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Letter

Indoor and Outdoor Volatile Organic Compound Levels during and after the 2025 Los Angeles Wildfires

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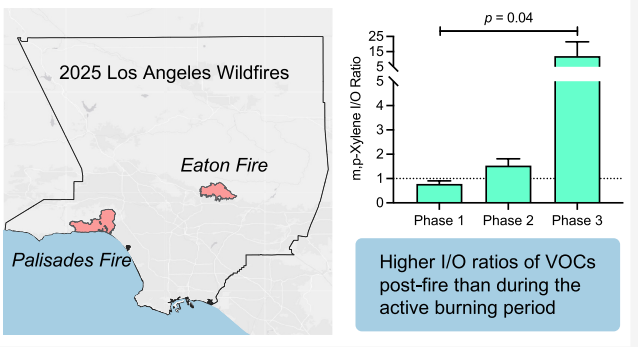
ABSTRACT: The January 2025 Los Angeles wildfires released large amounts of air pollutants and exposed millions of residents to smoke containing hazardous volatile organic compounds (VOCs). To assess exposure risks, we conducted indoor and outdoor VOCs sampling at 22 households near the Palisades and Eaton Fires across three phases: active burning with less than 50% containment (January 8−15), active burning period with more than 50% containment (January 24−31), and postfire (February 11−18). Outdoor benzene concentrations peaked during Phase 1, with a median (interquartile range) of 0.38 (0.27) ppb, decreased over time, and remained below the California Office of Environmental Health Hazard Assessment health benchmarks. Compared with the active burning period, indoor-to-outdoor ratios of *m,p*-xylene (p = 0.004), carbon tetrachloride (p = 0.002), and heptane (p = 0.02) were significantly higher in the postfire period. Elevated VOC levels were particularly evident in uninhabited homes within burn zones, suggesting ongoing indoor emissions from smoke-impacted materials. These findings raise concerns about indoor air quality postwildfire and the potential for prolonged exposure, underscoring the need for targeted mitigation and ongoing monitoring to protect public health during recovery.



KEYWORDS: *volatile organic compounds, BTEX, wildfire, I/O ratio, off-gassing*

1. INTRODUCTION

The Los Angeles urban wildfires (LA Fires) that began on January 7, 2025, have now become collectively one of the most destructive disasters in U.S. history.[1,2] The Palisades Fire burned over 23,448 acres in the Western part of the region, while the Eaton Fire in the Northeastern part of the region scorched approximately 14,021 acres.[3] Both fires erupted on January 7 and were fully contained by January 31. Together, they destroyed more than 16,000 structures, claimed at least 31 lives, and exerted untold costs to the health and wellbeing of millions of residents who experienced high levels of wildfire smoke exposure.[4,5]

What made these urban wildfires particularly concerning was the potential toxicity of the resulting smoke, which likely contained volatile organic compounds (VOCs), such as benzene, toluene, ethylbenzene, and xylenes (BTEX), some of which are carcinogenic and harmful to human health.[6,7] Indoor VOCs are ubiquitous in residential environments, with common sources including building materials, household products, and occupant activities such as cooking and cleaning.[8,9] Nevertheless, uncertainty about the magnitude and distribution of VOCs during and after the fires has heightened community anxiety over short- and long-term health effects.[10,11] Moreover, recent studies have shown that indoor VOCs levels can persist long after wildfires are contained, often exceeding outdoor concentrations.[12] Some of these VOCs have been linked to physical symptoms lasting up to six months after residents return to homes near burn zones.[13] Despite its importance, indoor air quality remains understudied in wildfire research, yet it is critical for informing public health mitigation strategies.[14]

To evaluate the environmental and health impacts of the 2025 LA Fires, we collected indoor and outdoor air samples including VOCs starting on the second day of the fires and continuing through the postfire period. Our objectives were 2-fold: (1) to assess how outdoor VOC concentrations compared with prefire and postfire levels and (2) to determine how VOC indoor-to-outdoor (I/O) ratios changed across different fire phases.

