Residential Volatile Organic Compound (VOC) Measurements in the San Joaquin Valley: Findings from the SPHERE Study

Rosemary Castorina[1,2*†], *Karla* Vargas[1*], *Flavia* Wong[1], *Zhong-Min* Wang[1], *Aditya* Simha[2], *Elizabeth* Noth[3], *Asa* Bradman[4,5], and *Kazukiyo* Kumagai[1]

[1]Environmental Health Laboratory Branch, Center for Laboratory Sciences, California Department of Public Health, Richmond, CA 94804, USA
[2]Center for Environmental Research and Community Health (CERCH), School of Public Health, University of California, Berkeley, Berkeley, CA 94720, USA
[3]Division of Environmental Health Sciences, School of Public Health, University of California, Berkeley, Berkeley CA 94720, USA
[4]Department of Public Health, School of Social Sciences, Humanities and Arts, University of California, Merced, Merced, CA 95343, USA
[5]Health Sciences Research Institute, University of California, Merced, Merced, CA 95343, USA

*These authors share lead authorship

Abstract. California's San Joaquin Valley, a major agricultural region surrounded by mountain ranges, experiences severe air pollution due to its basin-like topography, which traps emissions. The San Joaquin Valley Pollution and Health Environmental Research (SPHERE) Study is a collaborative, community-based project led by UC Berkeley, UC Merced, the California Department of Public Health (CDPH), and local partners to characterize air pollution exposures in the region. To evaluate residential exposures to volatile organic compounds (VOCs), we performed 4-hour active air sampling in 16 homes in Fresno, CA between September and November 2023. A total of 23 indoor and 8 outdoor samples were collected and analyzed to quantify VOC concentrations. Twenty-three unique VOCs were measured. The nine most frequently detected indoor VOCs (detection frequency >50%) included toluene, para-xylene, 4-isopropyltoluene, styrene, ethylbenzene, 1,2,4-trimethylbenzene, ortho-xylene, meta-xylene, and benzene, six of which are BTEX compounds (benzene, toluene, ethylbenzene, and xylenes). Median (95th percentile) indoor BTEX concentrations were 0.26 (0.84) μg/m³ for benzene, 2.06 (5.06) μg/m³ for toluene, 0.56 (1.30) μg/m³ for ethylbenzene, and 2.10 (4.91) μg/m³ for total xylenes. Average indoor-to-outdoor (I/O) ratios exceeded 1 for all compounds except benzene (mean I/O ratios ranged from 0.70 to 20.4), indicating substantial indoor sources. Outdoor BTEX concentrations were inversely correlated with residential distance from State Route 99 (rho = -0.75; $p<0.05$) and positively correlated with ambient NO_2 (rho = 0.88; $p < 0.05$), consistent with traffic-related emissions. Outdoor BTEX levels were negatively correlated with ozone, consistent with photochemical degradation processes that reduce BTEX concentrations as ozone forms. Real-time total VOC (TVOC) concentrations were measured using Atmotube Pro monitors, capturing temporal variability in indoor air quality. Overall, results indicate that indoor environments are the predominant source of VOC exposure in sampled homes, with concentrations frequently exceeding outdoor levels. Although measured levels were below federal health-based reference values, these findings highlight meaningful patterns of localized exposure in disadvantaged communities. Continued air quality monitoring, source attribution, and targeted interventions are warranted to reduce exposures among vulnerable populations.

Keywords. San Joaquin Valley homes, indoor air quality, volatile organic compounds (VOCs), active air sampling, total volatile organic compounds (TVOCs)

1 Introduction

California's San Joaquin Valley (SJV) is a major agricultural region with a trough-like geography surrounded by mountain ranges, creating conditions that trap air pollutants. The region lies between major high-traffic corridors linking the San Francisco Bay Area and Los Angeles, further contributing to its air quality challenges [1]. With over 4 million residents, half of whom are Hispanic/Latino, the SJV is home to communities that face disproportionate environmental health burdens [2,3].

