Draft Final Report – Contract 20RD015

HIFIVE - Health **I**mpacts of **F**iltration **I**mpro**V**ements in **E**lementary Schools

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Disclaimer

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Abstract

The goal of this study was to provide data on the benefits of improved air filtration in elementary schools via the use of standalone High-Efficiency Particulate Air (HEPA) cleaners. In this crossover randomized controlled trial, 435 instructional classrooms in 17 Los Angeles Unified School District elementary schools received the HEPA filter intervention over the course of two school years (2022-23 and 2023-24). The schools were already using minimum efficiency reporting value (MERV) 13 filters in their HVAC systems because of COVID-19. Daily particulate matter data in classrooms with and without the intervention were measured and compared in statistical analyses to determine the effect of the intervention on air quality. $PM_{2.5}$ levels in classrooms located in permanent buildings were also compared to levels in classrooms located in bungalows/portable buildings on the school campuses. In addition, two epidemiologic analyses were conducted to examine the effect of the intervention on (1) student attendance days by classroom and (2) parental report of children's asthma events and respiratory symptoms. The results of the air quality monitoring showed that the average annual indoor $PM_{2.5}$ in classrooms with HEPA filters was 0.9 $\mu g/m^3$ and 1.4 $\mu g/m^3$ in school years 2022-23 and 2023-24, respectively. This was significantly lower than annual $PM_{2.5}$ in non-HEPA filter control classrooms by 40% and 50% ($p<0.001$). Average annual $PM_{2.5}$ concentration in non-HEPA filter control classrooms was 1.5 $\mu g/m^3$ and 2.8 $\mu g/m^3$ in school years 2022-23 and 2023-24, respectively. Average $PM_{2.5}$ concentrations in classrooms located in permanent buildings was 1.1 $\mu g/m^3$ and 2.0 $\mu g/m^3$ for the HEPA treatment group and the non-HEPA control group in 2022-24, respectively. This was significantly higher than the average $PM_{2.5}$ in classrooms located in bungalows/portable buildings by 18% and 20% ($p<0.001$). Average $PM_{2.5}$ concentrations in classrooms located in bungalows/portable buildings was 0.9 $\mu g/m^3$ and 1.6 $\mu g/m^3$ for the HEPA treatment group and the non-HEPA control in 2022-24, respectively. For the epidemiologic analyses, the rate ratio and 95% confidence interval for the effect of the HEPA filter treatment on attendance rate was 1.000 (0.997, 1.003) in the model adjusted for 2021-22 baseline attendance and not statistically significant ($p = 0.98$). The average number of symptoms per week ranged from 1 to 10 symptoms and did not differ significantly by treatment group (Cochran's Q: $\chi 2= 0.035$, $p = 0.85$). This study showed that further improvements in classroom air quality can be achieved with additional filtration, but these differences may be too small to have an impact on attendance or health.

Executive Summary

Background

The California Air Resources Board's (CARB) Community Incentives 2019 guidelines include an incentive program that provides funds for school districts to upgrade filtration in their classrooms via the installation of higher particle removal efficiency filters on existing Heating, Ventilation, and Air Conditioning (HVAC) systems or the purchase of standalone High-efficiency particulate air (HEPA) purifiers. These measures aim to reduce the particulate matter (PM) 2.5 exposures inside classrooms in Assembly Bill (AB) 617 communities, where in many cases children are already disproportionately exposed to $PM_{2.5}$ compared to children living in other communities. There is a substantial body of scientific evidence supporting the link between air pollutant exposure and child respiratory outcomes (Garcia et al., 2021; Mukharesh et al., 2023; Munoz-Pizza et al., 2020); however, few intervention studies appear to be available for directly estimating the health benefits of air filtration improvements in schools.

The effectiveness of classroom filtration improvements in reducing air pollutant concentrations has been assessed in some California schools (e.g., Polidori et al., 2012), and a substantial body of observational scientific evidence supports the link between criteria air pollutant exposure and child respiratory dysfunction (Garcia et al., 2021; Mukharesh et al., 2023; Munoz-Pizza et al., 2020; Gilliland et al., 2017; Girguis et al., 2018; Khalili et al., 2018). Randomized controlled trials are widely recognized as the most robust type of evidence for evaluating health interventions.

