels of UFP inside and can help reduce the CO_2 buildup in the store. More studies need to be conducted to assess exposures to various harmful air pollutants also vaped and related health effects for workers in vape shops and nearby business.

Supplemental Material

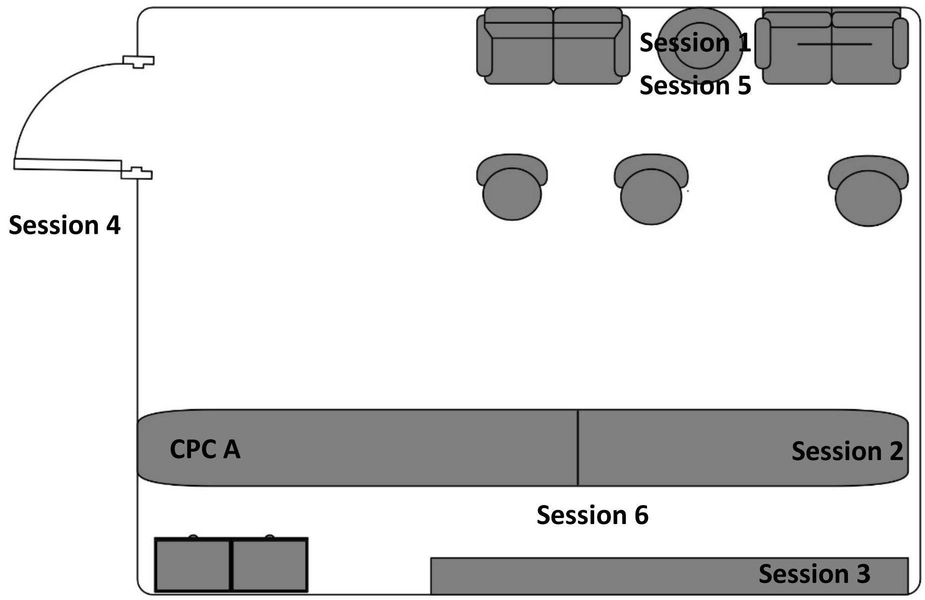


Figure S1 Layout for Vape Shop A and CPC B session locations. The dimensions are 6.44m x 8.63m x 5.72m. (Not drawn to scale respect to vape shop B)

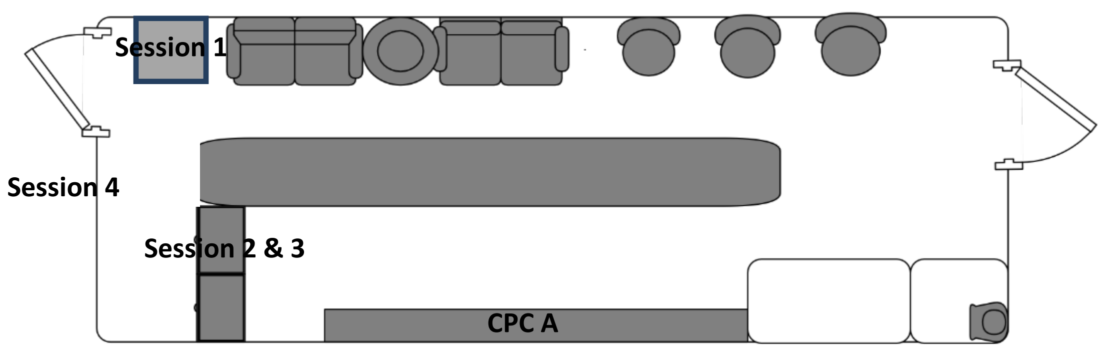


Figure S2 Layout of Vape Shop B and CPC B session locations. The dimensions are 4.40m x 22.81m x 2.61m. (Not drawn to scale respect to vape shop A)