Although air quality in the SJV has improved in recent years, long-term data since the late 1980s indicate that air pollution levels in the SJV remain elevated and continue to pose a public health concern for residents [4]. Fresno County, located in the heart of the valley, is a

† Corresponding author: rosemary.castorina@cdph.ca.gov

national leader in agricultural production and has the highest asthma prevalence in California [3,5]. Exposure to air pollution in the region has been associated with increased emergency room visits for asthma and adverse respiratory outcomes [3]. These trends highlight the need to better understand and reduce pollutant exposures, particularly in indoor environments where people spend most of their time.

Volatile organic compounds (VOCs) are among the most prevalent indoor air pollutants and are often found at significantly higher concentrations indoors than outdoors [6]. Among VOCs, benzene, toluene, ethylbenzene, and xylenes (BTEX) are especially concerning due to their widespread presence and health risks. These compounds are primarily emitted from vehicle exhaust, with inhalation being the main pathway of human exposure [7].

In 2017, Assembly Bill 617 (AB 617) established the Community Air Protection Program with the goal of reducing air pollution exposure and health impacts in disproportionately burdened communities across the state. South-Central Fresno, an AB 617-designated community, is affected by industrial activity, freight operations, and proximity to State Route 99 [8]. This study contributes to these efforts by characterizing indoor and outdoor exposure to VOCs in homes across Fresno and surrounding areas of the SJV, to help inform future monitoring and intervention strategies.

2 Methods

2.1 Study Design

VOC air sampling was conducted in 16 residential homes in Fresno, California, between September and November 2023. Eligible participants included English- or Spanish-speaking parents living in Fresno with at least one child between the ages of 4 to 13 years old. The Central California Asthma Collaborative (CCAC) facilitated participant recruitment through word-of-mouth and snowball sampling. Recruitment prioritized disadvantaged neighborhoods to assess air pollution exposure in highly impacted communities. Participants completed pre- and post-sampling questionnaires that included home characteristics and activities. Study participants also completed a 24-hour activity log to document household activities including cooking, use of gas appliances, vaping, use of candles, and ventilation practices.

All study activities were approved by the Institutional Review Board (IRB) at the University of California, Berkeley.

2.2 Air VOC Sampling and Analytical Methods

Active air sampling was conducted to collect indoor and outdoor air samples for laboratory analysis of VOCs. Sampling followed EPA Method TO-17 using a cart-mounted platform. Air monitoring equipment was mounted on the sampling carts and placed inside and outside of the participants' homes for 24 hours. AirChek XR5000 pumps were operated for four hours at a calibrated flow rate of 100 mL/min, verified with a Chek-mate SKC flowmeter equipped with a low-flow adapter. Samples were collected on Markes thermal desorption (TD) Tenax tubes (Markes International, Bridgend, United Kingdom) for approximately 4 hours, yielding total air volumes ranging from 22.2 L to 25.8 L. Although 24-hour VOC sampling was initially attempted, the absence of a pump capable of maintaining a sufficiently low stable flow led to sorbent saturation over extended durations. The protocol was therefore refined to a 4-hour sampling window to ensure sample integrity and accommodate instrument constraints.

After collection, VOC sample tubes were sealed, capped, and transported on ice to the California Department of Public Health (CDPH) Environmental Health Laboratory in Richmond, CA, for analysis by thermal desorption gas chromatography–mass spectrometry (TD-GC-MS). Repeat air sampling was performed at 7 homes approximately 30 days following the initial sampling date. In addition to the 23 indoor and 8 outdoor air samples, five field blanks and 5 collocated duplicate pairs were collected and analyzed to ensure data quality.

2.3 Air TVOC Monitoring Methods

Total volatile organic compounds (TVOC) concentrations were measured using Atmotube Pros portable air quality monitors. These devices employ active sampling and are equipped with the Sensirion SGPC3 sensor, a metal oxide sensing element known for its compact size, low cost, lightweight design, and long operational lifespan compared to electrochemical sensors (Wang et al. 2020). The sensor provides TVOC readings in the range of 0 to 60 ppm, with a typical accuracy of ±15% of the measured value. It operates with a 2-second measurement interval and a 1-minute time resolution, allowing for the detection of short-term fluctuations in TVOC levels.