2. MATERIALS AND METHODS

2.1. Study Location. We conducted this study in two wildfire-affected regions of Los Angeles County: the western

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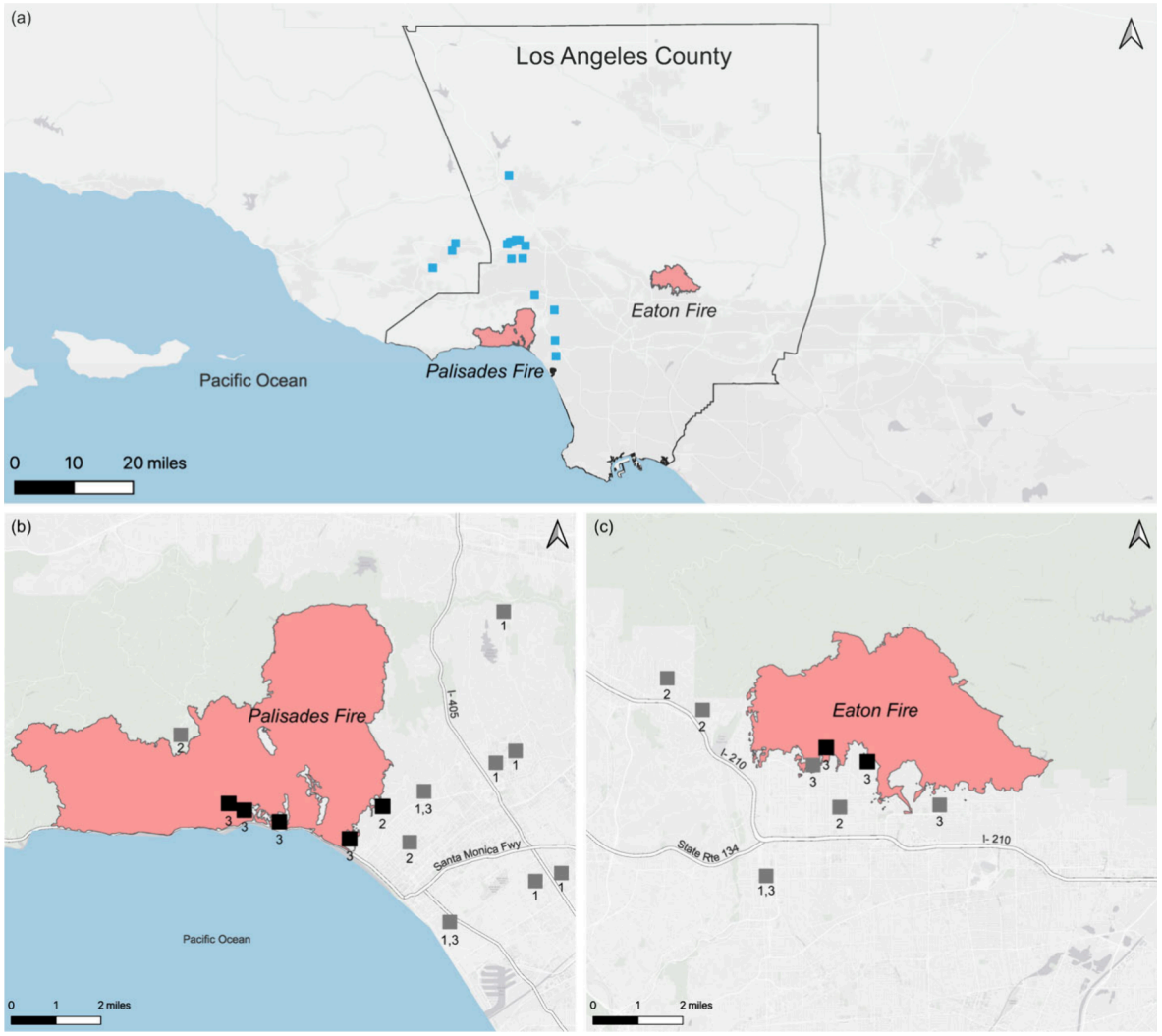

Figure 1. Field sampling locations: (a) Los Angeles County and 17 prefire sites (blue squares, October−November 2024), (b) Palisades Fire, and (c) Eaton Fire. Pink areas indicate burn zones. Gray and black squares denote inhabited and uninhabited households, respectively, with numbers indicating sampling phases. Data were collected during Phase 1 (January 8−15, 2025), Phase 2 (January 24−31, 2025), and Phase 3 (February 11−18, 2025).

