

Enhancing Environmental Health Literacy and Reducing Indoor PM_{2.5} Through Accessible Interventions in Underserved Communities: A Pilot Study in Homewood, Pennsylvania

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Abstract Indoor air pollution poses health risks, especially in resource-limited communities where inadequate ventilation contributes to exposures to fine particulate matter (PM_{2.5}), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and ozone (O₃). These pollutants can worsen asthma and other respiratory conditions. This pilot study, conducted in Homewood, a historically underserved Pittsburgh, Pennsylvania, neighborhood, aimed to improve environmental health literacy (EHL) and test low-cost interventions (i.e., MERV-13 HVAC filters and HEPA purifiers) paired with an EHL training module. Using AQMesh pods, indoor air quality was monitored in 9 homes and 1 outdoor reference site for 2 weeks pre- and post-intervention. Monitors measured PM_{2.5}, NO₂, SO₂, and O₃. Participants completed an Air Quality Index (AQI) quiz before and after EHL training, and spirometry was pilot tested to assess feasibility for future studies. Post-intervention, PM_{2.5} declined in 6 of 8 intervention homes (75%), with significant reductions in 3 homes and a significant increase in 1 home. Pooled data showed a 21% decline in mean PM_{2.5}, although this finding was not statistically significant. AQI quiz scores improved in 7 of 9 participants (78%). No consistent changes were seen for gaseous pollutants. Our findings suggest that combining low-cost filtration or purifiers with EHL training can reduce particulate exposures, strengthen self-efficacy, and demonstrate feasibility of integrating spirometry into community-based indoor air quality research.

Keywords: indoor air quality, PM_{2.5}, air filtration interventions, environmental health literacy, residential exposure, low-cost interventions, community-based research, household air monitoring, urban environmental health, public health practice

Introduction

Air pollution is a leading environmental risk factor for premature death worldwide (World Health Organization, 2026). While outdoor air pollution is well-studied, indoor air quality (IAQ) is equally critical, as U.S. residents spend approximately 90% of their time indoors (U.S. Environmental Protection

Agency [U.S. EPA], 2025a). Poor IAQ contributes to respiratory symptoms and asthma exacerbations, particularly in children, older adults, and individuals with preexisting conditions (Logue et al., 2011; Zhang & Smith, 2003).

Exposure to fine particulate matter (PM_{2.5}), ozone (O₃), sulfur dioxide (SO₂),

and nitrogen dioxide (NO₂) is linked to asthma development and hospitalizations (Abbah et al., 2024; Varopichetsan et al., 2025). Asthma disproportionately affects disadvantaged populations, who experience higher prevalence and morbidity due to structural inequities such as proximity to highways, industry, and aging housing (Bell & Ebisu, 2012; Clark et al., 2014; Mikati et al., 2018). Elevated indoor pollutant levels—especially in poorly ventilated homes—are associated with increased asthma prevalence (Belanger et al., 2006; Lanphear et al., 2011), while early-life exposure to NO₂ and O₃ increases asthma risk (Blakemore, 2025; Nishimura et al., 2013).

HEPA purifiers, high-efficiency HVAC filters, and source control are recommended to

reduce indoor pollution (Barn et al., 2008; Fisk, 2013). When paired with education, these interventions also strengthen awareness and encourage lasting behavior change (Breysse et al., 2010; Butz et al., 2011). For individuals with asthma, management requires not only reducing environmental triggers but also building self-efficacy to recognize and respond to exposures. Our pilot study incorporated home-based spirometry to assess respiratory outcomes alongside environmental health literacy (EHL) training and linked observed IAQ changes to asthma-related health.

Conducted in the Homewood neighborhood of Pittsburgh, Pennsylvania, this pilot study evaluated the combined effect of affordable air filtration, targeted education, and at-home spirometry—supported by IAQ monitoring—to address health inequities in an underresourced urban community.

Methods

Study Area

Homewood, a neighborhood in eastern Pittsburgh with a population that is home to approximately 87% Black residents, according to the U.S. Census Bureau (2024), faces high poverty, aging housing, and disproportionate air pollution from local traffic and neighborhood sources. Although not adjacent to major industrial facilities, regional emissions—particularly from U.S. Steel's Clairton Coke Works, which is the largest coke plant in North America—contribute to countywide PM_{2.5} burdens through transport. These conditions reflect broader environmental justice patterns in Allegheny County (Marusic, 2024; U.S. EPA, 2025a).

According to the 2024 Environmental Justice Index (EJI) from the Centers for Disease Control and Prevention (CDC), Homewood ranked in the 94th percentile for air toxics cancer risk, 85th for PM_{2.5} exposure, 97th for cumulative environmental and social burdens, and 87th for poor air quality relative to all U.S. Census Bureau tracts. The EJI underscores chronic disease, housing quality, and environmental exposures as key drivers of health disparities.

Homewood experiences a disproportionate asthma burden compared with both county and national levels, reflecting broader regional trends of elevated asthma prevalence (Allegheny County Health Department,

2022). These health disparities contribute to a life expectancy gap of >10 years when compared with higher-resourced nearby neighborhoods such as Point Breeze (Lord, 2019). Despite these challenges, Homewood benefits from strong community infrastructure, including the University of Pittsburgh's Community Engagement Center (CEC), which supports research, resources, and resident engagement. Given the neighborhood's elevated asthma prevalence, our study focused on participants with physician-confirmed asthma to link indoor air quality (IAQ) interventions with health outcomes.

Study Design

Participants were recruited from the University of Pittsburgh Asthma & Environmental Lung Health Institute at UPMC (AELHI) Asthma Institute Research Registry, which includes >2,300 asthma patients, 118 of whom reside in the Homewood neighborhood. The registry provides demographics, comorbidities, medication data, lung function records, and family history, including asthma status of first-degree relatives (Schuyler & Wenzel, 2022).

Our study focused enrollment on asthmatic adults from distinct Homewood households in U.S. Census Bureau tracts 1301–1303, although 33% of participants lived just outside these boundaries. The University of Pittsburgh CEC outdoor monitor in tract 1303 served as the reference site for ambient air quality. Each participant was monitored for approximately 4 weeks (2 weeks pre- and 2 weeks post-intervention), with enrollment staggered between March and October 2024.

Eligibility criteria included central HVAC or alternative climate control and smartphone access. In addition to indoor monitoring, participants received Bluetooth-enabled portable spirometers to record lung function at home, which enabled the linking of pollutant changes with respiratory outcomes. Residential addresses were geocoded to confirm eligibility. The University of Pittsburgh institutional review board approved the protocol (STUDY23080092). We used anonymized samples in our analysis.

At the initial home visit, participants completed a structured environmental health survey that asked about household characteristics (housing type, ventilation, heating/cooling), indoor exposure sources (gas stoves, candles,

smoking), and self-reported respiratory symptoms (see Supplemental Survey).

Participants attended an in-person group session beginning with a 10-question AQI quiz developed by our study team to assess baseline knowledge of pollutants, health impacts, and AQI use. An educational presentation then reinforced these concepts and provided practical strategies for managing indoor exposures. Together, the quiz and presentation were part of the EHL intervention (see Supplemental Quiz).