During each 24-hour sampling period, one Atmotube Pro device was placed on a sampling cart to monitor indoor and outdoor TVOC concentrations. Atmotube Pro devices were retrieved by study staff at the end of each sampling event. Real-time TVOC data were collected in 39 SPHERE participant homes, yielding 42 indoor and 12 outdoor measurements, which were summarized as hourly averages for analysis.

2.4 Quality Assurance and Quality Control

Quality assurance and quality control (QA/QC) procedures were implemented throughout sample collection and analysis. Three field blanks were collected and analyzed to assess potential contamination during sample handling and transport; all blank concentrations were below detection limits. Duplicate samples (n=5)

were collected to evaluate analytical precision, with replicate results within ±20% relative percent difference. Instrument calibration was performed using certified VOC standards, and method accuracy was confirmed with spiked laboratory control samples. Sample flow rates were checked before and after each sampling event to ensure stable flow (~100 mL/min). All data were reviewed for completeness, consistency, and validity prior to statistical analysis.

2.5 Real-time Air Monitoring of Criteria Air Pollutants

Real-time measurements of nitrogen dioxide (NO_2) and ozone were collected inside and outside homes over 24-hours using the SENSIT® RAMP platform (Sensit Technologies, Valparaiso, Indiana). The RAMP is a relatively low-cost (<$4,000), portable air monitoring device that can be configured with sensors to measure a variety of air pollutants. Prior to data analysis, SENSIT measurements were quality-checked and processed following manufacturer-recommended procedures. Detailed monitoring methods for the criteria air pollutants used in this study have been described previously [9].

2.6 Data Analysis

Air concentrations of 23 VOCs were quantified across 16 homes in Fresno, CA. All statistical analyses were conducted using R (version 4.5.1; R Foundation for Statistical Computing, Vienna, Austria), with two-sided tests and a significance level of $p \leq 0.05$. VOC concentrations below the limit of detection (LOD) were imputed using LOD/√2. Descriptive statistics were calculated for compounds with detection frequencies (DF) greater than 50%. For summary tables and analyses, five sets of collocated indoor replicates were averaged.

To calculate summed VOC concentrations (ΣVOCs), individual VOC concentrations were first converted from μg/m^3 to parts per million (ppm) using compound-specific molecular weights and then summed. The ΣVOCs values were log-transformed to improve normality and meet assumptions for parametric statistical models. The concentrations of meta-, ortho-, and para-xylene isomers were summed to calculate total xylenes (μg/m^3), and concentrations of benzene, toluene, ethylbenzene, and xylenes were summed to calculate total BTEX levels.

Linear mixed-effects (LME) models were used to identify predictors of indoor and outdoor ΣVOCs concentrations (ppm), with the log-transformed ΣVOC concentration as the dependent variable. Survey variables considered included vaping, smoking, use of gas stoves, air fresheners, candle burning, air purifier use, number of residents in the household, and ventilation practices. A random intercept was included to account for within-home correlation due to repeated measures.

Indoor-to-outdoor (I/O) ratios were computed to assess the relative contribution of indoor versus outdoor sources for frequently detected VOCs (DF >50%), using data from eight homes with paired indoor and outdoor samples.

Spearman's rank correlation coefficients were used to evaluate associations between outdoor BTEX (benzene, toluene, ethylbenzene, and xylenes) concentrations and residential distance to the nearest major freeway (State Route 99), as well as correlations between BTEX, NO_2 and ozone concentrations, and the correlation between indoor and outdoor ΣVOC and TVOC concentrations (ppm).

Spatial analyses and map visualizations were conducted using ArcGIS Online (Esri, Redlands, CA), a cloud-based geographic information system. Participant addresses were geocoded and overlaid with AB 617 Community Air Protection Program boundaries to enable stratified comparisons.