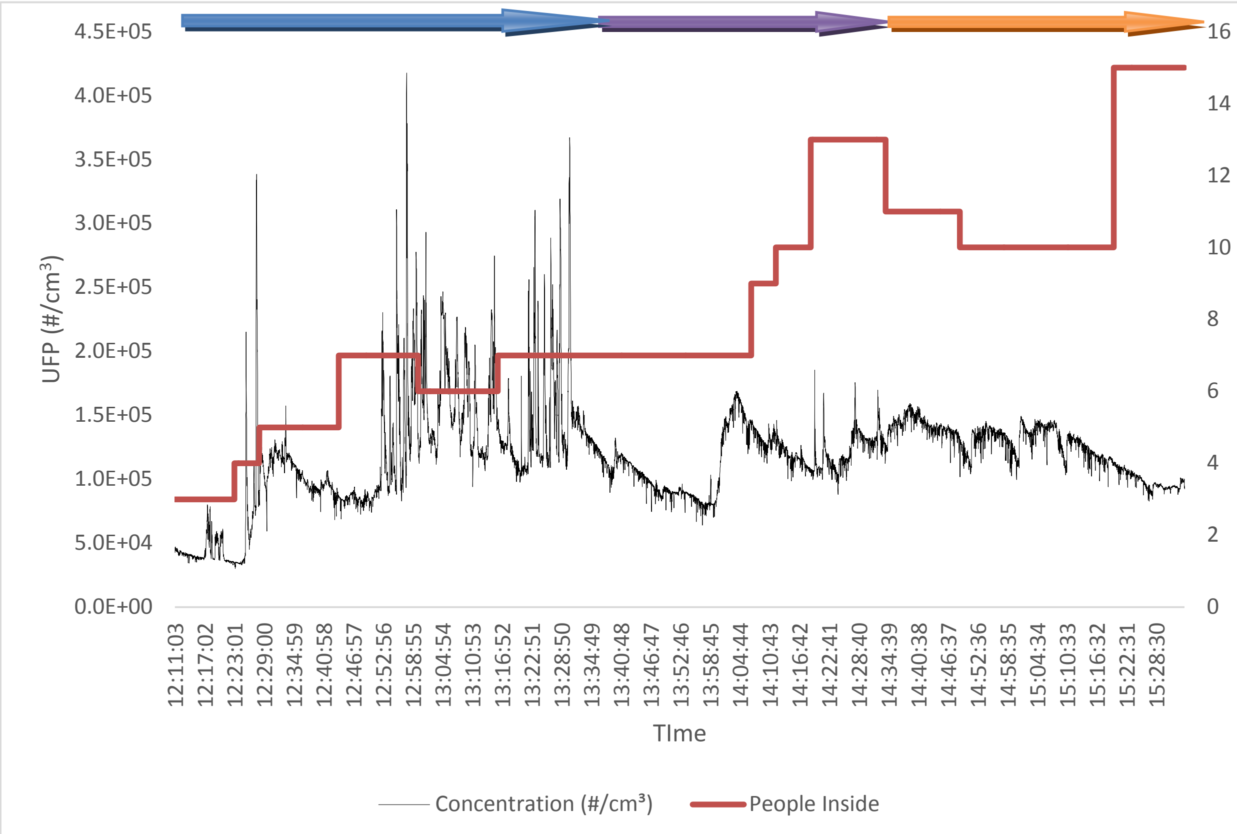


Figure S3 Vape Shop A Session 1 survey session. Blue arrow is when CPC A was placed on the left side of the display case, purple arrow is when CPC A was placed in the lounge and orange arrow CPC placed on left side of the display case. The solid line shows how many people are inside the store.

Table S1 Summary of UFP in sessions 1-6 for Vape Shop A and Vape Shop B.

Sessions	Vape Shop A CPC A	Vape Shop A CPC B	Vape Shop B CPC A	Vape Shop B CPC B
1	NA	NA	6.81E+04 ± 9.63E+04	3.40E+04 ± 2.35E+04
2	1.68E+05 ± 4.34E+04	6.58E+04 ± 4.52E+04	4.20E+04 ± 3.49E+04	3.98E+04 ± 3.24E+04
3	1.04E+05 ± 7.85E+04	5.48E+04 ± 2.28E+04	5.26E+04± 1.57E+04	3.09E+04 ± 9.25E+03
4	NA	NA	NA	NA
5	7.93E+04 ± 4.86E+04	6.41E+04 ± 3.74E+04	NA	NA
6	1.25E+05± 7.81E+04	1.20E+05± 7.58E+04	NA	NA

Table S2 Summary of CO2, Relative Humidity (RH%) and Temperature for the different sessions in Vape Shop A. A correction factor of 1.65 was used to correct the data for CO2.

Session	CO2(ppm)	RH (%)	Temperature F^{o}
1	2486.6 ± 229.6	42.9	76.7
2	NA	NA	NA
3	NA	NA	NA
4	1052.9 ± 187.8	29.5	76.4
5	691.3 ± 176.2	38.9	71.4
6	1074.15 ± 405.9	47.2	73.0
Total Average	1326.2 ± 686.9	39.6 ± 2.2	74.3 ± 2.2

Table S3 Summary of CO2, Relative Humidity (RH%) and Temperature for the different sessions in Vape Shop B. A correction factor of 1.65 was used to correct the data for CO2.

Session	CO_2 (ppm)	RH (%)	Temperature F^{o}
1	460±42.5	26.8	69.3
2	470±104.8	14.3	73.9
3	372±9.0	13.6	70.8
4	418±12.3	40.6	73.1
Total Average	430±38.8	28.1±11.0	71.8±1.8

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