Assessing Indoor Versus Outdoor $PM_{2.5}$ Concentrations During the 2025 Los Angeles Fires Using the PurpleAir Sensor Network

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Abstract

In January 2025, a series of fast-moving wildland-urban-interface (WUI) fires swept through the Los Angeles (LA) metropolitan area, causing severe air pollution. While the impacts of WUI fires on outdoor air quality have been extensively studied, indoor exposure remains less understood, despite most people sheltering indoors during WUI fires. This study investigates the spatial and temporal patterns of indoor and outdoor $PM_{2.5}$ concentrations across the South Coast Air Basin, with a focus on Los Angeles County during the LA fires. Using high-resolution data from co-located indoor and outdoor PurpleAir sensors, we analyze hourly $PM_{2.5}$ levels and indoor/outdoor ratios. Outdoor $PM_{2.5}$ concentrations spiked sharply during the fires, reaching unhealthy levels. Indoor concentrations increased concurrently but to a lesser extent, reflecting the partial shielding effect of indoor environments from outdoor air pollution. The mean daily indoor/outdoor $PM_{2.5}$ ratio was 0.50 during LA fire days, lower than that ratio (0.81) during non-fire days. Indoor/outdoor $PM_{2.5}$ ratios across sensors showed a wide distribution, reflecting differences in building characteristics and occupant behavior, such as the use of air purifiers. These findings emphasize the need for guidance and interventions to reduce indoor $PM_{2.5}$ exposure and protect public health during extreme WUI fire events.

Keywords

PurpleAir low-cost sensors, indoor air quality, wildland-urban-interface (WUI) fire, PM2.5, 2025 Los Angeles Fires

Synopsis

Using a low-cost sensor network, we analyzed spatiotemporal patterns of outdoor and indoor $PM_{2.5}$ increases during the 2025 Los Angeles fire and quantitatively assessed their differences, providing insights to inform health research and policy interventions.

Introduction

In January 2025, the Los Angeles metropolitan area experienced one of the most severe wildland-urban interface (WUI) fire events (referred to as *the LA fires* below) in recent history. Starting on January 7, multiple rapidly spreading WUI fires swept across Southern California, fueled by dry vegetation and strong Santa Ana winds.[1] The fires, especially the Palisades and Eaton fires, have caused destructive damage throughout the region; by January 23, these fires had burned more than 50,000 acres and destroyed at least 16,000 structures.[1]

WUI fires produce large volumes of smoke that contain a complex mixture of gases and airborne particles. Among these, fine particulate matter ($PM_{2.5}$) is of particular concern due to its small aerodynamic diameter (less than 2.5 micrometers), which allows it to penetrate deep into the lungs and even enter the bloodstream. These particles emitted from fires can travel hundreds of kilometers to surrounding urban areas, elevating ambient $PM_{2.5}$ concentrations well beyond health-based air quality standards.[2,3] Furthermore, these particles can also enter indoor spaces through ventilation systems, open windows, and building leaks. Additionally, people tend to keep their windows closed during smoke, leading to lower natural ventilation rate and the accumulation of indoor pollutants. Therefore, indoor $PM_{2.5}$ concentrations increase during fires, due to both outdoor pollutant penetration and indoor emissions, leading to increased exposure of residents to air pollution in the indoor environments where they spend most of their time. Exposure to air pollution from fire smoke has been consistently associated with increased hospital admissions for asthma, bronchitis, ischemic heart disease, premature mortality, and adverse birth outcomes, with particularly severe effects observed among children, the elderly, and those with pre-existing medical conditions.[4–6] Los Angeles is uniquely vulnerable to smoke exposure due to its high population density and rapid expansion of wildland-urban interfaces, exposing millions of residents to harmful pollution levels both outdoors and indoors.[1,7]

Previous studies have used multiple observational data and modeling tools to estimate the impact of fires on air pollution. Specifically, the Air Quality System (AQS), the ground-based regulatory air monitoring network maintained by the U.S. Environmental Protection Agency (EPA), has been used extensively to study the air quality impacts of fires.[8–10] While AQS offers reliable and accurate criteria pollutant measurements, its sparse spatial coverage limits its ability to capture local-scale pollution spikes during rapidly evolving WUI fire events. To address this shortcoming, some studies have used satellite data, but these approaches still face challenges in predicting ground-level air quality where most human exposures occur.[11–13] Other studies also combined satellite data with chemical transport models to estimate ground-level PM concentrations, but were mostly limited to the outdoor environment.[14,15] Particularly for the LA fires, Schollaert et al[11] recently identified January 7-14 as the days impacted by smoke using satellite data, AQS data, and PurpleAir sensors. However, most of the studies focused on the impact of outdoor air quality of fires; there has not been a study investigating indoor air quality during the LA fires, which motivates us to investigate this using data from PurpleAir sensors.

The PurpleAir low-cost sensors provide valuable high-resolution data for both indoor and outdoor air quality, significantly increasing the spatial coverage of air quality monitoring. Their growing adoption in recent years across the Western U.S., particularly in Southern California, presents a unique opportunity for us to investigate the indoor air quality impacts of the LA fires. Previous studies have investigated the spatial and temporal patterns of outdoor $PM_{2.5}$ concentrations in Southern California using PurpleAir data combined with machine learning, geostatistical, and chemical transport models.[16–20] These studies showed that after using appropriate data correction and calibration, the PurpleAir network data could complement the regulatory monitors by providing additional temporal and spatial variation details on fire smoke-impacted air quality.[21] Fewer studies have investigated indoor air quality during fire events using low-cost sensors. Krebs et al (2021)[22] assessed the heterogeneity of PurpleAir $PM_{2.5}$ concentrations from indoor and outdoor across a whole year, confirming the validity of comparing and analyzing PurpleAir indoor and outdoor $PM_{2.5}$ concentrations. Liang et al (2021)[23] compared indoor and outdoor $PM_{2.5}$ measurements from PurpleAir sensors in California, and found that indoor $PM_{2.5}$ levels increased noticeably during WUI fire events, while the infiltration rate (from outdoor to indoor) during WUI fire days was half of non-fire days. O'Dell et al (2023)[24] paired indoor and outdoor PurpleAir monitors in the western U.S. and found that $PM_{2.5}$ indoor-to-outdoor ratio varies by region, while mean indoor concentrations are 82% higher in fire days compared to non-fire days.

While the PurpleAir sensor data is useful for addressing spatial and temporal gaps in $PM_{2.5}$ data, assessing indoor air quality using PurpleAir data requires addressing several challenges. First, the metadata specifying whether a sensor is designated for indoor or outdoor use is occasionally inaccurate. To address this issue, we developed a reclassification method based on temperature variability, allowing us to more accurately distinguish between indoor and outdoor sensors. Second, the number of co-located indoor-outdoor sensor pairs is very limited. Meaningful comparison between indoor and outdoor measurements requires careful collocation, ensuring sensors are close to each other.

Previous studies typically selected the nearest outdoor counterpart of indoor sensors or set a distance threshold of 1 kilometer for comparison,[24,25] while it is clear whether they are sufficiently close for representative comparisons.[23] In our study, we were able to determine 50 pairs of indoor and outdoor sensors located within close spatial proximity (30 meters) in Los Angeles to identify differences attributable specifically to indoor versus outdoor $PM_{2.5}$ concentrations, reducing the influence of spatial variability of outdoor $PM_{2.5}$ concentrations.

Our study investigates how the disastrous LA fire affects both outdoor and indoor air quality, and for the first time quantitatively compares their difference in $PM_{2.5}$ concentrations. Using hourly-averaged PurpleAir data across the South Coast Air Basin (SCAB), we calibrated $PM_{2.5}$ measurements and sensor location types (i.e., indoor and outdoor), identified pollution hotspots, and analyzed PM concentrations of co-located indoor–outdoor sensor pairs before, during, and after the fire. The indoor and outdoor $PM_{2.5}$ concentration levels reported in this study could be further analyzed for public health studies. Furthermore, our study offers insights for individuals seeking to reduce exposure to smoke and suggestions for air quality management agencies aiming to strengthen public health protection.