3 Results

3.1 VOC Concentrations

A total of 23 unique VOCs were measured from indoor and outdoor samples collected at 16 participant homes in Fresno, CA (n=31 samples). These VOCs spanned a range of chemical classes, including aromatics, chlorinated solvents, aliphatic hydrocarbons, and methacrylates. Measured VOCs reflect industrial and household sources, including benzene (CAS 71-43-2), toluene (108-88-3), and methyl methacrylate (CAS 80-62-6; a formaldehyde substitute), as well as chlorinated compounds such as chloroform (CAS 67-66-3), methylene chloride (CAS 75-09-2), and tetrachloroethene (CAS 127-18-4).

Summary statistics for the most frequently detected indoor air VOC concentrations (μg/m³) from 23 samples are presented in Table 1. Toluene and p-xylene were detected in 100% of indoor samples, with median concentrations of 2.1 μg/m³ and 1.2 μg/m³, respectively. Median concentrations for other frequently detected indoor VOCs (DF >50%) included 4-isopropyltoluene (1.0 μg/m³; DF: 95.7%), styrene (0.5 μg/m³; DF: 82.6%), ethylbenzene (0.6 μg/m³; DF: 77.3%), 1,2,4-trimethylbenzene (0.6 μg/m³; DF: 73.9%), o-xylene (0.4 μg/m³; DF: 73.9%), m-xylene (0.4 μg/m³; DF: 65.2%), and benzene (0.3 μg/m³; DF: 56.5%).

Table 1. Summary of indoor air VOC concentration measurements (μg/m^3) (n= 23 samples collected from 16 homes in Fresno, CA).

VOC	DF (%)	Mean (SD)[a]	Median	75th	95th	Max	I/O mean	I/O range
Toluene	100	2.7 (2.6)	2.1	3.3	5.1	13.2	2.4	0.7, 7.1
p-Xylene	100	1.4 (1.4)	1.1	1.8	2.7	6.6	3.8	0.5, 9.5
4-Isopropyltoluene	96	1.9 (2.1)	1.0	1.5	5.7	7.9	20.4	2.5, 38.5
Styrene	83	0.7 (0.4)	0.5	0.8	1.6	1.8	4.7	1.0, 10.9
Ethylbenzene	74	0.8 (0.5)	0.5	0.8	1.3	2.4	3.1	0.6, 5.2
1,2,4-Trimethylbenzene	74	1.0 (0.9)	0.4	0.9	2.7	3.4	4.8	0.6, 23.1
o-Xylene	74	0.9 (0.6)	0.6	0.9	1.5	2.7	3.1	0.6, 6.3
m-Xylene	65	0.7 (0.5)	0.4	0.6	0.9	2.5	2.6	0.7, 5.8
Benzene	57	0.5 (0.3)	0.3	0.6	0.8	1.0	0.7	0.4, 1.2
Tetrahydrofuran	39	0.3 (0.1)	--	0.2	0.4	0.5	--	--
1,3,5-Trimethylbenzene	35	0.4 (0.2)	--	0.3	0.4	0.8	--	--
Chloroform	22	0.7 (0.5)	--	--	0.5	2.4	--	--
Isobutyl alcohol	22	0.6 (0.2)	--	--	0.7	0.8	--	--
Xylenes[b]	100	2.6 (2.5)	2.1	3.3	4.9	11.9	3.2	0.5, 5.9
Sum of VOCs (ppm)	100	0.004 (0.003)	0.003	0.004	0.009	0.013	3.1	0.7, 11.4

Abbreviations: DF=detection frequency; I/O=indoor-to-outdoor concentration ratio; Limit of detection = 5.0 ng; VOC concentrations <LOD were imputed as LOD/square root of 2. [a]Mean VOC concentrations were calculated using values >LOD. [b]Xylenes are the sum of p-, m- and o-xylene concentrations.

Outdoor air VOC concentrations (μg/m³) from eight samples are summarized in Table 2. Toluene was detected in all outdoor samples (median: 0.9 μg/m³). Concentrations for outdoor VOCs were generally lower than indoor levels. Mean indoor-to-outdoor (I/O) ratios ranged from 0.5 for benzene to 20.4 for 4-Isopropyltoluene (Table 1). Figure 1 presents a comparison of indoor and outdoor air concentrations for the nine most frequently detected VOCs showing indoor VOC concentrations generally exceeded outdoor concentrations, except for benzene. Ethylbenzene, toluene, and the xylene isomer concentrations were substantially higher indoors than outdoors. Toluene exhibited the widest interquartile range indoors, with one outlier exceeding 10 μg/m³.