Participants were trained to use a Bluetooth-enabled portable spirometer (Spirobank Smart, Medical International Research) and asked to use it several times a week. Each spirometry effort recorded lung function testing results: FEV₁, FVC, and the FEV₁/FVC ratio. Device-assigned quality grades (A–F, based on American Thoracic Society criteria) flagged errors (e.g., coughs, abrupt terminations), and acceptable spirometry tests were prioritized for analysis. The first spirometry effort, which was at installation, was excluded for all participants. Percent predicted values, independent of race, were calculated with Global Lung Initiative equations. Metadata included demographics, date and time, and attempt quality.

Participants completed a 2-week baseline monitoring period with an air quality monitor (AQMesh pods, Environmental Instruments Ltd.), followed by an in-person session to install their assigned intervention (air filter or air purifier). Participants then began a 2-week post-intervention phase using the same air quality monitor. Weekly check-ins during both phases ensured device function, adherence, and technical support. IAQ was monitored continuously for approximately 4 weeks.

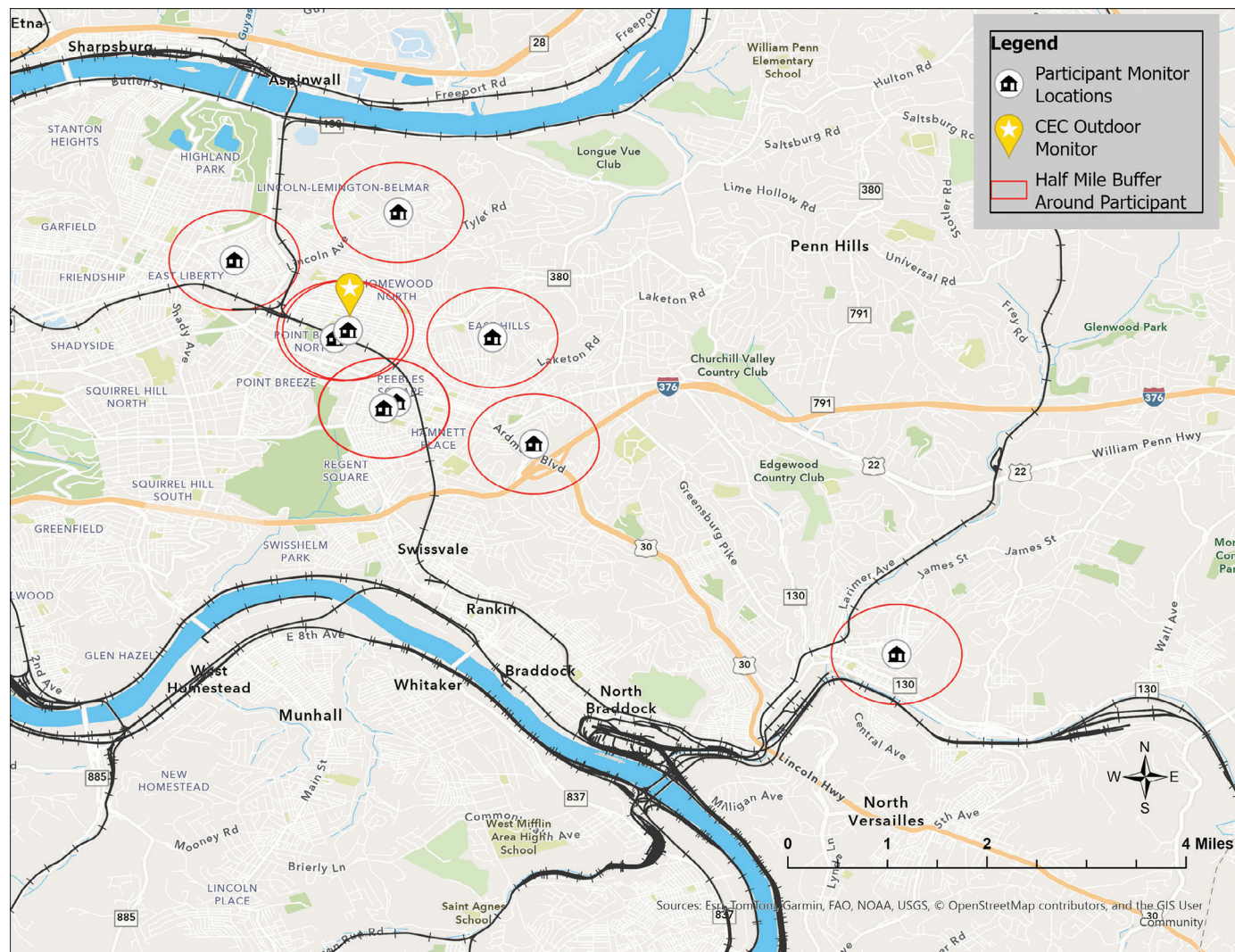
At study completion, our study team conducted in-person home visits to retrieve monitoring equipment. Participants then attended a group session where the team administered the post-intervention AQI quiz and shared individualized monitoring summaries.

Air Sampling

IAQ was continuously monitored with AQMesh multisensor pods for 4 weeks (2 weeks baseline, 2 weeks post-intervention). Pods recorded hourly PM_{2.5}, NO₂, O₃, SO₂, temperature, and humidity. The pods were placed at breathing height in commonly occupied rooms, typically living areas.

FIGURE 1

Map of Neighborhood in Homewood, Pennsylvania, With Participant Residences and University of Pittsburgh Community Engagement Center (CEC) Outdoor Monitor Locations



Note. Map created using ArcGIS Pro. The house icons indicate participant monitoring locations. The yellow marker shows the CEC outdoor monitor. Red circles represent a 0.5-mi buffer around each participant's residence to assess proximity to the outdoor monitor and other environmental sources.

For reference, a pod was installed outdoors on the University of Pittsburgh CEC roof, approximately 1.3 mi from the average residence in our study. Outdoor monitoring coincided with indoor sampling, although power failures prevented calculation of indoor to outdoor ratios (I/O ratios) for three homes.

Following baseline sampling, 6 homes with central HVAC systems received -13 filters (FilterBuy, Inc.); 2 homes without HVAC received portable HEPA purifiers (GermGuardian AC4825, Guardian Technologies); and 1 home

received no intervention due to HVAC access limitations. All MERV-13 filters were of the same rating and brand, and the filters were matched to individual HVAC sizes. These filters capture $\geq 90\%$ of particles $\geq 0.3 \mu\text{m}$, with evidence of respiratory benefits (Batterman et al., 2012; Sarnat et al., 2014). The HEPA purifiers are specified to remove up to 99.97% of particles $\geq 0.3 \mu\text{m}$ and are designed for fine particle and volatile organic compound (VOC) reduction in small-to-medium rooms (manufacturer specifications from Guardian Technologies).

Prior to air monitor deployment, a 2-week colocation calibration was conducted for all AQMesh pods at the University of Pittsburgh CEC to evaluate inter-device consistency. Correlation coefficients for $\text{PM}_{2.5}$ across all AQMesh monitors ranged from 0.90 to 0.99, indicating strong agreement and confirming monitor field suitability (Mead et al., 2013; U.S. EPA, n.d.). Reported detection limits were $1 \mu\text{g}/\text{m}^3$ for $\text{PM}_{2.5}$, 10 ppb for NO_2 and SO_2 , and 5 ppb for O_3 .