Methods

PurpleAir data description

PurpleAir (PA) provides real-time monitoring air quality data through wide deployment of low-cost sensors globally. We retrieved data of hourly-averaged $PM_{2.5}$ concentrations along with temperature and relative humidity (RH) for all publicly available and activated sensors located within the South Coast Air Basin from the Purple Air API from January 1 to January 31, 2025.[25] Metadata such as GPS coordinates, location type (as labeled by users when first activated), and sensor start date were included for further classification and analysis.

The PA dataset used in this study includes measurements from both PA-I and PA-II sensors. The majority are PA-II sensors, which contain two Plantower PMS5003 laser-scattering particle counters, referred to as channels A and B, that alternate measurements every 10 seconds. By incorporating two sensing channels, the design allows for cross-validation between channels, enhancing data reliability through internal consistency checks. PA-I sensors are primarily designed for indoor use and contain a single particle counter (typically the Plantower PMS1003). These sensors report multiple estimated $PM_{2.5}$ mass concentrations, based on particle counts in different size bins and calibration algorithms developed by Plantower, known as CF=1, ATM, and ALT-CF3.4. All sensors also include a Bosch BME280 sensor for measuring temperature, relative humidity, and pressure.

For our analysis, we used the "CF_ATM" data field (referred to as "pm2.5_cf_atm" in the PurpleAir API), which represents the calibrated $PM_{2.5}$ concentrations by Plantower accounting for particle hygroscopic growth under varying humidity. We further calibrated both indoor and outdoor PurpleAir sensor readings based on the US EPA method (as described in the following section). We used the same calibration methods for indoor and outdoor $PM_{2.5}$ concentrations to ensure comparability between them, since our analysis is focused on indoor-to-outdoor relationships.

Data cleaning and calibration

We conducted multi-step cleaning and calibration of hourly PurpleAir measurements.

First, we removed data from PurpleAir sensors that did not report any temperature, relative humidity (RH), and $PM_{2.5}$ data. We also removed sensors that have a data coverage of $PM_{2.5}$ concentrations less than 50% in our study period, January 2025. The data coverage for each sensor was computed as a ratio of the number of available hourly $PM_{2.5}$ observations to the total number of hours in January 2025.

Second, we removed implausible measurements. Specifically, we removed sensors if recorded temperatures were outside the range of −200°F to 1000°F (−129°C to 537°C) or if RH values were outside the 0–100% range.[18] We also removed sensors whose monthly average $PM_{2.5}$ concentration exceeded 500 μg/m^3, as persistently high values may indicate sensor malfunction.

Third, we assessed the quality and consistency of $PM_{2.5}$ readings from the dual optical particle counters, channels A and B within the Plantower PMS5003 sensor. These two channels operate in alternating 10-second intervals and generate averaged $PM_{2.5}$ values over two-minute periods. Each channel uses a laser-based method that measures 90° light scattering from airborne particles, utilizing a 680 ± 10 nm wavelength. Records were removed when data from both channels was missing or equal to zero. For records with both A and B available, consistency checks were performed: when the mean concentration was <100 μg/m^3, records were retained only if the absolute difference between A and B was ≤10 μg/m^3; for mean concentrations ≥100 μg/m^3, the relative difference |A – B| / average was required to be ≤10%. When both channels A and B provided valid and consistent readings, the average of the two was used. Note that, to maintain an adequate number of observations for analysis, we did not remove data from sensors that only have one channel.

Lastly, to correct for biases in PurpleAir $PM_{2.5}$ measurements, we applied the RH-based calibration method developed by the US EPA, using different equations for typical ambient PM2.5 concentrations and high concentrations due to fire smoke et al. (2022)].[21] Figure S3 shows the comparison between our calibrated PurpleAir $PM_{2.5}$ concentrations and those measured by a nearby EPA air monitoring station.

Indoor and outdoor sensor reclassification

The metadata provided by PurpleAir users regarding sensor location type (indoor or outdoor) could be inaccurate. To address this issue, we reclassified each sensor based on its observed temperature variability. Specifically, we calculated the average daily temperature range (i.e., daily maximum minus minimum) for each sensor from January 1 to January 31, 2025. Sensors with low daily temperature ranges (<5 °C) were likely installed indoors, as indoor climate is more stable, while those with high ranges (>10 °C) were likely outdoors. Based on this approach, we identified 35 of the 933 sensors retained after data cleaning as likely misclassified. We reclassified 16 originally labeled as indoor sensors to outdoor, and 19 outdoor sensors to indoor (Figure S1).

Identification of co-located indoor and outdoor sensors

To identify co-located indoor and outdoor PurpleAir sensors for analyzing indoor–outdoor air quality relationships, we used sensor metadata containing geographic coordinates. Coordinates were converted to a projected coordinate reference system (EPSG:3857), and a spatial proximity analysis was conducted. For each indoor sensor, we identified all outdoor sensors located within 30 meters and active during the study period (January 1–31, 2025). Sensor pairs (one indoor and at least one outdoor sensor) within this 30-meter buffer were classified as co-located. When multiple outdoor sensors were paired with an indoor sensor, we averaged their outdoor $PM_{2.5}$ concentrations. Figure S4 shows the spatial distribution of these sensor pairs; of the 62 co-located pairs identified in the South Coast Air Basin, 50 pairs are located in Los Angeles County, covering the downwind area of smoke plume .

Identification of fire days

For our further analysis of indoor vs outdoor daily concentrations in Los Angeles County, we identified days when co-located indoor and outdoor PurpleAir sensors' air quality readings were impacted and not impacted by smoke from the LA fire. We used the cleaned and calibrated dataset described above and retained only sensors-days with at least 18 valid hourly observations to ensure data reliability. We classified a sensor-day as fire-impacted within the fire period (January 7–12, 2025) if its daily average outdoor $PM_{2.5}$ concentration exceeded 12 μg/m^3. This threshold, based on the U.S. National Ambient Air Quality Standards (NAAQS) for annual average $PM_{2.5}$, was used as a conservative indicator of possible WUI fire smoke influence. All other days that were not classified as fire days were considered as "non-fire days".

Results and Discussion

Number of available indoor and outdoor PurpleAir sensors

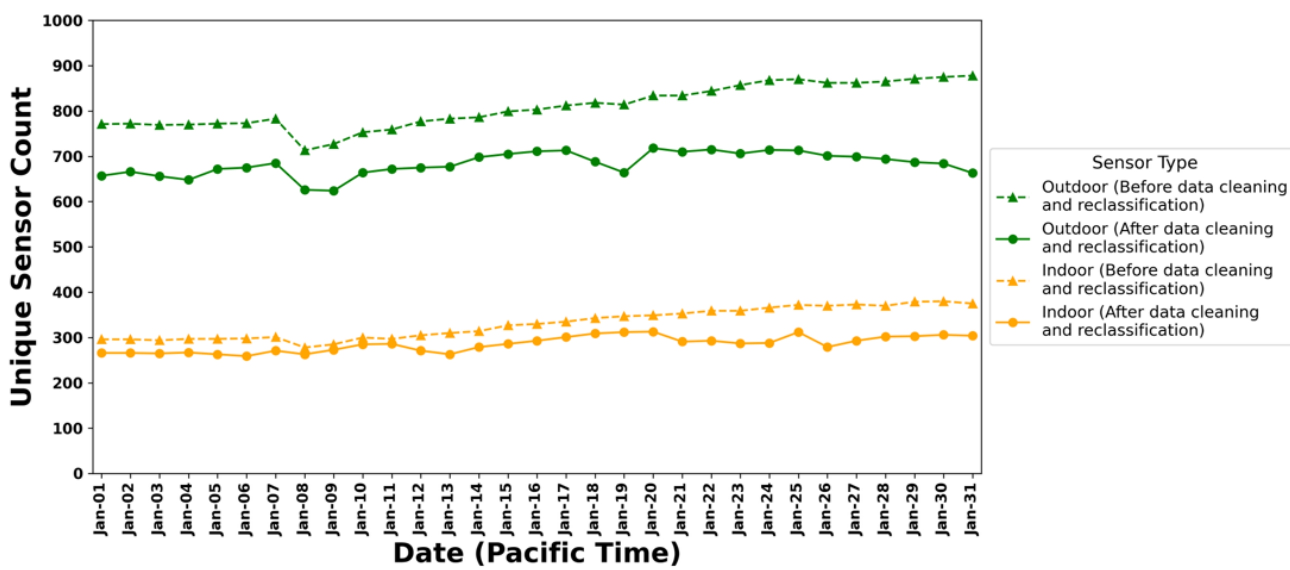

Figure 1. Daily count of unique indoor and outdoor activated PurpleAir sensors operating in the South Coast Air Basin (SCAB) during January 2025. Solid lines with circle markers represent sensors retained after data cleaning and reclassification, while dashed lines with triangle markers show counts before data cleaning and reclassification. Daily counts only include sensors recording at least 18 hours of data on a given day in Pacific Standard Time (PST).