Table 2. Summary of outdoor air VOC concentration measurements (μg/m^3) (n= 8 samples collected from 8 homes in Fresno, CA).

VOC	DF (%)	Mean (SD)[a]	Median	75th	95th	Max
Toluene	100	1.4 (1.3)	0.9	1.4	3.5	4.5
Benzene	88	0.5 (0.5)	0.4	0.5	1.2	1.6
p-Xylene	75	0.9 (0.8)	0.5	0.6	2.0	2.6
1,2,4-Trimethylbenzene	63	0.5 (0.4)	0.2	0.3	0.9	1.2
o-Xylene	50	0.5 (0.4)	0.2	0.3	0.9	1.3
Ethylbenzene	38	0.5 (0.3)	--	0.3	0.7	1.0
m-Xylene	38	0.5 (0.3)	--	0.2	0.7	0.9
Acetonitrile	25	4.7 (3.2)	--	0.2	6.0	9.1
4-Isopropyltoluene	13	--	--	--	--	0.2
Naphthalene	13	--	--	--	--	0.3
Tetrachloroethene	13	--	--	--	--	0.3
Tetrahydrofuran	13	--	--	--	--	0.3
trans-1,3-Dichloropropene	13	--	--	--	--	0.2
1,3,5-Trimethylbenzene	13	--	--	--	--	0.4
Xylenes[b]	75	1.3 (1.5)	0.8	1.1	3.6	4.8
Sum of VOCs (ppm)	100	0.002 (0.002)	0.001	0.002	0.006	0.007

Abbreviations: DF=detection frequency; I/O=indoor-to-outdoor concentration ratio; LOD= 5.0 ng; [a]Mean VOC concentrations were calculated using values >LOD only; [b]Xylenes: sum of p-, m- and o-xylene concentrations.

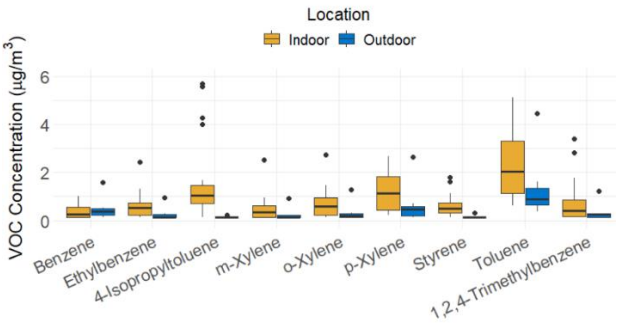

Fig. 1. Comparison of indoor and outdoor air for frequently detected VOCs (µg/m^3)

Note: One indoor toluene outlier (max=13.2 µg/m^3) was excluded from the figure.

Figure 2 presents indoor-to-outdoor (I/O) ratios for these compounds based on 8 matched indoor-outdoor air sample pairs. The average I/O ratios ranged from 0.7 for benzene to 20.4 for 4-isopropyltoluene (p-cymene), a naturally occurring aromatic organic compound found in essential oils such as thyme and cumin and also used industrially as a solvent and fragrance ingredient [10]. Benzene was the only compound with an average I/O ratio <1, suggesting significant indoor sources for the other VOCs.