TABLE 1

Participant Demographics and Household Characteristics

Characteristic	# (%)
Sex (n = 9)	
Female	8 (89)
Male	1 (11)
Asthma-related characteristics	
Confirmed asthma diagnosis (n = 9)	9 (100)
Age at asthma diagnosis (years) (n = 7)	Mean = 12 (Range: <1–40)
Regular inhaled steroid use (controller) (n = 8)	3 (38)
Rescue medication use (inhaled or nebulized β -agonist) (n = 8)	
Current use	3 (38)
Past use only	3 (38)
No use	1 (18)
Recent symptoms (last 30 days) (n = 9)	
Frequent cough	6 (67)
Wheezing	5 (56)
Runny nose/watery eyes	7 (78)
Nasal congestion	6 (67)
Multiple colds (>2)	1 (11)
Shortness of breath	6 (67)
Indoor air quality complaints (n = 9)	
Temperature	3 (33)
Odor	2 (22)
Humidity	2 (22)
Dust	5 (56)
Environmental exposures (n = 9)	
Use of strong cleaners	8 (89)
Use of air fresheners	8 (89)
Use of candles	9 (100)
Residents who smoke	2 (22)
Secondhand smoke exposure	3 (33)
Time allocation of symptoms (n = 9)	
Symptom relief within 1 hr after leaving home	5 (56)
Symptom relief during vacation	2 (22)
Work outside the home (n = 9)	
Yes	5 (56)
No	4 (44)

*continued on page 18***Data Analysis**

Data were analyzed in JMP Pro (version 17.0, SAS Institute Inc.). Normality of pollutant concentrations and AQI quiz scores were tested with the Shapiro–Wilk test and found

nonnormal ($p < .05$). The primary analysis used paired pre/post comparisons within each intervention home ($n = 8$). Wilcoxon signed-rank tests were applied, with p -values adjusted using the Holm–Bonferroni method. Effect

sizes were estimated with Cliff's delta, and 95% confidence intervals (CIs) calculated via bootstrapping to account for small, nonparametric samples. One home, without an intervention due to HVAC access issues, was excluded.

As a complementary analysis, pooled pre/post comparisons across all intervention homes assessed overall changes, reported as median differences with 95% CIs. For $PM_{2.5}$, pooled effects were quantified with the Wilcoxon signed-rank test and Hodges–Lehmann estimator of the median shift.

Next, I/O ratios were calculated by dividing each participant's daily indoor mean by the corresponding outdoor mean from the CEC monitor, which served as the reference. Ratios of 1 indicate equal concentrations, >1 indicate higher indoor levels, and <1 indicate lower indoor levels (Fabian et al., 2012).

Spirometry analyses retained weekly best and worst efforts to summarize variability. Pre/post changes in FEV_1 , FVC, and FEV_1/FVC were described. Device adherence was characterized by percent acceptable spirometry tests, attempt frequency, and median quality grade.

A spatial map in ArcGIS Pro (v3.3, ESRI) displayed participant distribution and monitoring locations, with 0.5-mi buffers around residences. To protect confidentiality, residential points were randomly offset within a small radius, per institutional review board guidance.

Results

In total, 9 participants (8 female, 1 male, ages 22–75 years, $M = 46.4 \pm 15.5$ years) with physician-confirmed asthma enrolled. Most participants lived in Homewood or nearby East End neighborhoods (East Liberty, Wilkinsburg, Larimer); one participant from Turtle Creek was included due to recruitment challenges and registry eligibility (Figure 1). Housing types included single-family homes, apartments, and senior housing, with most structures built before 1970 (Table 1).

Of the participants, 6 participants received MERV-13 HVAC filters, 2 received portable HEPA purifiers, and 1 participant did not receive an intervention due to HVAC access and filter sizing limitations.

Nearly all participants reported using strong cleaners (89%), air fresheners (89%), and all used candles (100%), while more than one half of participants reported gas stove use (56%). Asthma symptoms were

common: two thirds of participants reported cough, nasal congestion, or shortness of breath in the past 30 days, and more than one half of participants noted symptom relief after leaving their home. Most participants also expressed concern about outdoor air quality and interest in learning more about environmental triggers (Table 1).

Environmental Health

Literacy Outcomes

Average AQI quiz scores increased from $74 \pm 10\%$ to $89 \pm 9.1\%$ ($p < .01$) between pre- and post-training. The largest gains were observed in understanding criteria pollutants (+58.0%) and air inversions (+23.8%) (Table 2). Smaller improvements were observed in ozone adverse health effects (+19.3%) and awareness of ozone adverse effects (+11.1%), while knowledge of $PM_{2.5}$ -sensitive groups rose slightly (+0.25%). Respondents reached 100% accuracy post-test on several quiz items.

Indoor Pollutant Concentrations

Pre-intervention indoor $PM_{2.5}$ levels in the 8 intervention homes ranged from 2.4 to $14.0 \mu\text{g}/\text{m}^3$ ($M = 7.7 \pm 4.0$; $Mdn = 6.6$). Moreover, 2-week averages from 4 homes (50%) exceeded the 2024 U.S. Environmental Protection Agency (U.S. EPA) outdoor annual standard of $9.0 \mu\text{g}/\text{m}^3$, although all remained below the 24-hr standard of $35 \mu\text{g}/\text{m}^3$. These comparisons reference ambient standards for context because U.S. EPA has not established IAQ standards.

Our analyses excluded 1 home without an intervention. Pooled across the 8 intervention homes, the median change in $PM_{2.5}$ (pre/post) was $+1.1 \mu\text{g}/\text{m}^3$ (95% CI [0.1, 6.5]), corresponding to a 21% decline in mean concentrations (from 8.8 to $6.9 \mu\text{g}/\text{m}^3$). This reduction was not statistically significant, though (Wilcoxon signed-rank, $p = .20$) (Table 3). Individually, 6 out of 8 homes showed numerical reductions, 3 of which were significant; 1 home had a significant increase and 4 showed smaller nonsignificant changes. The largest decrease was -60.4% ($-7.3 \mu\text{g}/\text{m}^3$), whereas the only increase was $+163\%$ ($+10.7 \mu\text{g}/\text{m}^3$) (Table 4).

I/O ratios for $PM_{2.5}$ ranged from 0.64 to 0.82. Ratios for SO_2 and O_3 were consistently <1.0 , while 4 homes had NO_2 I/O ratios >1.0 (Table 5). Indoor NO_2 ranged from 1.7 to 22.3 ppb, SO_2 from 2.9 to 78.4 ppb, and O_3 from 7.5 to 20.2 ppb. No statistically signifi-

TABLE 1 continued

Participant Demographics and Household Characteristics

Characteristic	# (%)
Time spent indoors (overall) ($n = 9$)	
0–25%	1 (11)
26–50%	3 (33)
51–75%	4 (44)
76–100%	1 (11)
Time spent outdoors ($n = 9$)	
0–25%	8 (89)
26–50%	0
51–75%	1 (11)
76–100%	0
Time spent at work ($n = 9$)	
0–25%	2 (22)
26–50%	2 (22)
51–75%	3 (33)
76–100%	0
Vacuuming frequency ($n = 9$)	
Daily	2 (22)
1 time per week	4 (44)
2–3 times per week	1 (11)
2 times per month	1 (11)
Never	1 (11)
Dusting frequency ($n = 9$)	
Daily	1 (11)
1 time per week	1 (11)
2–3 times per week	1 (11)
2 times per month	6 (67)
Never	0
Home dustiness perception ($n = 9$)	
Extremely	1 (11)
Sometimes dusty	3 (33)
Not dusty	1 (11)
More when windows are closed	3 (33)
More when windows are open	1 (11)

continued ►

cant pre/post changes were detected for gaseous pollutants within the homes (Table 6).