Figure 1 shows the changes in the number of activated sensors in our study period. The change in count of activated sensors throughout January 2025 in the South Coast Air Basin, reflect both fire-related disruptions and human responses to WUI fire events. Both indoor and outdoor sensor activity dropped on January 8, likely due to power outages or connectivity loss caused by WUI fires. However, after January 10, the number of sensors began to increase steadily. This upward trend might be attributed to increased public interest in local air quality, as more individuals activated existing PurpleAir sensors or installed new PurpleAir Sensors in response to fire events. From January 8 to January 31, 2025, the total number of activted indoor sensors increased from 278 to 380, while the number of activated outdoor sensors increased from 713 to 878. These trends may reflect public interest in understanding and responding to air quality challenges following extreme air pollution events like WUI fires.

Figure 1 also compares the number of available sensors before and after data cleaning and reclassification of indoor/outdoor sensor types. Following these procedures, the number of sensors included in our analysis (solid lines) is slightly lower than the total number of available sensors (dashed lines). Their difference reflects our removal of data with dual-channel inconsistencies, temperature and humidity-related anomalies, and low data coverage. In particular, the difference was much higher after mid-January, because many newly activated sensors had less than 50% data coverage in January and were excluded from our analysis. Nonetheless, the cleaned dataset still provided a substantial number of high-quality observations, with more than 250 indoor sensors and more than 650 outdoor sensors, providing both strong data quality and sufficient spatial coverage for subsequent analysis.

Hotspots of Indoor and Outdoor $PM_{2.5}$ Concentrations

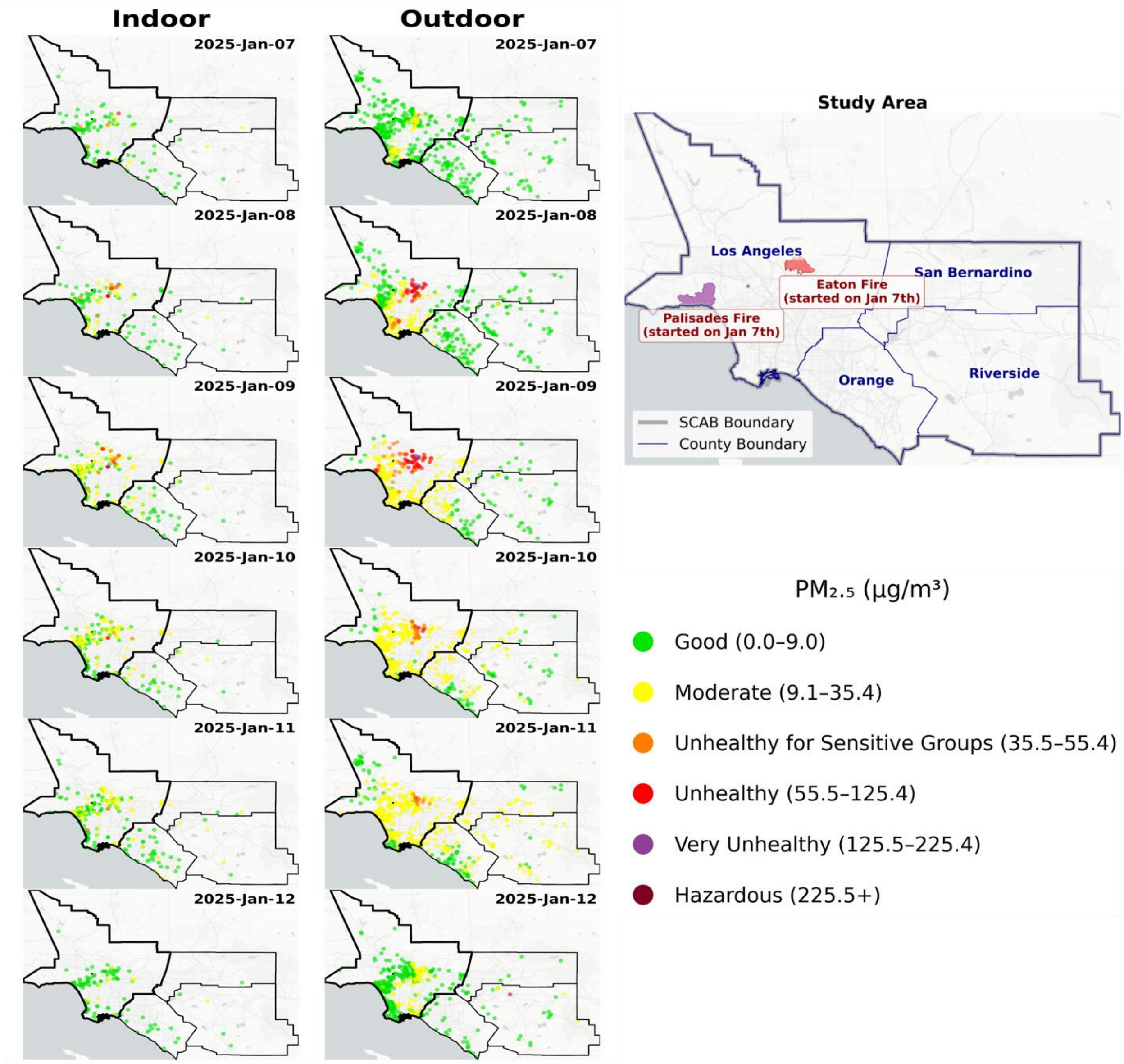

Figure 2. Daily maps showing the spatial distribution of indoor and outdoor $PM_{2.5}$ concentrations across the South Coast Air Basin (SCAB) from January 7-12, 2025 (Pacific Time). Each dot represents a PurpleAir sensor, and its color represents daily average $PM_{2.5}$ concentration, categorized into seven concentration bins according to the U.S. EPA Air Quality Index (AQI) thresholds: Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Very Unhealthy, and Hazardous. For each day, only sensors with at least 18 valid hourly readings are included. SCAB and county boundaries are shown in black, with the boundary of the intersection of Los Angeles County and SCAB highlighted in bold.

The high density of indoor and outdoor PurpleAir sensors in the South Coast Air Basin (especially LA County) enables us to investigate the spatial and temporal variability of $PM_{2.5}$ concentrations during the LA fire period (Figure 2). Figure 2 shows drastic increases in outdoor $PM_{2.5}$ concentrations between January 7 and January 11, peaking on January 9. Outdoor sensors in LA County recorded elevated $PM_{2.5}$ concentrations in the unhealthy range, reaching the unhealthy and very unhealthy Air Quality Index (AQI) levels. In the center of LA County, some sensors recorded extremely high outdoor $PM_{2.5}$ concentrations above 125.5 $\mu g/m^3$. In contrast, San Bernardino, Riverside, and Orange Counties had fewer sensors and experienced much milder PM2.5 pollution during the same period, with most outdoor $PM_{2.5}$ concentrations remaining in Good or Moderate AQI levels. The spatial pattern of elevated $PM_{2.5}$ concentrations during the LA fire is likely driven by prevailing Santa Ana winds and the location of fires, which blew Palisades Fire smoke offshore and constrained Eaton Fire smoke largely within the LA basin.[26,27] As a result, the LA fires predominantly affected $PM_{2.5}$ levels in LA County,[11] with limited impact on neighboring counties during this time period.