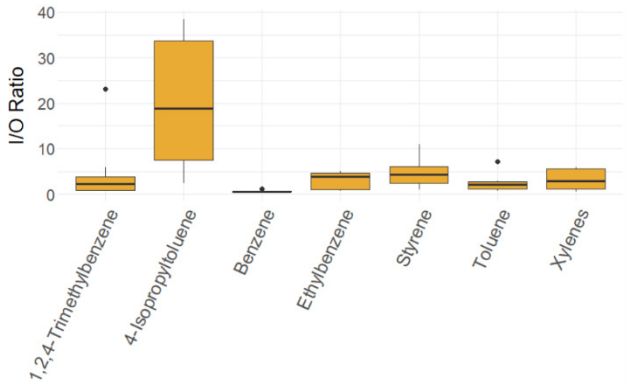

Fig. 2. Indoor-to-outdoor (I/O) ratios of most frequently detected VOCs (n=8 matched pairs)

Similarly, summed VOC concentrations were generally higher indoors (median = 0.003 ppm) compared to outdoors (median = 0.001 ppm). The average (range) I/O ratio for the summed VOC concentrations was 3.1 (0.7, 11.4) (Table 1). A comparison of summed VOC indoor (n=23) and outdoor (n=8) concentrations (ppm) is presented in Figure 3.

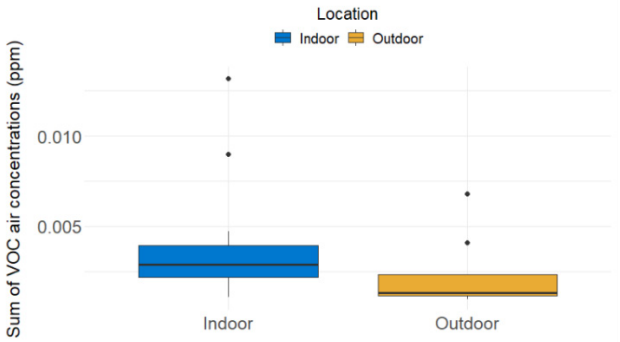

Fig. 3. Comparison of summed indoor (n=23) and outdoor (n=8) air VOC concentrations (ppm)

3.2 Predictors of BTEX concentrations in Fresno homes

We calculated Spearman correlations between indoor and outdoor BTEX concentrations and residential proximity to Highway SR-99 (Table 3). Inverse correlations were observed for all BTEX compounds measured outdoors, with statistically significant associations between ethylbenzene (rho = -0.83, p = 0.01) and xylenes (rho = -0.76, p = 0.03). Outdoor total BTEX concentrations were also inversely associated with residential distance from State Route 99 (rho = -0.75; $p < 0.05$) and showed a significant and positive correlation with ambient NO_2, consistent with traffic-related emissions (rho = 0.88; $p < 0.05$). In addition, outdoor BTEX levels were negatively correlated with ozone (rho = -0.86; $p < 0.05$), consistent with photochemical degradation of BTEX in the atmosphere (Table 4).

Indoor BTEX concentrations were not correlated with residential proximity to SR-99 (rho = -0.08). Similarly, summed indoor VOC concentrations showed no association with distance to SR-99 (rho = -0.05, p = 0.85;), while summed outdoor VOCs were inversely associated, albeit not significantly (rho = -0.83, p = 0.06).

Table 3. Correlations between outdoor BTEX levels (µg/m^3) and residential proximity (km) to Highway SR-99 (n=8)

VOC	Spearman rho	p-value
Benzene	-0.47	0.24
Toluene	-0.70	0.05
Ethylbenzene	-0.83	0.01
Xylenes	-0.76	0.03
BTEX	-0.75	0.03

Table 4. Correlation matrix of outdoor concentrations of air pollutants from 8 homes

Outdoor	NO_2	O_3	BTEX
NO_2	1		
O_3	-0.28*	1	
BTEX	**0.88***	**-0.86***	1

*Spearman coefficient p-values <0.05

Table 5 summarizes indoor and outdoor BTEX concentrations (µg/m³) stratified by whether households were located within the AB 617 community boundary. Indoor measurements were available for 23 homes, including 9 within the AB 617 boundary and 14 outside. Indoor BTEX concentrations were higher in homes located within the AB 617 community boundary, with a median of 8.64 µg/m³ compared to 4.58 µg/m³ in homes outside the boundary. The upper percentiles showed a similar pattern, with the 95th percentile reaching 20.9 µg/m³ inside the boundary versus 8.42 µg/m³ outside.