Outdoor $PM_{2.5}$ Reference Monitoring

I/O ratios for O_3 and SO_2 were consistently <1 , while several homes had NO_2 ratios >1 (Table 5). Outdoor $PM_{2.5}$ at the CEC air quality monitor ($5.89 \pm 7.13 \mu\text{g}/\text{m}^3$) was compared with the

Lawrenceville U.S. EPA site ($12.62 \pm 4.38 \mu\text{g}/\text{m}^3$), which is 2 mi away, during March 24–October 30, 2024. Overlapping dates showed a correlation of $r = .65$ between monitors.

Spirometry Outcomes

Across participants, mean FEV_1 increased by 83 ml (+4.5%) and mean FVC by 347 ml

TABLE 1 continued

Participant Demographics and Household Characteristics

Characteristic	# (%)
Home environment (<i>n</i> = 9)	
Recent renovation/demolition activities	2 (22)
Housing type (<i>n</i> = 9)	
Apartment	2 (22)
House	6 (67)
Senior housing	1 (11)
Year residence was built (<i>n</i> = 9)	
Pre-1970	6 (67)
1970–2000	1 (11)
Post-2000	2 (22)
Unknown	1 (11)
Pest and water management (<i>n</i> = 9)	
Water leaks/signs of moisture	1 (11)
Pest/rodent presence	2 (22)
Ventilation and heating (<i>n</i> = 9)	
Gas stove usage	5 (56)
Gas dryer usage	2 (22)
Gas water heater usage	5 (56)
Regular ventilation usage in kitchen	4 (44)
Fireplace usage	2 (22)
Structural characteristics (<i>n</i> = 9)	
Attached garage	1 (11)
Basement presence	5 (56)
Carpeting coverage (>50% of rooms)	5 (56)
Furry pet(s) presence (<i>n</i> = 9)	
Yes	2 (22)
No	7 (78)
Cooling System (<i>n</i> = 9)	
Central air conditioning usage	6 (67)
Window air conditioning usage	3 (33)
Fan usage	3 (33)
Open window(s)	3 (33)

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(+13.4%), while the FEV₁/FVC ratio remained stable. The median percentage of acceptable spirometry tests was 58.1%, with an average of 1.16 attempts per day. In total, 2 participants produced fewer than 10 acceptable efforts; 1 participant submitted no acceptable efforts; and 1 participant developed pneumonia, affecting results. The group median quality grade was “D,” reflecting low reliability

(Table 7). Participant-level plots show variability; Figure 2 displays FEV₁ trajectories and Figure 3 shows FVC trajectories.

Discussion

This pilot study evaluated affordable IAQ interventions (i.e., MERV-13 HVAC filters and HEPA air purifiers) paired with EHL education in an underserved Pittsburgh

neighborhood. Findings highlight both the potential and the challenges of applying exposure-reduction strategies in real-world, resource-limited settings.

PM_{2.5} Findings

As expected, PM_{2.5} was the pollutant most responsive to the study intervention. Pooled analysis across 8 intervention homes showed a nonsignificant 21% decline. Expressed as a median change, indoor PM_{2.5} decreased by 1.1 µg/m³ (95% CI [0.1, 6.5]); Wilcoxon signed-rank *p* = .20), suggesting a modest but directionally beneficial reduction. At the individual level, most homes exhibited decreases, 3 of which remained significant after multiple-testing adjustment, while 1 home showed a significant increase.

These mixed outcomes suggest that low-cost filtration and purifier interventions can meaningfully reduce exposures in some households but could have limited or adverse effects in others. Variability underscores the influence of housing characteristics, intervention fidelity, and occupant behavior. The observation that homes with higher baseline PM_{2.5} often showed the largest decreases aligns with prior studies and suggests that targeting households with the highest PM_{2.5} burdens could maximize impact. Conversely, the increase of PM_{2.5} levels in one home highlights that interventions are not universally protective and that changes in airflow or resident activities can offset intervention benefits.

Taken together, these findings indicate that while accessible interventions hold promise, their effectiveness is context dependent. The wide confidence interval around the pooled estimate (95% CI [0.1, 6.5] µg/m³) reflects the uncertainty of the findings from this small pilot study, but its directionality supports potential benefit. Larger studies with longer follow-up are needed to confirm if these modest reductions can be sustained and scaled in resource-limited communities.

Baseline Concentration Effects

Homes with higher pre-intervention PM_{2.5} appeared to benefit most. The largest decreases occurred in homes starting above 12 µg/m³, with reductions of approximately 20–60%. This finding suggests that interventions are most effective where baseline exposures are elevated, which is consistent with prior

research findings on the differential benefits of filtration in high-burden environments.

Mixed Outcomes

Although most homes showed reductions, one home experienced a significant post-intervention increase in $PM_{2.5}$, rising from 6.6 to 17.3 $\mu g/m^3$ ($p < .001$). This increase could reflect resident behavior or resuspension of particulates from airflow changes. Prior studies similarly have shown that filtration effectiveness depends not only on equipment but also on usage patterns and household activities (Barn et al., 2008; Butz et al., 2011; Fisk, 2013; Zhang & Smith, 2003). Taken together, these findings underscore that effectiveness varies with infrastructure, behavior, and indoor sources.

Outdoor Reference and Spatial Variability

Comparison of the CEC air quality monitor with the nearby Lawrenceville U.S. EPA site (March 24–October 30, 2024) showed a moderate correlation ($r = .65$), indicating similar temporal patterns. Mean concentrations at the CEC site were consistently lower, likely reflecting differences in siting, instrumentation, or data completeness.

While most days fell within the “good” AQI category, the correlation and known spatial variability underscore the need for multisite monitoring in environmental justice communities, where exposures can be highly localized (Clark et al., 2017; Mikati et al., 2018). Reliance on a single fixed-site monitor introduces uncertainty, especially for pollutants such as NO_2 that has strong local variation (Apte et al., 2017; Marshall et al., 2008). Future studies should consider paired indoor–outdoor monitors at each participating home to better capture heterogeneity.

Behavioral Influences

Our survey data revealed frequent occupant behaviors linked to indoor particulate generation, including gas stove usage (56%), candle/incense burning (44%), and cleaning agent usage (67%). These activities could have contributed to smaller or absent post-intervention reductions. Of note, the home with the sharpest $PM_{2.5}$ increase had an air filter installed; the increase, then, suggests that occupant behavior and ventilation changes can offset the benefits of having an air filter.

TABLE 1 continued

Participant Demographics and Household Characteristics

Characteristic	# (%)
Frequency of open windows in warm weather ($n = 9$)	
Sometimes	4 (44)
Always	3 (33)
Never	2 (22)
Concerns about outdoor air worsening asthma ($n = 9$)	
Yes	6 (67)
No	3 (33)
Interest in learning about environmental asthma triggers ($n = 9$)	
Yes	8 (89)
No	1 (11)
Interest in in-home air monitoring discussion ($n = 9$)	
Yes	8 (89)
No	1 (11)
Intervention Type ($n = 9$)	
Air filter	6 (67)
Air purifier	2 (22)
No intervention	1 (11)
Community improvement suggestions for asthma ($n = 9$)	
Air quality	2 (22)
Housing conditions (includes housing, hazards, environmental hazards)	5 (56)
Trees	2 (22)
Pollen	1 (11)
Knowledge and precautions (includes knowledge, air alert, precautions)	4 (44)
Trash	4 (44)
Exhaust from cars and school buses (includes exhaust, cars, school buses)	4 (44)

This finding underscores the need to pair technical interventions with education that targets behaviors that negatively affect IAQ.