area impacted by the Palisades Fire and the northeastern area affected by the Eaton Fire (Figure 1). Because of the emergency nature of the events, we identified opportunity sampling sites from our existing field sampling networks, allowing for rapid recruitment for sample collection. We conducted air sampling across three fire phases: the active burning period with less than 50% containment (January 8−15, 2025), the active burning period with more than 50% containment (January 24−31, 2025), and the postfire period (February 11−18, 2025).[3] In Phase 1, which began on January 8, we recruited eight households within five miles of the burn zones by approaching residents who were still in or near areas under evacuation orders. In Phase 2, after evacuation orders were partially lifted, we enrolled six households located closer to the burn zones. In Phase 3, we expanded recruitment to 11 households in and near the burn zones, including three that had previously participated in Phase 1. Most households located near or within the burn zones were uninhabited (black squares in Figure 1), and sampling was conducted with permission from the property owners. The study protocol was approved by the University of California, Los Angeles Institutional Review Board (IRB-25-0747).

2.2. Field Sampling. We collected integrated one-week samples of VOCs using Markes "EPA 325" thermal desorption diffusion tubes (Markes International, Bridgend, U.K.). Although the U.S. EPA Method 325 specifies a two-week passive monitoring period, we adopted a one-week duration during the 2025 LA fires to reduce the risk of tube overloading under high-concentration conditions. To ensure comparability across phases, the one-week sampling duration was maintained for all subsequent phases. These tubes rely on passive sampling and require no external power in the field. The paired indoor and outdoor samplers at each home were deployed concurrently and operated continuously for 1 week, which likely minimized the influence of diurnal variability on measured VOC concentrations. For indoor sampling, we placed the tubes in areas free from emission sources, such as kitchens, gas wall heaters, workshops, or studios containing dust or materials. For outdoor deployment, we selected locations away from potential combustion sources, including barbecues and grills. Each tube was mounted on a stand approximately 1.5 m above ground level. At the beginning of each sampling period, we opened one end of the tube, recorded the date and time, and secured it in place. At the end

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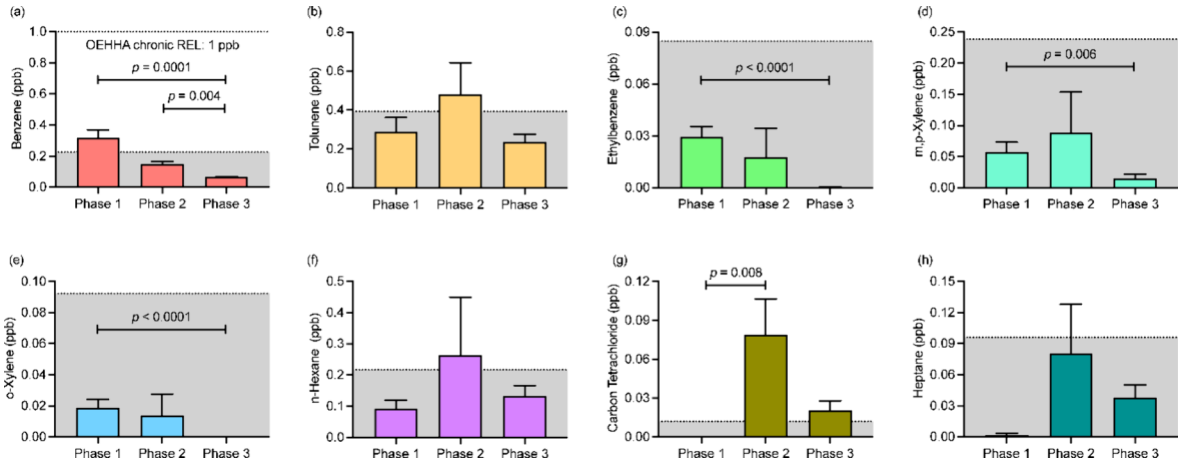

Figure 2. Outdoor VOC concentrations during different phases near the Palisades and Eaton Fires: (a) benzene, (b) toluene, (c) ethylbenzene, (d) *m*,*p*-xylene, (e) *o*-xylene, (f)*n*-hexane, (g) carbon tetrachloride, and (h) heptane. The gray area represents the range of two-week average outdoor VOC concentrations before the fires (October and November 2024) at the 17 locations shown in Figure 1. Data were collected during Phase 1 (January 8−15, 2025), Phase 2 (January 24−31, 2025), and Phase 3 (February 11−18, 2025). OEHHA: California Office of Environmental Health Hazard Assessment. REL: Reference Exposure Level.

of the period, we capped the tube, noted the closing time, and transported it to the laboratory for VOCs analysis.