Outdoor concentrations showed the same trend: homes within the boundary had a higher median (3.27 µg/m³) than those outside (1.62 µg/m³), and substantially higher upper-range values (95th percentile 10.7 µg/m³ vs. 2.56 µg/m³). Overall, both indoor and outdoor BTEX levels appeared elevated in residences located within the AB 617 community boundary.

Table 5. Indoor and outdoor BTEX concentrations (µg/m³) and residence within the AB 617 community boundary.

Location	AB 617	n	Mean (SD)	50th	75th	95th
Indoor	No	14	4.77 (2.63)	4.58	5.41	8.42
	Yes	9	8.64 (8.06)	8.64	9.09	20.9
Outdoor	No	4	1.77 (0.67)	1.62	1.98	2.56
	Yes	4	5.05 (4.62)	3.27	5.75	10.7

3.3 Vaping Status and VOC exposure

Indoor and outdoor summed VOC concentrations by vaping status are presented in Figure 4. Households that responded "Yes" to the survey question, *"Does anyone ever vape at this home? (Please include all vaping – tobacco, cannabis, etc. Vape devices are also called e-cigs or mods)"*, had higher summed VOC concentrations than households that responded "No." Indoors, median and 95th percentile summed VOC concentration was 0.0046 ppm and 0.0084 in vaping homes compared with 0.0026 ppm and 0.0052 in non-vaping homes, a borderline significant difference (p = 0.05). This p-value was obtained from a linear mixed-effects model (LME) with a random intercept for household.

Outdoor concentrations showed a similar pattern, with vaping homes exhibiting a higher median (0.0054 ppm) than non-vaping homes (0.0012 ppm). However, the outdoor sample size for vaping households was small (n=2), so these comparisons should be interpreted with caution.

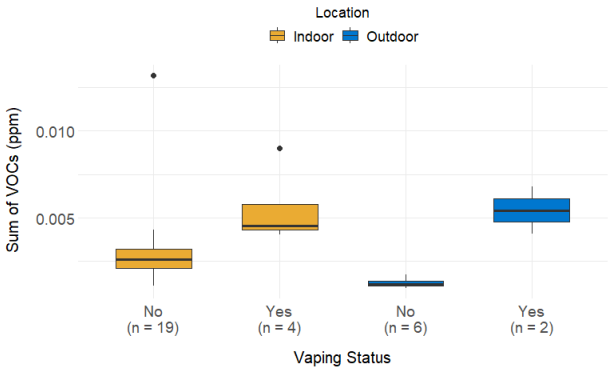

Fig. 4. Comparison of indoor and outdoor summed VOC concentrations (ppm) stratified by reported vaping in or around the home. n denotes the number of analyzed samples.

3.4 TVOC Measurements

Table 6 summarizes indoor and outdoor TVOC concentrations (ppm) for 46 participant homes. Indoor TVOC concentrations were generally higher than outdoor concentrations in most homes. The mean (standard deviation) indoor TVOC concentrations (n=42) was 0.51 (0.80) ppm, with values reaching a maximum of 4.62 ppm. The median indoor concentration was 0.33 ppm, and the 95th percentile was 0.95 ppm, indicating a right-skewed distribution driven by elevated levels in a small number of homes.

Outdoor samples (n=12) had lower TVOC concentrations, with a mean (SD) of 0.23 (0.11) ppm and a maximum of 0.46 ppm. Indoor-to-outdoor (I/O) ratios, calculated for eight homes, had a mean of 3.72, with a wide range from 0.32 to 15.5, suggesting that indoor sources were often the dominant contributors to TVOC exposure.

As expected, TVOC concentrations were not correlated with the summed concentrations of individual VOCs. Among indoor samples (n = 18), the correlation between ΣVOCs and TVOC was weak and not statistically significant (rho = –0.31, p = 0.22). Similarly, outdoor ΣVOC and TVOC concentrations showed no meaningful relationship (rho = 0.21, p = 0.66; n = 7). This lack of correlation is expected because TVOC provides a broad, nonspecific measure influenced by many uncharacterized compounds and short-term indoor activities, whereas ΣVOCs reflects only the specific analytes included in the analytical panel.