Spirometry Outcomes

Spirometry results highlighted both feasibility and limitations. Across participants, mean FEV_1 increased by 83 ml (+4.5%) and mean FVC by 347 ml (+13.4%), while the FEV_1/FVC ratio remained stable. Data quality restricted interpretation: 1 participant provided no results; 2 participants submitted fewer than 10 efforts; and 1 participant developed pneumonia, which affected spirometry results. The median quality spirometry test grade of “D” reflected low reliability. Participant-level variability is shown in Table 7 and FEV_1 and FVC trajectories in Figures 2 and 3, respectively.

These findings suggest that although at-home spirometry is feasible, consistent technique and adherence are crucial for meaningful results. Stronger protocols with real-time feedback, adherence tracking, and symptom diaries are needed to improve interpretability and better assess the links between IAQ interventions and asthma outcomes (as measured by spirometry).

Regulatory Benchmarks

The 2024 U.S. EPA annual $PM_{2.5}$ standard of 9.0 $\mu g/m^3$, although intended for outdoor air, served as a benchmark. Pre-intervention $PM_{2.5}$ exceeded this level in 5 of 9 homes, suggesting that indoor exposures in underserved housing might surpass outdoor health-based standards (U.S. EPA, 2026).

TABLE 2

Comparison of Correct Answers to the Pre- and Post-Tests for the Environmental Health Literacy Quiz

Theme and Test Question	Pre-Test (%)	Post-Test (%)	Average Score (%)	Score Improvement (%)
Understanding air quality and AQI				
1. AQI definition	86.7	100	93.3	13.3
9. Groups sensitive to PM _{2.5}	71.1	71.4	71.2	0.3
Health effects of pollutants				
3. Pollutant effect	68.9	71.4	70.1	2.5
4. Ozone adverse health effect	64.4	83.8	74.1	19.4
5. Awareness of ozone adverse effect	88.9	100	94.5	11.1
8. Unhealthy air quality	100	100	100	0
Sources and conditions affecting air quality				
2. Criteria pollutants	13.3	71.4	42.3	58.0
6. Air pollution causes	100	100	100	0
7. Air inversions	60.0	83.9	71.9	23.9
10. Air quality information	100	100	100	0

Note. One participant's response was omitted from the data because they did not complete the post-knowledge assessment. AQI = Air Quality Index.

TABLE 3

Group-Level PM_{2.5} Pre- and Post-Intervention Concentrations Across Intervention Homes (n = 8)

Analysis	Pre-Intervention <i>M</i> ± <i>SD</i> (µg/m ³)	Post-Intervention <i>M</i> ± <i>SD</i> (µg/m ³)	% Change	Absolute Change (µg/m ³)	Median Change (95% CI)	<i>p</i> -Value	Significance
All intervention homes	7.7 ± 4.0	6.1 ± 4.8	−21	−1.6	1.1 [0.1, 6.5]	.20	Not significant

Note. CI = confidence interval.

I/O ratios for PM_{2.5} ranged from 0.64 to 0.82, indicating generally lower indoor concentrations than outdoors. This finding aligns with prior study results that showed limited outdoor infiltration and stronger influence of indoor sources where ventilation or filtration is inadequate (Fabian et al., 2012; Logue et al., 2011).

Nitrogen Dioxide

NO₂ results were variable. All indoor concentrations remained below the U.S. EPA 1-hr outdoor standard of 100 ppb, but post-intervention changes were inconsistent. Moreover, 4 of the 6 homes had I/O ratios >1.0, suggesting possible indoor sources

such as gas stoves (Belanger et al., 2006; U.S. EPA, 2025b). Our study results could also reflect spatial heterogeneity in outdoor levels, as homes near busways or roadways could have higher exposures than what was captured by the single CEC air quality monitor. Overall, our study findings highlight the difficulty of mitigating gaseous pollutants with filtration and the need for more spatially resolved monitoring.

Sulfur Dioxide

SO₂ was detected in all homes at relatively low concentrations. Although 1 home showed short-term pre-intervention peaks above the U.S. EPA 1-hr standard of 75

ppb, these detected levels were episodic. No homes exceeded the standard when averaged across monitoring periods. The SO₂ I/O ratios were <1.0, suggesting outdoor contributions from traffic and industry. Seasonal differences could also explain variability, as SO₂ can rise in colder months with increased heating demands (Chen & Zhao et al., 2011).

Ozone

Indoor O₃ levels were consistently low and unchanged post-intervention. I/O ratios <1.0 reflect the short indoor half-life of O₃ due to surface reactivity (Weschler, 2000). All O₃ levels were well below the U.S. EPA 8-hr standard of 70 ppb.

TABLE 4

PM_{2.5} Pre- and Post-Intervention Concentrations and Statistical Significance by Participant

Participant	Intervention	Pre-Intervention <i>M ± SD</i>	Post-Intervention <i>M ± SD</i>	% Change	Absolute Change	<i>p</i> -Value	Significance
1	Air filter	12.1 ± 18.8	9.5 ± 17.3	−21	−2.6	.54	Not significant
2	Air filter	8.0 ± 17.3	6.7 ± 6.6	−15	−1.2	.36	Not significant
3	Air purifier	2.4 ± 4.1	1.8 ± 0.5	−23	−0.6	.047	*
4	Air filter	6.0 ± 17.5	5.0 ± 10.9	−17	−1.0	.47	Not significant
6	Air filter	6.6 ± 15.3	17.2 ± 26.8	163	10.7	<.001	***
7	Air purifier	14.0 ± 22.5	6.8 ± 9.1	−52	−7.3	<.001	***
8	Air filter	3.6 ± 1.4	3.5 ± 3.9	−4	−0.1	.59	Not significant
9	Air filter	12.0 ± 24.9	4.8 ± 9.3	−60	−7.3	<.001	***

p* < .05. *p* < .01. ****p* < .001.

Note. Values are reported as *M ± SD* (rounded to 1 decimal). Due to the non-normal distribution of PM_{2.5} data, Wilcoxon signed-rank tests were used for pre- and post-comparisons. Participant 5 was omitted because no intervention was provided.

Environmental Health Literacy

The EHL intervention produced promising gains. Quiz scores improved significantly, with the largest increases observed on items with low baseline knowledge, whereas items already answered correctly showed little change, which is consistent with ceiling effects. Participants also reported greater confidence in interpreting AQI values and linking exposures to asthma symptoms.

Notably, several participants described experiencing symptom relief after leaving their homes, suggesting an opportunity for future EHL efforts to emphasize strategies that empower occupants to recognize and mitigate IAQ issues, thereby potentially reducing symptom severity in the home environment. These improvements mirror prior research findings that have showed EHL can promote protective behaviors and intervention use (Ramirez-Andreotta et al., 2016). Future studies should employ validated instruments and tailor EHL modules to context-specific exposures (e.g., gas stoves, candles, cleaning products) to maximize the intervention's effect.