Indoor sensors also recorded increases in $PM_{2.5}$ concentrations during this period, though levels remained considerably lower than outdoor concentrations. Most indoor sensors showed concentrations in the 9–55.4 $\mu g/m^3$ range during January 8–9 (yellow to orange dots on the maps), with a few in central Los Angeles exceeding 55.4 $\mu g/m^3$, reaching unhealthy AQI levels. Note that AQI is designed for outdoor air quality assessment, but we also describe it for indoor air quality just to put numbers into perspective.

Both outdoor and indoor $PM_{2.5}$ concentrations started to decline after January 9 with the spatial range and intensity of hotspots (red and purple dots) visibly shrinking on the map. $PM_{2.5}$ concentrations returned to Good and Moderate AQI levels on January 12. This rapid decrease may reflect both reduced fire intensity and favorable meteorological conditions for dispersion outdoors, reduced infiltration indoors, and potentially greater air cleaning and filtration indoors.

Comparison of $PM_{2.5}$ Concentrations between Indoor and Outdoor Sensors

As shown in Figure 2, the LA fires led to much higher increases of outdoor $PM_{2.5}$ levels in LA County, compared to other counties within the South Coast Air Basin. To better understand indoor and outdoor exposure trends during the fire period and compare them, we focused our temporal analysis of $PM_{2.5}$ concentrations on sensor data aggregated in LA County to capture fluctuations in both indoor and outdoor air quality (Figure 3).

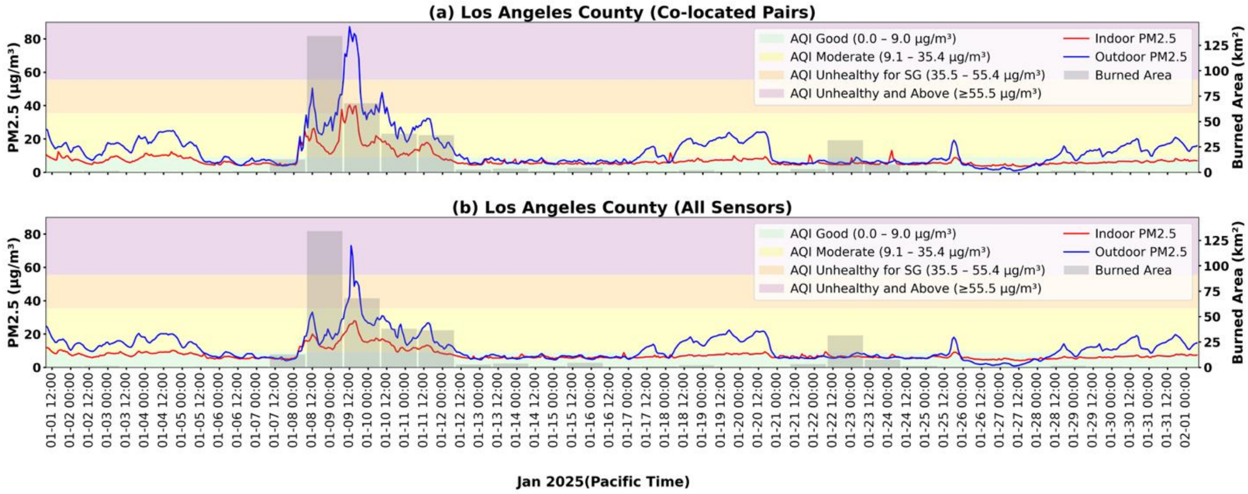

Figure 3. Hourly average PM2.5 concentrations from PurpleAir sensors in Los Angeles County within SCAB during January 2025. Panel (a) shows co-located indoor and outdoor sensor pairs in LA County; panel (b) includes all available indoor and outdoor sensors in LA County. Indoor and outdoor PM2.5 concentrations are plotted as solid red and blue lines, respectively. Shaded background colors represent updated U.S. EPA AQI thresholds: green (Good ≤9.0 μg/m^3), yellow (Moderate ≤35.4 μg/m^3), orange (Unhealthy for Sensitive Groups ≤55.4 μg/m^3), and purple (Unhealthy and Above ≥55.5 μg/m^3). Daily burned area in LA County (km^2) is overlaid as gray bars. All data is shown in Pacific Time.

From January 1 to 7, $PM_{2.5}$ concentrations were consistently low. Outdoor levels typically ranged from 10–25 μg/m^3, while indoor $PM_{2.5}$ levels were below 15 μg/m^3 in most cases. Average outdoor PM levels were within the Good and Moderate AQI levels, suggesting relatively clean air quality conditions.

The Eaton and Palisades fires, which began on January 7, triggered drastic $PM_{2.5}$ concentration increases across the LA County (and SCAB). Data from co-located sensors shown in Figure 3(a) is especially useful for comparing indoor versus outdoor concentrations, because each indoor sensor is positioned within 30 meters of corresponding outdoor sensors. The mean outdoor concentrations surged rapidly and peaked in the afternoon of January 9 at ~87 μg/m^3, reaching the Unhealthy AQI level. Indoor $PM_{2.5}$ concentrations from co-located sensors also rose substantially, peaking at ~40 μg/m^3 in the afternoon of January 9. During the peak smoke period (January 8–11), indoor and outdoor $PM_{2.5}$ concentrations exhibited similar temporal patterns. Overall, the indoor $PM_{2.5}$ concentrations were lower than outdoors, suggesting that indoor environments offer a degree of protection from WUI fire smoke. However, the concentrations still exceeded the "Unhealthy for Sensitive Groups" AQI threshold, indicating notable indoor exposure when outdoor $PM_{2.5}$ is heavily impacted by smoke.

Following the peak $PM_{2.5}$ concentrations in the afternoon of January 9, both indoor and outdoor $PM_{2.5}$ declined rapidly, returning to pre-fire levels by the end of January 12. In the absence of new WUI fire activity, outdoor $PM_{2.5}$ still had fluctuations, possibly due to the influence of other emission sources and meteorological factors such as vehicle exhaust, atmospheric stagnation, or residential wood burning. During this same period, indoor $PM_{2.5}$ concentrations remained relatively stable, suggesting the role of indoor environments in buffering occupants from ambient air pollution. Figure 3(b) includes the mean concentrations of all available ~700 outdoor and ~300 indoor sensors across Los Angeles County. The overall temporal trends are similar to those of the 50 co-located sensor pairs in Figure 3(a). Figures 3(a) and 3(b) both show clear peaks of outdoor $PM_{2.5}$ concentrations on January 9 at ~87 $\mu g/m^3$ for outdoor sensors of co-located pairs and ~71 $\mu g/m^3$ for all outdoor sensors.

Figure 3 also presents the daily burned area data to provide context for the fire burning situation. The temporal alignment between periods of burned area and $PM_{2.5}$ peaks confirms WUI fire smoke as the primary pollution driver during early January. In contrast, $PM_{2.5}$ fluctuations in mid-to-late January occurred without significant burning, suggesting other emission sources or meteorological factors. It is also worth noting that an increase in burned area may not necessarily result in measured increases in concentrations. This could be partially due to limited or no sensor coverage in the downwind area of fires (e.g., the ocean). This could explain the lack of observed elevated $PM_{2.5}$ concentrations correlated with the burned area in late January (mainly from the Hughes Fire in North of SCAB).