2.3. VOCs Analysis. The diffusion tubes were analyzed using an Agilent 6890/5973N gas chromatograph/mass spectrometer (Agilent Technologies, Santa Clara, CA) equipped with a Markes "Unity 2" gas sampling/thermal desorption system and a Markes Ultraxr tube autosampler. Sample tubes were desorbed at 250 °C for 5 min, and the released compounds were recollected on a focusing trap packed with a proprietary sorbent suitable for this analysis. The trap was then desorbed at 280 °C for 3 min under a helium flow, which carried the analytes directly to the head of the analytical column via a heated transfer line. The gas chromatograph was operated in constant pressure mode (32 bar) with helium as the carrier gas. Separation was achieved using an Agilent J&W DB-VRX column (60 m × 0.25 mm × 1.40 μm). The temperature program was as follows: initial hold at 45 °C for 3 min, ramp from 45 to 190 °C at 10 °C/min, ramp from 190 to 250 °C at 20 °C/min, and final hold for 8 min. Quantification was performed using a 7-point calibration curve prepared from a custom gas standard mixture (Air Liquide). Analyte concentrations in the original air samples were calculated using sorbent uptake rates published by Markes and the U.S. Environmental Protection Agency (Table S1).

2.4. Quality Assurance and Quality Control. All participating households were nonsmoking and situated away from major traffic corridors or commercial plazas to minimize potential confounding from local emission sources. Before deployment, each diffusion tube was conditioned with ultrapure nitrogen at 330 °C for 45 min, immediately sealed, and stored in clean containers to prevent contamination during handling and transport. Instrument performance and laboratory cleanliness were verified by analyzing system blanks prior to each batch of VOC analyses. For samples with concentrations below the limit of quantification (LOQ), we substituted half of the LOQ as the representative value (Table S2). A total of seven samples were excluded: four collected near the Palisades Fire and three near the Eaton Fire, either due to restricted indoor access during mandatory evacuations, overloading, or contamination in the field. After applying these quality control procedures, the final data set comprised 43 valid samples from 22 households.

2.5. Statistical Analysis. We calculated descriptive statistics for indoor and outdoor VOC concentrations, including mean, standard deviation (SD), median, interquartile range (IQR), and range. To assess relative exposure, we derived I/O ratios by dividing indoor concentrations by corresponding outdoor concentrations. Because the data were not normally distributed, we used the Mann−Whitney test to compare VOC concentrations across fire phases. We also compared outdoor concentrations during and after the fires with regional background levels measured prior to the events, using diffusion tube samples collected from 17 sites in October−November 2024 (Figure 1a). All statistical analyses were conducted in R (version 4.1, Vienna, Austria), with statistical significance defined as $p < 0.05$ (two-tailed).

3. RESULTS AND DISCUSSION

3.1. Outdoor VOC concentrations during different phases. In total, we analyzed 22 VOCs; however, due to low detection rates for some compounds (Table S2), we removed those with <40% detection rates and focused our analysis on the remaining species: benzene, toluene, ethylbenzene, *m*,*p*-xylene, *o*-xylene, *n*-hexane, carbon tetrachloride, and heptane. Figure 2 presents outdoor VOC concentrations measured across the Palisades and Eaton Fire sites during different fire phases, with the gray shading denoting background levels collected several months before the fires. For benzene, median (IQR) outdoor concentrations were 0.38 (0.27) ppb during Phase 1, 0.15 (0.06) ppb during Phase 2, and 0.06 (0.03) ppb during Phase 3. Mann−Whitney U tests indicated significantly higher benzene levels during Phase 1 compared with Phase 3 ($p = 0.0001$) and during Phase 2 compared with Phase 3 ($p = 0.004$). By comparison, prefire background concentrations across 17 locations ranged from 0.00007 to 0.23 ppb, highlighting the elevated benzene levels observed during the first week of the 2025 LA fires. Although outdoor benzene concentrations peaked during the fires, their levels remained below the California Office of Environmental Health Hazard Assessment (OEHHA) health benchmarks, including the chronic Reference Exposure Level (REL) of 1 ppb and the