Limitations

The small sample size (*n* = 9) of our pilot study limits statistical power and generalizability, underrepresenting variability in housing, behavior, and environmental conditions. Monitoring spanned only 4 weeks across

TABLE 5

Ratio of Indoor to Outdoor (I/O) Air Pollutants by Participant

Participant	PM _{2.5} I/O Ratio	NO ₂ I/O Ratio	SO ₂ I/O Ratio	O ₃ I/O Ratio
1	0.82	1.02	0.58	0.71
2	0.77	1.13	0.62	0.75
3	0.64	0.91	0.67	0.79
4	0.70	0.95	0.55	0.82
5	0.68	1.06	0.61	0.73
9	0.79	1.01	0.69	0.76

Note. Participants 6, 7, and 8 were excluded due to the absence of matched outdoor data. NO₂ = nitrogen dioxide; SO₂ = sulfur dioxide; O₃ = ozone.

spring–fall 2024, restricting assessment of seasonal or long-term trends.

Intervention fidelity varied due to HVAC access, air purifier placement, and inconsistent use. Verification was limited, and self-reports can be biased. Future work should incorporate objective tools (e.g., smart plugs, data loggers, photo documentation) to improve adherence tracking.

We excluded 27% of AQMesh air monitor data because of missing or negative values. Most homes in our study retained >80% completeness, but 2 homes had extended gaps from unplugging the AQMesh or loose connections, and the outdoor monitor failed dur-

ing one period. While no devices routinely malfunctioned, participant-related interruptions highlight the need for proactive monitoring (e.g., daily checks, backup power). Even with calibration, such loss in air quality monitoring might skew exposure estimates, as noted in other continuous monitoring studies (Mead et al., 2013; U.S. EPA, n.d.).

We conducted multiple within-home comparisons, and although we applied *p*-value adjustments, the small sample size limits confidence in observed findings. The pooled PM_{2.5} estimate showed a modest median reduction but with a wide 95% CI, underscoring uncertainty in effect size. Still, reduc-

TABLE 6

Indoor and Outdoor Gaseous Pollutant Concentrations (Pre- and Post-Intervention) by Participant

Participant	Intervention	NO ₂ Pre-Intervention <i>M</i> ± <i>SD</i> (ppb)	NO ₂ Post-Intervention <i>M</i> ± <i>SD</i> (ppb)	SO ₂ Pre-Intervention <i>M</i> ± <i>SD</i> (ppb)	SO ₂ Post-Intervention <i>M</i> ± <i>SD</i> (ppb)	O ₃ Pre-Intervention <i>M</i> ± <i>SD</i> (ppb)	O ₃ Post-Intervention <i>M</i> ± <i>SD</i> (ppb)
1	Air filter	4.3 ± 1.2	2.6 ± 1.9	13.5 ± 11.5	15.8 ± 8.5	14.0 ± 2.3	19.1 ± 7.0
2	Air filter	22.3 ± 26.9	17.4 ± 3.7	78.4 ± 107.4	53.7 ± 15.2	19.1 ± 3.6	20.1 ± 2.1
3	Air purifier	10.0 ± 0.6	11.2 ± 1.4	3.7 ± 1.7	5.1 ± 1.4	11.6 ± 1.0	10.7 ± 0.6
4	Air filter	12.8 ± 2.4	14.4 ± 4.5	15.3 ± 27.6	14.8 ± 31.3	11.1 ± 2.9	10.7 ± 3.9
6	Air filter	9.8 ± 2.5	10.6 ± 2.7	13.7 ± 6.6	24.5 ± 13.3	9.2 ± 2.4	7.5 ± 1.5
7	Air purifier	14.8 ± 8.4	13.8 ± 7.0	5.4 ± 1.7	4.4 ± 2.1	14.1 ± 4.8	12.3 ± 3.3
8	Air filter	1.7 ± 1.7	2.1 ± 2.1	31.1 ± 62.4	18.9 ± 20.5	20.4 ± 1.9	20.2 ± 2.3
9	Air filter	7.4 ± 1.7	8.8 ± 1.0	2.9 ± 6.5	3.9 ± 7.1	8.0 ± 2.6	10.0 ± 1.7
CEC outdoor, spring (March–April 2024)	Reference	15.0 ± 10.5	15.2 ± 11.0	9.4 ± 11.7	14.9 ± 15.2	29.1 ± 11.2	35.2 ± 14.5
CEC outdoor, fall (September–October 2024)	Reference	15.7 ± 5.6	13.0 ± 8.7	0.5 ± 2.1	3.0 ± 6.8	22.4 ± 13.2	24.2 ± 16.2

Note. No statistically significant pre- and post-change differences were observed for nitrogen dioxide (NO₂), sulfur dioxide (SO₂), or ozone (O₃) using Wilcoxon signed-rank tests. Participant 5 was omitted because no intervention was performed. University of Pittsburgh Community Engagement Center (CEC) outdoor values are shown separately for the spring and fall monitoring windows to account for seasonal variability.

TABLE 7

Spirometry Usage Metrics

Participant	Spirometry Quality Grade	Acceptable Spirometry Tests (#)	Total Test Attempts (#)	Acceptable Spirometry Tests (%)	Test Attempts per Day (<i>M</i>)	Test Attempts per Unique Day (<i>M</i>)
1	B	7	33	21.2	1.2	1.7
2	D	55	125	44.0	4.2	4.2
3	D	115	136	84.8	4.7	4.7
4	D	9	25	36.0	1.0	2.3
5	A	26	33	78.8	1.1	1.5
6	D	13	18	72.2	0.6	2.6
8	A	25	32	78.1	1.1	1.4
9	D	14	58	24.1	1.5	4.8
Group median	D	19.5	33	58.1	1.2	2.4

Note. Participant 7 did not submit spirometry data, resulting in no usable results.

tions in 6 of 8 homes (75%) suggest potential benefit, although larger trials with adequate power are warranted.

Spirometry results were also limited by adherence: 1 participant submitted no data; 2 participants submitted fewer than 10 valid

efforts; and 1 participant developed pneumonia, which skewed spirometry results. The median quality spirometry grade of “D” indicated low reliability, limiting the ability to link lung function changes to pollutant reductions. Future protocols should extend

monitoring, add real-time feedback, and pair spirometry with symptom diaries to improve interpretability.

Interpretation of EHL outcomes requires caution. Percent change scores are influenced by baseline knowledge, with greater relative

gains when initial knowledge was low and minimal change when items were already correct (i.e., ceiling effects). Moreover, the AQI quiz and training module were developed for this project and used for the first time. Although they were informed by U.S. EPA resources, they are not validated instruments, which limits comparability and underscores the need for validated or refined community-specific tools in future work.

Conclusion

Our pilot study demonstrates the feasibility of combining low-cost IAQ interventions with EHL training in an underserved, asthma-affected community. A nonsignificant pooled reduction in $PM_{2.5}$ was observed, with 6 of 8 (75%) homes showing a decline in $PM_{2.5}$ levels and 1 home showing an increase. The increased $PM_{2.5}$ level, despite the house having an air filter, reflects the influence of housing conditions, occupant behaviors, and intervention fidelity. Overall, the pooled median reduction of $1.1 \mu g/m^3$ (95% CI [0.1, 6.5]) suggests a directionally beneficial effect, although the wide confidence interval highlights uncertainty. Gaseous pollutants (NO_2 , SO_2 , O_3) showed inconsistent trends, underscoring limitations of filtration-based strategies for these pollutants.