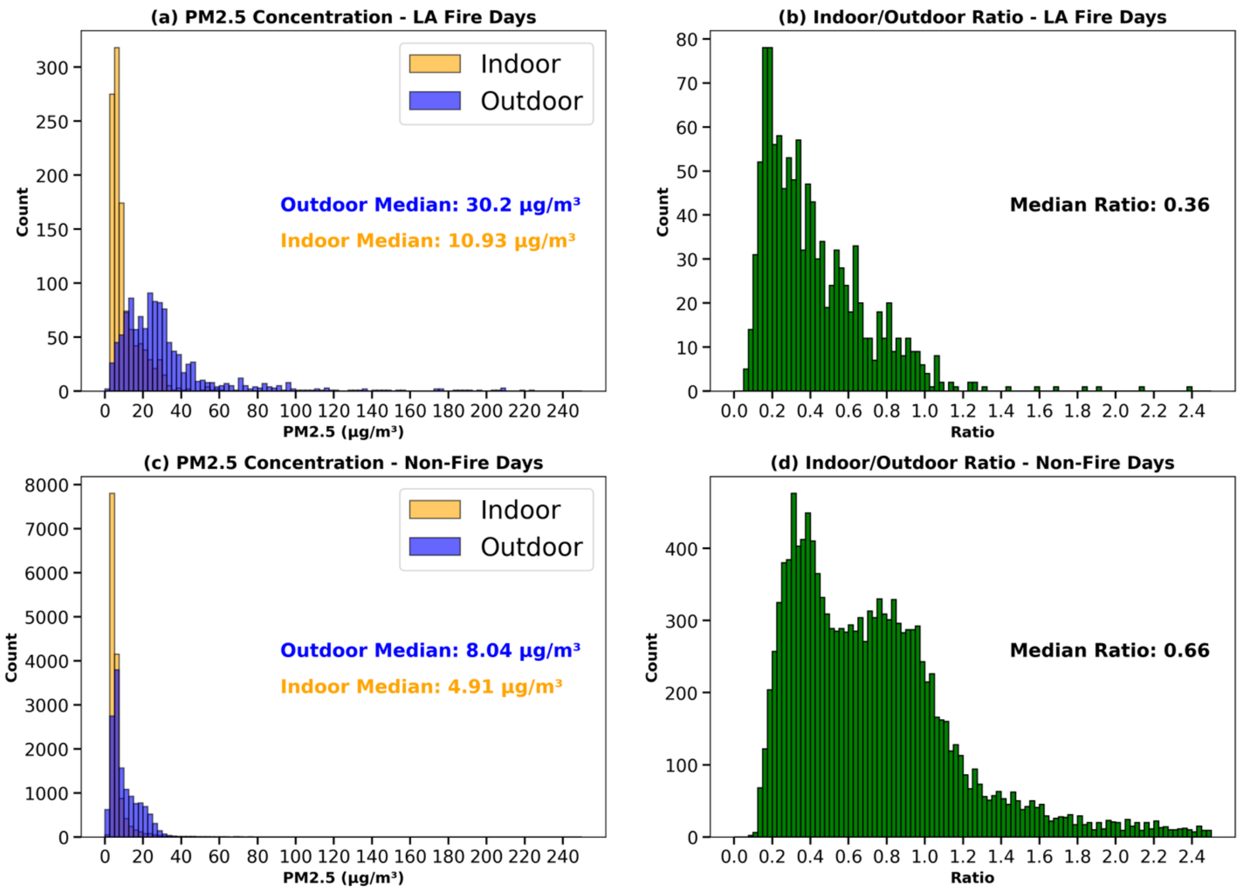

Figure 4. Histograms of hourly $PM_{2.5}$ concentrations and indoor/outdoor PM2.5 ratios from co-located PurpleAir sensor pairs in LA County during LA fire days and non-fire days in January 2025. Panels (a) and (b) show histograms of hourly indoor (yellow bars) and outdoor (blue bars) PM2.5 concentrations and indoor/outdoor PM2.5 ratios during WUI fire-impacted days, while panels (c) and (d) display the corresponding distributions for non-impacted days. Indoor/outdoor ratios (panels b and d) are calculated as the indoor concentration divided by the outdoor concentration, measured by each co-located sensor pair.

We further classified the $PM_{2.5}$ concentration data of co-located sensors into sensor-days impacted by LA fire and non-fire days, and presented the distribution of hourly $PM_{2.5}$ concentrations for days impacted and not impacted by the LA fire. During the LA fire days (Figure 4a), outdoor $PM_{2.5}$ levels had a wide variability with many readings exceeding 50 µg/m^3 and some surpassing 100 µg/m^3 (the 90th percentile reaching 85.2 µg/m^3). In contrast, during non-fire days (Figure 4c), the vast majority of outdoor $PM_{2.5}$ concentrations remained below 25 µg/m^3, with a 90th percentile at 22.7 µg/m^3, much lower than the concentrations during fire days.

Indoor $PM_{2.5}$ concentrations remained comparatively lower and more stable. For both LA fire days and non-fire days, indoor $PM_{2.5}$ distribution were heavily skewed to the right (Figures 4a and 4c). Despite the increases in indoor $PM_{2.5}$ concentrations, they generally remained within the “Good” and "Moderate" AQI categories.

Distribution of both indoor and outdoor $PM_{2.5}$ concentrations shifted towards higher concentrations during the LA fire days, as compared to non-LA fire days. During LA fire-impacted days, the median hourly outdoor and indoor $PM_{2.5}$ concentrations were 30.2 $\mu g/m^3$ and 10.9 $\mu g/m^3$, respectively. The median hourly outdoor and indoor concentrations were 8.0 $\mu g/m^3$ and 4.9 $\mu g/m^3$ during non-fire days, respectively. Overall, we found that indoor concentrations were lower than those outdoors.

Indoor/outdoor PM2.5 ratios during LA fire days and non-fire days

Despite the increases in $PM_{2.5}$ concentrations for both indoor and outdoor sensors during LA fire days, Figure 4b shows that hourly indoor/outdoor $PM_{2.5}$ ratios were significantly lower during LA fire days, where most ratios fell within 0.1 to 1, with a peak between 0.1 and 0.2 and median ratio of 0.36. In contrast, as shown in Figure 4d, during non-fire days, the distribution had a higher median ratio of 0.66 and double modes with peaks observed at ~0.3 and ~0.8. Notably, during LA fire days, a much smaller portion of ratios exceeded 1.0 compared to non-fire days, indicating less frequent instances where indoor $PM_{2.5}$ concentrations surpassed outdoor levels during LA fire days.

The indoor/outdoor $PM_{2.5}$ ratios also exhibit a wide range. For LA fire days, their interquartile range (IQR) is 0.34, with Q1 at 0.23 and Q3 at 0.57. Their IQR for non-fire days (0.55) is even higher, with Q1 at 0.39 and Q3 at 0.94. The high variability in indoor/outdoor $PM_{2.5}$ ratios (Figures 4b and 4d) suggests that the protective role of indoor environments in reducing PM2.5 exposure varies.

Table 1. Summary statistics of daily $PM_{2.5}$ concentrations from co-located indoor and outdoor PurpleAir sensors in the area of Los Angeles County that is within the South Coast Air Basin during January 2025. The table reports the mean ± standard deviation of outdoor $PM_{2.5}$, indoor $PM_{2.5}$, indoor/outdoor ratios, and differences of indoor minus outdoor concentrations for days impacted and not impacted by the LA fire. N indicates the number of sensor-day pairs used in each calculation, with each pair representing one day of data from co-located indoor and outdoor sensors.

	Mean Indoor concentration (µg/m^3)	Mean Outdoor concentration (µg/m^3)	Mean Indoor/outdoor ratio	Mean Indoor-Outdoor difference (µg/m^3)
LA fire days (N=119)	18.6±19.2	41.2±29.5	0.50±0.40	-22.7±26.5
Non-fire days (N=1297)	7.0±7.6	11.3±10.9	0.81±0.75	-4.3±9.2

Table 1 shows a summary of mean and standard deviation for PurpleAir daily indoor and outdoor $PM_{2.5}$ concentrations. Outdoor mean $PM_{2.5}$ concentrations reached 41.2 µg/m^3 during the LA fire days, a factor of four times higher than the mean $PM_{2.5}$ concentrations during non-fire days (11.3 µg/m^3). Indoor mean concentration was 18.6 µg/m^3 during fire-impacted days, a factor of 2.7 higher than the concentration during non-fire days (7.0 µg/m^3). The increases in indoor concentrations we observed during the Los Angeles fires are comparable to findings by Liang et al. (2021),[23] which concluded that indoor mean concentrations tripled during fire-impacted days in Northern California.

Table 1 also compares the indoor versus outdoor $PM_{2.5}$ concentrations. The mean indoor/outdoor ratio decreased from 0.8 during non-fire days to 0.5 during LA fire days. The absolute difference between mean indoor $PM_{2.5}$ concentrations and outdoor $PM_{2.5}$ concentrations during LA fire days reached 22.7 µg/m^3, which is significantly larger than 4.3 µg/m^3 on non-fire days. These differences, together with the pattern shown by Figures 4a and 4b, reflect the protective role of indoor environments in mitigating exposure to WUI fire-related $PM_{2.5}$. They may also reflect actions taken by residents during high pollution events, such as the active use of air filters.