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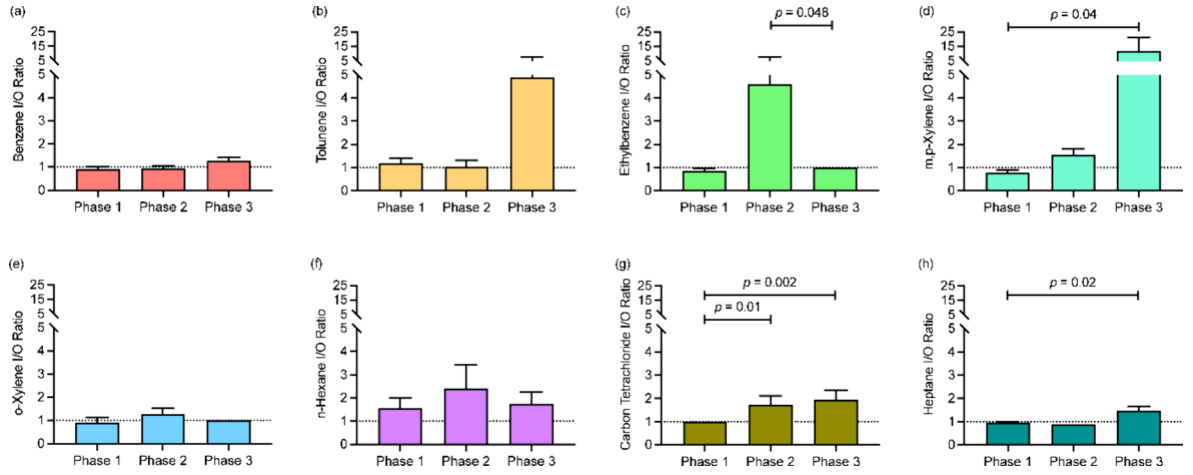

Figure 3. I/O ratios of VOCs during different phases near the Palisades and Eaton Fires: (a) benzene, (b) toluene, (c) ethylbenzene, (d) *m,p*-xylene, (e) *o*-xylene, (f)*n*-hexane, (g) carbon tetrachloride, and (h) heptane. The dotted line represents an I/O ratio of 1. Data were collected during Phase 1 (January 8−15, 2025), Phase 2 (January 24−31, 2025), and Phase 3 (February 11−18, 2025).

acute REL of 8 ppb.[15,16] Nevertheless, the World Health Organization emphasizes that benzene is carcinogenic to humans and that no safe threshold of exposure can be established.[17]

For ethylbenzene and *o*-xylene, outdoor concentration patterns across phases resembled those of benzene, with the highest levels detected in Phase 1 and a gradual decline through Phases 2 and 3. All remained within the range of prefire background concentrations. In contrast, toluene, *m,p*-xylene, *n*-hexane, carbon tetrachloride, and heptane showed persistently elevated levels from Phase 1 to Phase 2, indicating continued emissions during the later stage of active burning (Phase 2, with more than 50% containment). Notably, toluene, *n*-hexane, and carbon tetrachloride exceeded prefire concentrations during this period, highlighting potential ongoing emissions even as the fires became more contained. These patterns underscore that certain VOCs dissipated quickly following peak fire activity, while others lingered at elevated levels during the later phase of active burning.[18,19] Such differences are important when evaluating potential health risks, particularly in relation to established RELs set by OEHHA and other agencies.[20,21]