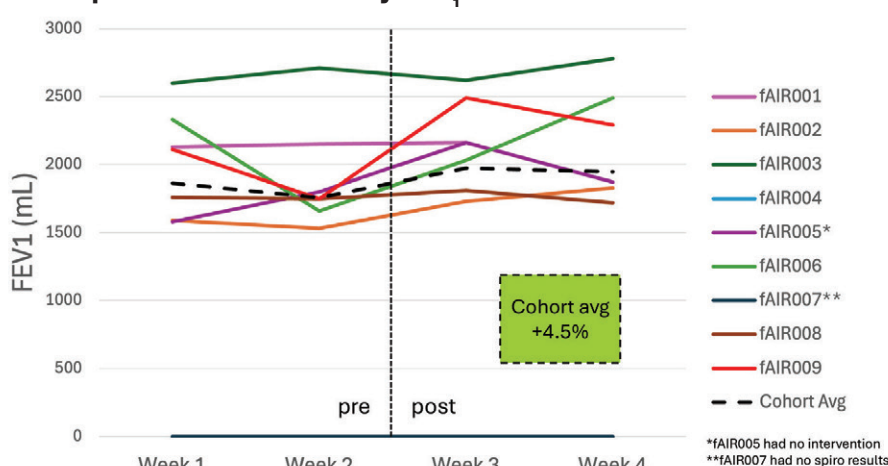
EHL training improved knowledge of air quality indicators and mitigation strategies, illustrating the value of pairing technical interventions with education. Spirometry implementation proved feasible, but limited adherence and poor data quality prevented robust conclusions about respiratory outcomes. Still, at-home lung function monitoring provided participants with a tangible link between air quality and asthma management.

Overall, multimodal approaches—integrating filtration, education, and self-monitoring—hold promise for reducing exposures and strengthening self-efficacy in disproportionately burdened communities. Effectiveness remains context dependent, however. Larger, longer-term studies with stronger adherence verification, validated educational tools, and improved spirometry protocols are needed to confirm these pilot study results and guide scalable interventions. ✨

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FIGURE 2

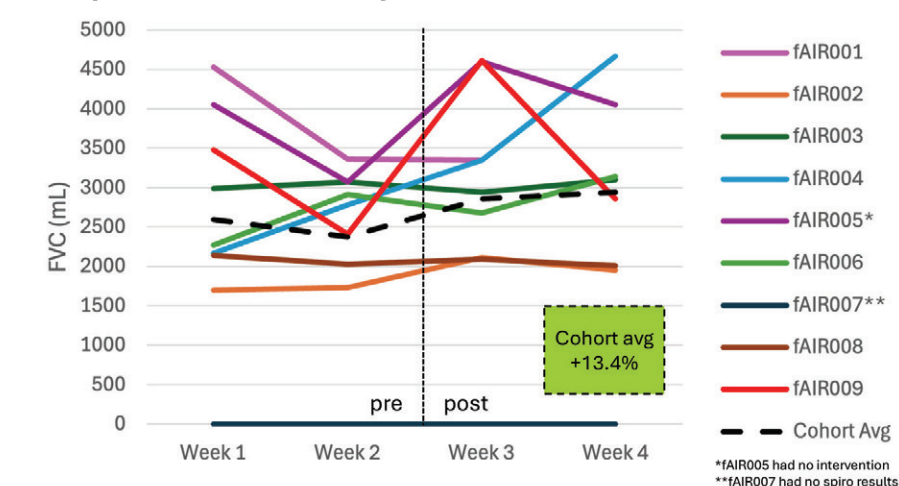
Participant-Level Best Weekly FEV₁ Values



Note. Participant-level weekly best efforts for forced expiratory volume in 1 s (FEV₁) recorded during the pre- and post-intervention monitoring periods. Each trajectory represents an individual participant. One participant provided no valid spirometry measurements and was excluded from the figure.

FIGURE 3

Participant-Level Best Weekly FVC Values



Note. Participant-level weekly best efforts for forced vital capacity (FVC) recorded during the pre- and post-intervention monitoring periods. Each trajectory represents an individual participant. One participant provided no valid spirometry measurements and was excluded from the figure.

advancing community-based initiatives in environmental lung health. We also thank the Asthma Institute Research Registry for facilitating participant recruitment and outreach. Most importantly, we extend our sincere appreciation to the participants and their families for volunteering their time and sharing their lived experiences, which made this study possible.