Table 6. Summary of indoor and outdoor TVOC concentrations (ppm) in 39 Fresno homes[a]

TVOC	n	Mean (SD)	50th	75th	95th	Max	I/O mean[b]	I/O range
Indoor	42	0.5 (0.7)	0.3	0.5	1.0	4.5	3.6	0.3, 14.7
Outdoor	12	0.2 (0.1)	0.2	0.3	0.5	0.5	--	--

[a]Summary statistics were calculated based on average hourly TVOC concentrations.
[b]Indoor-to-outdoor (I/O) ratios were calculated using measurements from eight homes.

4 Discussion

Air concentrations of VOCs, BTEX, and TVOCs were consistently higher indoors than outdoors in most participating residences. Indoor-to-outdoor (I/O) ratios indicated that indoor sources were the predominate contributors to elevated VOC concentrations, which is consistent with findings from previous studies [6,11]. Toluene, p-xylene, and 4-isopropyltoluene were among the most frequently detected VOCs indoors, suggesting common household sources such as cleaning products, personal care items, building materials, and combustion during cooking as potential sources. The largest I/O ratio was observed for 4-isopropyltoluene (p-cymene), a compound commonly found in spices and household products [10,12]. Recent studies have also shown that tobacco and cannabis vape products emit VOCs and BTEX [13,14], and in this study, homes reporting vaping activity had higher indoor summed VOC concentrations, suggesting that vaping may contribute to elevated indoor air pollution. Indoor air concentrations exceeded outdoor levels for nearly all VOCs, with the exception of benzene, which showed similar indoor and outdoor concentrations.

Outdoor concentrations of summed VOCs, toluene, ethylbenzene, xylenes, and total BTEX were inversely correlated with residential distance from Highway SR-99, with closer residences tending to have higher levels. Outdoor BTEX was positively correlated with NO_2, consistent with common vehicular sources. Outdoor BTEX was inversely correlated with O_3, which can be explained by photochemical reactions in warm months when O_3 accumulates and VOCs are reduced [7,15]. These findings align with studies that observed associations between traffic emissions and BTEX levels. Although TVOC measurements do not provide compound-specific profiles, they offered useful insight into temporal variability and peaks potentially related to occupant activities; indoor TVOC levels were typically higher than outdoor levels, further supporting the importance of indoor sources.

A key strength of this pilot study is that both indoor and outdoor VOC and TVOC samples were collected across multiple homes, allowing for direct comparisons and I/O ratio analyses. Incorporating geospatial data, such as proximity to Highway SR-99 and AB 617 community designation, further provides insight into intra-city variability and environmental exposure disparities. Several limitations should be considered when interpreting these findings. The relatively small sample size of 16 homes limited statistical power and restricted the ability to evaluate predictors of VOC exposure. Sampling was conducted over a short, three-month period (September–November 2023), which did not allow for assessment of seasonal or longer-term temporal variability in VOC concentrations. In addition, the study was limited to residences in Fresno, which may not be representative of other areas in the San Joaquin Valley or California. Finally, information on household behaviors and indoor activities, such as vaping and product use, was based on self-reported data and may be subject to recall or reporting bias.

Despite these constraints, the findings provide valuable preliminary insights into indoor and outdoor VOC exposure patterns in Fresno homes and help inform directions for future, larger-scale studies. The results underscore the need for expanded investigations to examine the role of vaping on VOC exposure, to incorporate time-activity journals that better capture the influence of human behaviors on indoor air quality, and to assess the effectiveness of interventions aimed at reducing indoor and outdoor air pollution.

Overall, this study provides a detailed characterization of indoor and outdoor VOC and TVOC measurements in Fresno homes, with an analysis of proximity to a major traffic corridor, participant behaviors, and AB 617 community residence as potential determinants of air pollutant concentrations. Indoor VOC concentrations were consistently higher than outdoor concentrations, reinforcing previous findings that identify indoor sources as primary contributors to elevated VOC levels. Practical implications include the need for targeted interventions, such as improved ventilation, reductions in traffic-related emissions, and strategies to address environmental disparities in vulnerable communities.

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