3.2. I/O Ratios during Different Phases. Figure 3 shows I/O ratios of VOCs across the three study phases. The dotted line indicates an I/O ratio of one. Detailed indoor and outdoor VOC concentrations for the different phases are provided in Table S3. Overall, the I/O ratio increased steadily postfire compared with active burning, reflecting shifts in indoor and outdoor VOC dynamics over time. For benzene, median (IQR) I/O ratios were 0.94 (0.46) during Phase 1, 1.01 (0.31) during Phase 2, and 1.41 (0.81) during Phase 3. Although the I/O ratios of benzene showed an upward trend, differences across phases were not statistically significant. In contrast, *m,p*-xylene (p = 0.004), carbon tetrachloride (p = 0.002), and heptane (p = 0.02) all exhibited significantly higher postfire I/O ratios compared with the active burning period with less than 50% containment, suggesting that indoor emission sources became more prominent after the fires.[22,23] Prior studies of wildfire-impacted homes have similarly reported elevated indoor BTEX and alkanes in the weeks following smoke intrusion, attributed to off-gassing from contaminated materials, deposition of particulate residues, and sorption−desorption from indoor surfaces.[18,24] Carbon tetrachloride, which typically shows I/O ratios near unity,[25,26] displayed a marked postfire increase, indicating indoor contributions likely related to smoke-impacted building materials. It should be noted that other indoor VOC sources and household activities in inhabited homes may also have contributed to indoor VOC concentrations.[22] Notably, several uninhabited homes within the burn zones—particularly near the Eaton Fire—showed elevated indoor BTEX levels compared with outdoor air (Figure S1). Differences in wind direction between the two fire regions may have influenced outdoor VOC concentrations. Compared with Eaton Fire homes (all three phases) and Palisades homes (Phases 1 and 2), the three coastal Palisades homes sampled in Phase 3 experienced stronger sea breezes from the west and southwest (Figure S2). Therefore, the lower outdoor VOC levels observed near the Palisades area during Phase 3 were likely related to these shifts in local wind patterns. Overall, these findings suggest that during the active fire, I/O ratios of VOCs were generally lower; however, indoor concentrations remained comparable to outdoor levels, indicating that staying indoors did not fully prevent exposure to fire-related pollutants. This I/O pattern shifted during the postfire recovery phase, likely driven by off-gassing from smoke-impacted materials,[18] highlighting the potential for prolonged indoor VOC exposure even after outdoor fire activity subsides.

3.3. Public Health Implications. Our results underscore an important health concern: even after wildfires are extinguished, residents may remain at risk of exposure to indoor VOCs. This pattern suggests that smoke-impacted materials within the home could continue to release VOCs into the indoor environment, creating a prolonged source of exposure.[18] To mitigate these risks, residents returning to affected homes should adopt measures to improve ventilation and filtration. Practical strategies may include regularly opening windows, operating central heating, ventilation, and air conditioning (HVAC) systems with filters rated at least Minimum Efficiency Reporting Value (MERV) 13, and using portable High-Efficiency Particulate Air (HEPA) purifiers with charcoal filters when available.[27,28] These interventions may accelerate the off-gassing process and help restore indoor air

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quality, thereby reducing the risk of continued exposure during the postfire recovery period.[29]

4. LIMITATIONS

This study has several limitations. First, because of the emergency conditions during the 2025 Los Angeles wildfires and the associated evacuation orders, we were unable to systematically select sampling sites. Recruitment therefore relied on opportunity sampling, reflecting the best possible effort to secure households, sampling equipment, and researchers to deploy the samplers by the second day of the fires. Second, there was limited overlap in sampling locations across the three fire phases, which may limit comparability across phases and could affect the interpretation of apparent temporal trends. Third, we did not collect information on other indoor sources of VOCs or on building characteristics such as age, construction materials, and ventilation systems, which could influence indoor VOC concentrations.[30,31] Future studies should systematically evaluate these factors and examine potential mitigation strategies to reduce exposure during and after wildfire events.[32]

In summary, our study showed that indoor VOC concentrations were often higher than outdoor levels in burn-zone homes following the 2025 Los Angeles wildfires. These findings underscore the need for targeted interventions to minimize indoor exposures during the recovery phase. More broadly, this work enhances understanding of indoor and outdoor VOC dynamics during wildfire events and provides evidence to guide future research on smoke-related health impacts, as well as the development of regulations to better protect residents from indoor VOC exposure.[33]

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.estlett.5c00919.

Additional details, including sorbent uptake rates, limits of quantification of VOCs, indoor and outdoor concentrations of VOCs, and wind speed and direction near the Palisades and Eaton Fires (PDF)

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Author Contributions

Y.Y., J.L., M.J., and Y.Z. designed the study. Y.Y., J.L., and M.N. collected the samples. Y.Y. and D.G.-G. performed the data analysis and drafted the manuscript. Q.N. contributed to data analysis. M.J. and Y.Z. reviewed and revised the manuscript.

Notes

The authors declare no competing financial interest.

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