Discussion

Our analysis of PurpleAir sensor data provides a comprehensive comparison between indoor and outdoor $PM_{2.5}$ and for LA fire and non-fire days, providing valuable insights into the extent to which indoor environments may buffer residents from elevated outdoor pollution levels during WUI fire events. We found that both indoor and outdoor $PM_{2.5}$

concentrations experienced large increases during LA fire days in Los Angeles County and had similar temporal and spatial patterns. Across most co-located indoor–outdoor sensor pairs, indoor $PM_{2.5}$ concentrations were consistently lower than outdoor levels, reflected by an average indoor/outdoor ratio of 0.81 during non-fire days. This ratio declined further during the LA fire period to 0.50. All these findings highlight the partial protection offered by indoor environments against outdoor fire smoke. Given public health warning and messaging about the dangers of inhaling high concentrations of outdoor $PM_{2.5}$, it is expected that most individuals living in LA residences would have sealed up their homes to try and limit infiltration from outdoors, to the extent possible. People might have also avoided cooking and vacuum cleaning in response to widespread public health advisories. That said, even with changes in human behavior, indoor concentrations of $PM_{2.5}$ still increased during the LA fire, due to both infiltration from outdoors and emissions of indoor sources.

The distribution of indoor/outdoor $PM_{2.5}$ ratios was unimodal during fires (Figure 4b) and bimodal on non-fire days (Figure 4d). We hypothesized that the modes might indicate the extent of protective actions taken by individuals. On fire days, it is anticipated that most residents would employ protective measures, such as using air purifiers. In contrast, on non-fire days, there might be a mix of people who actively maintained protective measures and those who did not. The broad range of the indoor/outdoor ratios suggests that exposure outcomes can vary depending on building characteristics, such as the Minimum Efficiency Reporting Values (MERV) rating of filters in central air conditioning systems, outdoor climate, as well as the behaviors of occupants, such as whether they use air purifiers, aligning previous studies investigating infiltration rate variations.[28,29] Similarly, Xiang et al. (2021)[30] found that outdoor to indoor infiltration factors during wildfire days varied substantially across buildings, ranging from 0.33 - 0.76. They also found that high-efficiency particulate air (HEPA) air purifiers operating in auto mode could reduce indoor $PM_{2.5}$ concentrations by 48% - 78%.

We acknowledge several limitations of this study, some of which could be addressed by future studies. First, most households only have a single sensor, which may not adequately capture the spatial variability of $PM_{2.5}$ within indoor environments. Second, future analyses could be improved by identifying and excluding periodic indoor emissions (from activities such as cooking and cleaning) to better isolate WUI fire-related impacts. Moreover, quantifying infiltrated $PM_{2.5}$, which is the fraction of indoor $PM_{2.5}$ originating from outdoor sources, may help to more accurately characterize exposure attributable to WUI fire events.[23] Lastly, the PurpleAir sensor network could also be further expanded to enhance its spatial coverage and enable a more comprehensive assessment of $PM_{2.5}$ exposure patterns.

As shown in Figure 2, Los Angeles County has a much higher density of both indoor and outdoor sensors compared to the surrounding counties (San Bernardino, Riverside, and Orange) in SCAB. This higher adoption of PurpleAir sensors in LA County may be due to its denser population and greater public awareness. However, within LA County itself, there is also a data gap in Assembly Bill 617 disadvantaged communities, especially in the South and Southeast Los Angeles community (comparing Figure 2 and Figure S5). Both the data gaps within and outside of LA County underscore the critical role of building a high-resolution sensor network in tracking $PM_{2.5}$ concentrations during WUI fire events and in identifying pollution hotspots that may not be captured by sparse regulatory monitors.[31–33]

Our findings are important for conducting future exposure analysis and guiding effective public health interventions. Analyses of co-located PurpleAir sensors could provide information of exposure estimates in future epidemiological studies targeting WUI fire health effects.[34] Expanding such sensor networks across Los Angeles communities would provide further data support for both scientific research and public risk communication. With indoor levels still tripling despite reduced infiltration during WUI fire days, residents are advised to stay indoors with enhanced filtration systems to reduce high-level $PM_{2.5}$ exposure.[35] Public messaging during WUI fire events has also been shown to effectively prompt protective behaviors.[36] We suggest policymakers in Los Angeles support public outreach initiatives regarding the air quality impact of WUI fires and offer subsidies for HEPA purifiers and air quality monitors in disadvantaged and high-risk communities.

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are solely those of the authors and do not necessarily reflect those of the South Coast Air Quality Management District. South Coast Air Quality Management District does not endorse any products or commercial services mentioned in this publication.

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Supporting Information

Data cleaning and sensor type reclassification

Table S1. Number of indoor and outdoor PurpleAir sensors remaining after each data cleaning and reclassification step.

The number of sensors after each step

Data Cleaning Steps	Indoor Sensors	Outdoor Sensors	Indoor Sensor Removed	Outdoor Sensor Removed
Data before QC	418	960	0	0
Step1: Basic Filtering	326	798	92	162
Step2: Temperature & Humidity Check	324	768	2	30
Step3 : A/B Channel Check	323	738	1	30
Step4 : Reclassify Location	326	735	Outdoor → Indoor: 19	Indoor → Outdoor: 16

This table shows the number of indoor and outdoor sensors retained after each data cleaning step. "Data before QC" shows the initial sensor count, followed by the number of sensors after each step: (1) basic filtering for missing values and negative values, (2) removal of implausible temperature and humidity records, (3) A/B channel consistency check, (4) reclassification of sensor locations. The number of sensors removed at each step is listed, and final row summarizes sensors reclassified between indoor and outdoor categories.

Reclassifying PurpleAir Sensor Location Type

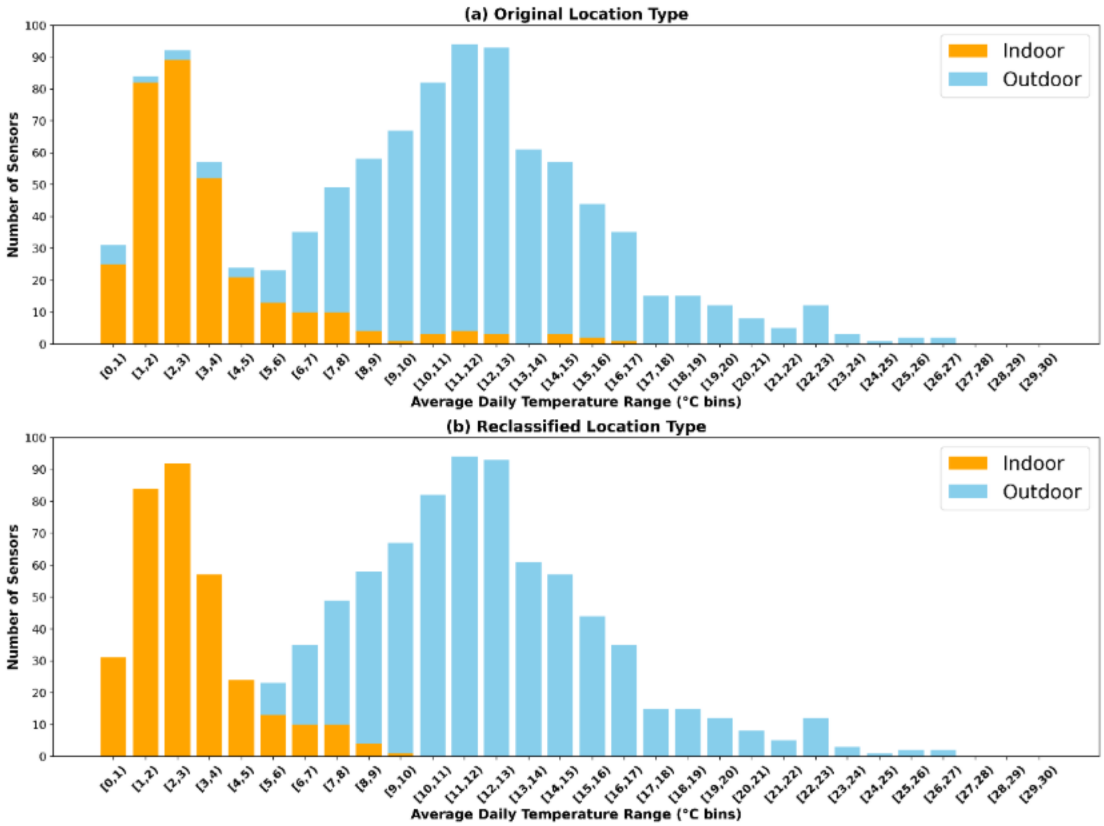

Figure S1. Comparison before and after location reclassification using daily average temperature range as a criteria. Panel (a) shows the distribution of sensors using the original location labels provided by PurpleAir, while panel (b) uses labels after reclassification based on temperature variability. Each bar represents the number of indoor (orange) and outdoor (blue) sensors falling within a specific 1°C-wide bin of average daily temperature range.