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References

- Abbah, A.P., Xu, S., & Johannessen, A. (2024). Long-term health effects of outdoor air pollution on asthma and respiratory symptoms among adults in low-and middle-income countries (LMICs): A systematic review and meta-analysis. *Frontiers in Environmental Health*, 3, Article 1352786. <https://doi.org/10.3389/fenvh.2024.1352786>
- Allegheny County Health Department. (2022). *Air quality annual report 2021*. <https://www.alleghenycounty.us/files/assets/county/v/1/government/health/documents/air-quality/reports/aq-annual-report/2021-air-quality-annual-report.pdf>
- Apte, J.S., Messier, K.P., Gani, S., Brauer, M., Kirchstetter, T.W., Lunden, M.M., Marshall, J.D., Portier, C.J., Vermeulen, R.C.H., & Hamburg, S.P. (2017). High-resolution air pollution mapping with Google Street View cars: Exploiting big data. *Environmental Science & Technology*, 51(12), 6999–7008. <https://doi.org/10.1021/acs.est.7b00891>
- Barn, P., Larson, T., Noullett, M., Kennedy, S., Copes, R., & Brauer, M. (2008). Infiltration of forest fire and residential wood smoke: An evaluation of air cleaner effectiveness. *Journal of Exposure Science & Environmental Epidemiology*, 18, 503–511. <https://doi.org/10.1038/sj.jes.7500640>
- Batterman, S., Du, L., Mentz, G., Mukherjee, B., Parker, E., Godwin, C., Chin, J.-Y., O'Toole, A., Rowe, Z., & Lewis, T. (2012). Particulate matter concentrations in residences: An intervention study evaluating stand-alone filters and air conditioners. *Indoor Air*, 22(3), 235–252. <https://doi.org/10.1111/j.1600-0668.2011.00761.x>
- Belanger, K., Gent, J.F., Triche, E.W., Bracken, M.B., & Leaderer, B.P. (2006). Association of indoor nitrogen dioxide exposure with respiratory symptoms in children with asthma. *American Journal of Respiratory and Critical Care Medicine*, 173(3), 297–303. <https://doi.org/10.1164/rccm.200408-1123oc>
- Bell, M.L., & Ebisu, K. (2012). Environmental inequality in exposures to airborne particulate matter components in the United States. *Environmental Health Perspectives*, 120(12), 1699–1704.
- Blakemore, E. (2025, April 13). Early-life ozone pollution linked to higher asthma risk in young kids. *The Washington Post*. <https://www.washingtonpost.com/health/2025/04/13/early-childhood-asthma-wheezing-ozone>
- Breyse, P.N., Diette, G.B., Matsui, E.C., Butz, A.M., Hansel, N.N., & McCormack, M.C. (2010). Indoor air pollution and asthma in children. *Proceedings of the American Thoracic Society*, 7(2), 102–106. <https://doi.org/10.1513/pats.200908-083RM>
- Butz, A.M., Matsui, E.C., Breyse, P., Curtin-Brosnan, J., Eggleston, P., Diette, G., Williams, D., Yuan, J., Bernert, J.T., & Rand, C. (2011). A randomized trial of air cleaners and a health coach to improve indoor air quality for inner-city children with asthma and secondhand smoke exposure. *Archives of Pediatrics & Adolescent Medicine*, 165(8), 741–748. <https://doi.org/10.1001/archpediatrics.2011.111>
- Chen, C., & Zhao, B. (2011). Review of relationship between indoor and outdoor particles: I/O ratio, infiltration factor and penetration factor. *Atmospheric Environment*, 45(2), 275–288. <https://doi.org/10.1016/j.atmosenv.2010.09.048>
- Clark, L.P., Millet, D.B., & Marshall, J.D. (2014). National patterns in environmental injustice and inequality: Outdoor NO₂ air pollution in the United States. *PLOS One*, 9(4), e94431. <https://doi.org/10.1371/journal.pone.0094431>
- Clark, L.P., Millet, D.B., & Marshall, J.D. (2017). Changes in transportation-related air pollution exposures by race-ethnicity and socioeconomic status: Outdoor nitrogen dioxide in the United States in 2000 and 2010. *Environmental Health Perspectives*, 125(9), Article 097012.
- Fabian, P., Adamkiewicz, G., & Levy, J.I. (2012). Simulating indoor concentrations of NO₂ and PM_{2.5} in multi-family housing for use in health-based intervention modeling. *Indoor Air*, 22(1), 12–23. <https://doi.org/10.1111/j.1600-0668.2011.00742.x>
- Fisk, W.J. (2013). Health benefits of particle filtration. *Indoor Air*, 23(5), 357–368. <https://doi.org/10.1111/ina.12036>
- Lanphear, B.P., Hornung, R.W., Khoury, J., Yolton, K., Lierl, M., & Kalkbrenner, A. (2011). Effects of HEPA air cleaners on unscheduled asthma visits and asthma symptoms for children exposed to secondhand tobacco smoke. *Pediatrics*, 127(1), 93–101. <https://doi.org/10.1542/peds.2009-2312>
- Logue, J.M., McKone, T.E., Sherman, M.H., & Singer, B.C. (2011). Hazard assessment of chemical air contaminants measured in residences. *Indoor Air*, 21(2), 92–109. <https://doi.org/10.1111/j.1600-0668.2010.00683.x>
- Lord, R. (2019, September 16). Why do people die young here? Project aims to send 'citizen scientists' out to investigate. *Pittsburgh Post-Gazette*. <https://www.post-gazette.com/news/health/2019/09/16/Life-expectancy-Pittsburgh-neighborhoods-citizen-scientists-Live-Longer-project/stories/201909120184>
- Marshall, J.D., Nethery, E., & Brauer, M. (2008). Within-urban variability in ambient air pollution: Comparison of estimation methods. *Atmospheric Environment*, 42(6), 1359–1369. <https://doi.org/10.1016/j.atmosenv.2007.08.012>
- Marusic, K. (2024, December 12). Environmental justice communities in southwestern Pennsylvania face higher rates of pollution violations. *Environmental Health News*. <https://www.ehn.org/southwestern-pennsylvania-environmental-justice-violations-2668612551.html>
- Mead, M.I., Popoola, O.A.M., Stewart, G.B., Landshoff, P., Calleja, M., Hayes, M., Baldovi, J.J., McLeod, M.W., Hodgson, T.F., Dicks, J., Lewis, A., Cohen, J., Baron, R., Saffell, J.R., & Jones, R.L. (2013). The use of electrochemical sensors for monitoring urban air quality in low-cost, high-density networks. *Atmospheric Environment*, 70, 186–203. <https://doi.org/10.1016/j.atmosenv.2012.11.060>

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References *continued from page 25*

- Mikati, I., Benson, A.F., Luben, T.J., Sacks, J.D., & Richmond-Bryant, J. (2018). Disparities in distribution of particulate matter emission sources by race and poverty status. *American Journal of Public Health*, 108(4), 480–485. <https://doi.org/10.2105/AJPH.2017.304297>
- Nishimura, K.K., Galanter, J.M., Roth, L.A., Oh, S.S., Thakur, N., Nguyen, E.A., Thyne, S., Farber, H.J., Serebrisky, D., Kumar, R., Brigino-Buenaventura, E., Davis, A., LeNoir, M.A., Meade, K., Rodriguez-Cintrón, W., Avila, P.C., Borrell, L.N., Bibbins-Domingo, K., Rodriguez-Santana, J.R., . . . Burchard, E.G. (2013). Early-life air pollution and asthma risk in minority children. The GALA II and SAGE II studies. *American Journal of Respiratory and Critical Care Medicine*, 188(3), 309–318. <https://doi.org/10.1164/rccm.201302-0264OC>
- Ramirez-Andreotta, M.D., Brody, J.G., Lothrop, N., Loh, M., Beamer, P.I., & Brown, P. (2016). Improving environmental health literacy and justice through environmental exposure results communication. *International Journal of Environmental Research and Public Health*, 13(7), 690. <https://doi.org/10.3390/ijerph13070690>
- Sarnat, J.A., Golan, R., Greenwald, R., Raysoni, A.U., Kewada, P., Winquist, A., Sarnat, S.E., Flanders, W.D., Mirabelli, M.C., Zora, J.E., Bergin, M.H., & Yip, F. (2014). Exposure to traffic pollution, acute inflammation and autonomic response in a panel of car commuters. *Environmental Research*, 133, 66–76. <https://doi.org/10.1016/j.envres.2014.05.004>
- Schuyler, A.J., & Wenzel, S.E. (2022). Historical redlining impacts contemporary environmental and asthma-related outcomes in Black adults. *American Journal of Respiratory and Critical Care Medicine*, 206(7), 824–837. <https://doi.org/10.1164/rccm.202112-2707OC>
- U.S. Census Bureau. (2024). *American Community Survey 5-year estimates: Homewood, PA*. <https://censusreporter.org/profiles/16000US4235488-homewood-pa/>
- U.S. Environmental Protection Agency. (n.d.). *How to evaluate low-cost sensors by collocation with Federal Reference Method monitors*. https://www.epa.gov/sites/default/files/2018-01/documents/collocation_instruction_guide.pdf
- U.S. Environmental Protection Agency. (2025a). *Indoor air quality*. <https://www.epa.gov/report-environment/indoor-air-quality>
- U.S. Environmental Protection Agency. (2025b). *Nitrogen dioxide's impact on indoor air quality*. <https://www.epa.gov/indoor-air-quality-iaq/nitrogen-dioxides-impact-indoor-air-quality>
- U.S. Environmental Protection Agency. (2026). *Air data—Daily air quality tracker*. <https://www.epa.gov/outdoor-air-quality-data/air-data-daily-air-quality-tracker>
- Varopichetsan, S., Bunplod, N., Dejchanchaiwong, R., Tekasakul, P., & Ingviya, T. (2025). Short-term exposure to fine particulate matter and asthma exacerbation: A large population-based case-cross-over study in Southern Thailand. *Environmental Health*, 24(1), 28. <https://doi.org/10.1186/s12940-025-01182-7>
- Weschler, C.J. (2000). Ozone in indoor environments: Concentration and chemistry. *Indoor Air*, 10(4), 269–288. <https://doi.org/10.1034/j.1600-0668.2000.010004269.x>
- World Health Organization. (2026). *Air pollution*. <https://www.who.int/health-topics/air-pollution>
- Zhang, J., & Smith, K.R. (2003). Indoor air pollution: A global health concern. *British Medical Bulletin*, 68(1), 209–225. <https://doi.org/10.1093/bmb/ldg029>



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