Co-located PurpleAir Sensor-EPA Air Quality Monitoring Stations in SCAB

Table S2. Co-Located EPA Air Quality Monitoring Stations and Purple Air Outdoor Sensors

Co-Located EPA Sites and Purple Air Outdoor Sensors

Station Name	Matched EPA Air Monitoring Sation	Matched PurpleAir Sensors	ID of matched PurpleAir Sensors
Rubidoux	60658001	7	2612, 3537, 4748, 5280, 5284, 6806, 180081
Long Beach Route 710 Near Road	60374008	1	104940

Based on Euclidean distances calculated in projected coordinates, PurpleAir sensors reclassified as outdoor were matched to EPA air monitoring stations (AMS) if located within 30 meters. This table lists EPA AMS and the AQS site number and IDs of nearby matched sensors, serving as reference for sensor comparison analyses. EPA AMS 060374008 had one matched sensors, while EPA AMS 060658001 had seven.

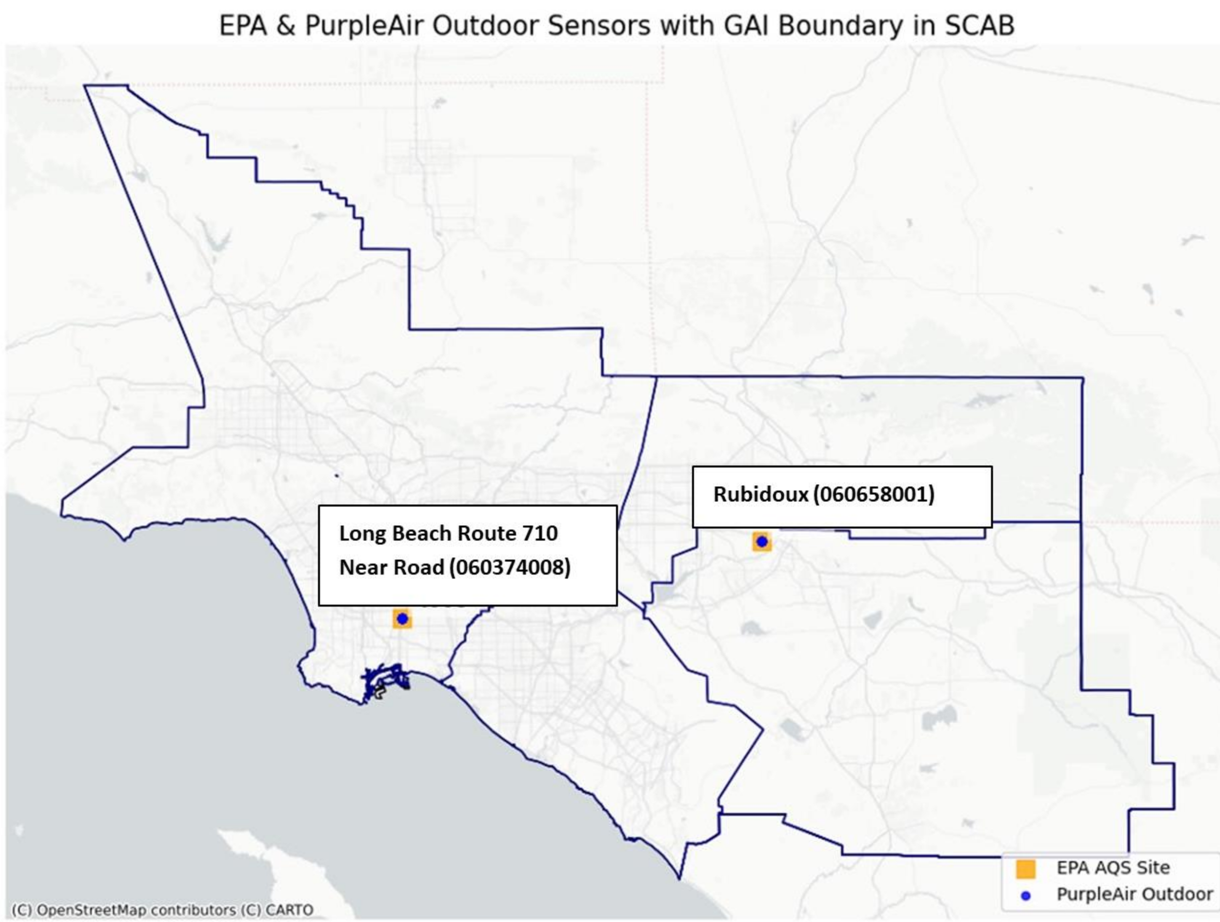

Figure S2. Co-located EPA AMS and PurpleAir outdoor sensors in SCAB. Orange squares indicate EPA monitoring sites, and blue circles represent matched PurpleAir outdoor sensors.

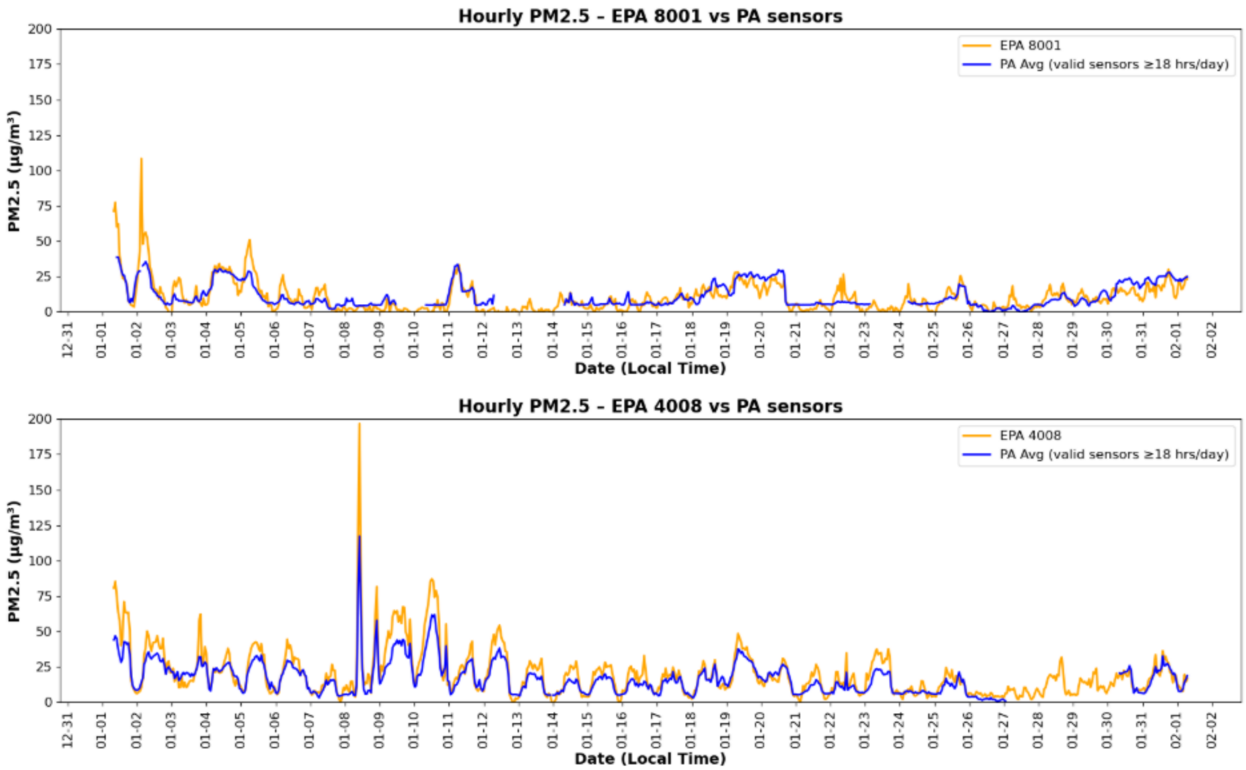

Figure S3. Comparison of hourly $PM_{2.5}$ concentrations measured by EPA regulatory monitors and co-located PurpleAir outdoor sensors. Hourly $PM_{2.5}$ concentrations recorded by EPA regulatory monitors (orange lines) and the corresponding average of co-located PurpleAir outdoor sensors (blue lines) at two monitoring sites (060658001 and 060374008) in the South Coast Air Basin (SCAB). Only PurpleAir sensors with ≥18 valid hourly records per day were included in the hourly average. The comparison spans January 1 to January 31, 2025.

Number and Location of Co-located Indoor-Outdoor PurpleAir Sensor in SCAB

Table S3. The number of co-located indoor-outdoor pairs in each county in SCAB.

County name	Number of Pairs
Los Angeles	50
Orange	7
Riverside	4
San Bernadino	1

A sensor pair was defined as an indoor–outdoor sensor combination located within 30 meters of each other. Los Angeles County hosts the vast majority of sensor pairs (50), while Orange, Riverside, and San Bernardino Counties contain fewer pairs, reflecting differences in sensor network density and urban data availability.

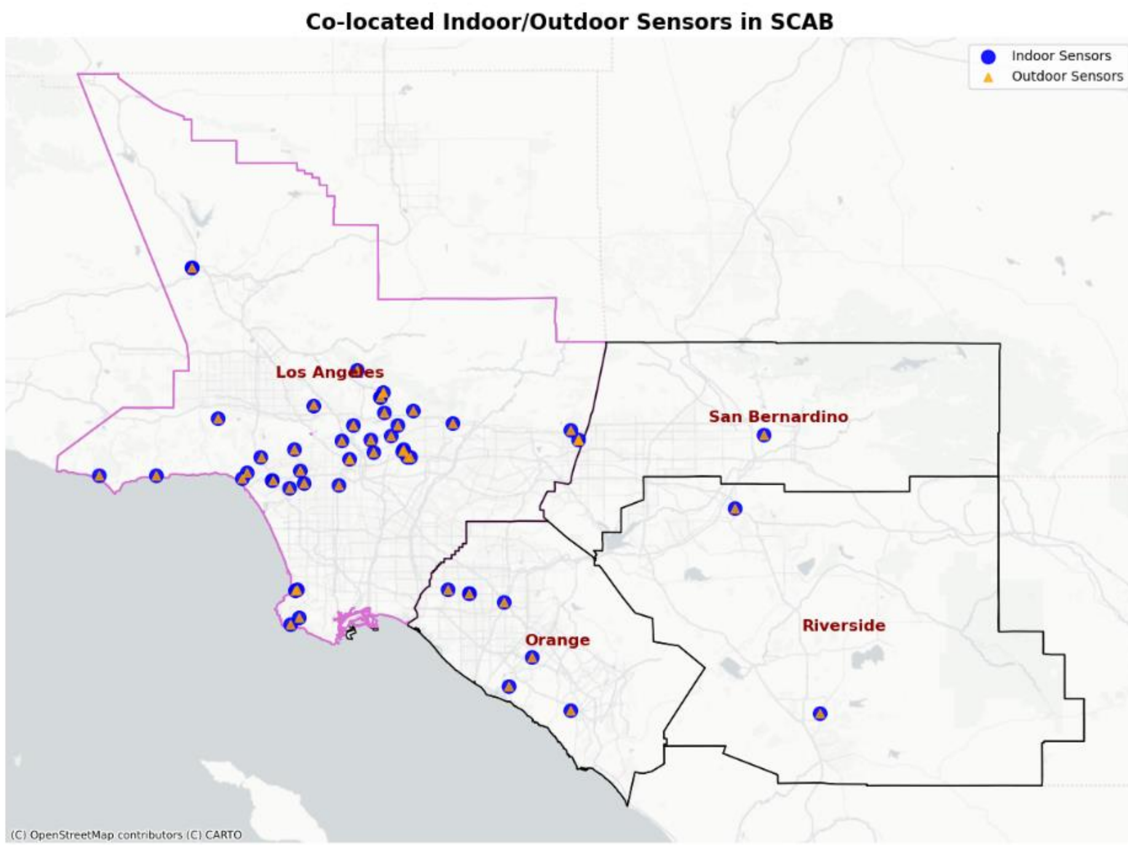

Figure S4. Map of 62 co-located indoor–outdoor PurpleAir sensor pairs identified across SCAB. Each pair consists of one indoor sensor (blue circle) and at least one outdoor sensor (orange triangle) located within 30 meters of each other. Co-located pairs were primarily concentrated in urbanized areas of Los Angeles County.

Disadvantaged communities in SCAB

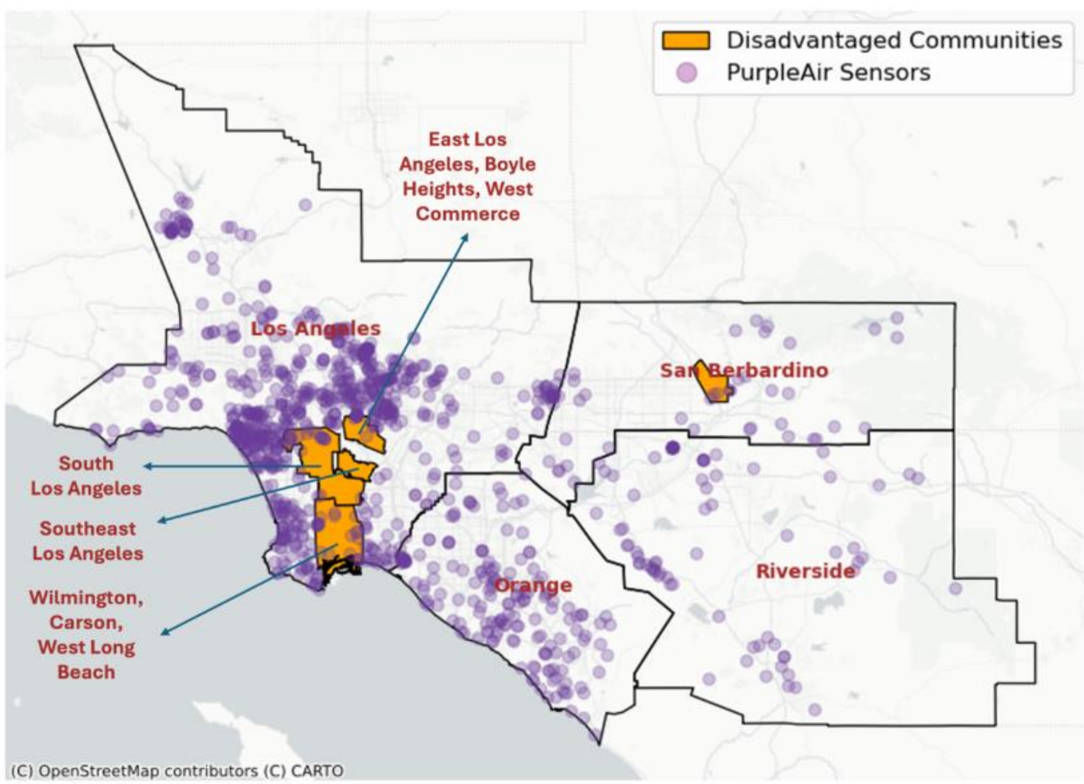

Figure S5. Map of Assembly Bill 617 disadvantaged communities (orange polygons) and PurpleAir sensors (purple dots) across SCAB.

The disadvantaged communities within LA County (especially in South Los Angeles and Southeast Los Angeles) have sparser PurpleAir sensors coverage.