Objective and Methods

UC Irvine worked with Los Angeles Unified School District (LAUSD) Office of Environmental Health & Safety to identify seventeen elementary schools located in Carson, Torrance, Harbor City, and Lomita within the Carson and Harbor City/Lomita Community of Schools that could benefit from air cleaners in their classrooms. These schools are in South LA County, near the Port of Los Angeles, major highways, industrial sites, and oil refineries. The project provided portable HEPA air cleaners in 435 classrooms where students spent most of their time. These 435 classrooms had been identified by LAUSD in the spring of the 2021-2022 school year as instructional classrooms, as opposed to classrooms for Art, Music, Science Lab, Computer Lab, Intervention (Set-Aside), or Specific Learning Disability. During the study, three of the schools (n=85 classrooms) received other air cleaners to use in their classrooms in addition to the study air cleaners, although one of those schools (n=34 classrooms) did not install the new air cleaners until after the study intervention concluded. Because there was additional air filtration beyond the intervention, those classroom data could not be included in the air quality analyses. A total of 51 classrooms from two schools were excluded, leaving a total of 384 classrooms in the study. Air quality sensors that measure real-time PM concentrations were also installed at each intervention school, both indoors and outdoors, to monitor air quality. The priority of this project was to provide air filtration interventions to elementary schools in a way that maximized the benefits to the school community and provided meaningful data for understanding the benefits associated with the intervention. To accomplish this goal, the study included the following objectives:

1. Monitor $PM_{2.5}$ levels at school locations

2. Analyze classroom-level attendance
3. Analyze individual-level health outcomes

From July 2022 - June 2024, a block randomized crossover trial was conducted to test the benefits of adding portable HEPA filter air cleaners to classrooms with existing HVAC systems. Each classroom also had an existing HVAC system maintained by LAUSD that used minimum efficiency reporting value (MERV) 13 filters since the COVID-19 pandemic. The portable air purifiers used in this study provided air filtration that was in addition to the existing HVAC filtration.

In the first year (2022-23), classrooms were randomized into intervention groups using a crossover randomized controlled trial and then changed group in the following school year (2023-24). In this design, each classroom received the intervention, but during different school years. In August 2023, classrooms switched intervention groups so that classrooms with non-HEPA filter sham controls in 2022-23 had HEPA filters in the academic year 2023-24 and vice versa. This design helps protect against any potential lack of balance in unmeasured confounders across the HEPA treatment and non-HEPA control groups, by allowing investigators to examine and compare the intervention effect across both phases. It also allows comparisons to be made for control versus intervention groups at the same time, and across multiple seasons. Intention to treat (ITT) analysis of the data was conducted to protect against potential noncompliance, protocol deviations, or anything that might have occurred after randomization. ITT analysis avoids overestimation of treatment effects (i.e., any bias from post-randomization factors is most likely towards the null) (Pendlebury et al., 2023).

1. Monitor $PM_{2.5}$ levels at school locations
Among the 435 classrooms with air cleaners, there were funds to have IQair monitors placed in 200 of them, and data from those monitors were downloaded every 6 months. Classrooms were selected for an IQair monitor so that air quality was measured in each school building (permanent and portable), each school floor (if more than one story) and each end of the floor. Classroom PM concentrations were compared for the HEPA treatment and non-HEPA control classrooms over two academic school years. Of the 200 air monitors, 14 were unable to be located for downloading data, leaving 186 classrooms with available air quality data. Outdoor air quality data was collected and compared to indoor classroom data by school.

2. Analyze classroom-level attendance
Absenteeism data was provided by LAUSD for each school year. If all the classrooms with an air cleaner had attendance data available for both years, then 870 classroom-years of data would have been available for analyses (435 classrooms multiplied by 2 years). Attendance was not collected for some classrooms (due to small class size or change from instructional classroom to other type) or one or both schools years (n=140 classroom-year records). In addition, classroom-year records for the 2 schools with additional air filters in the classrooms were also excluded from the analyses (91 classroom-year records). The final analytic dataset included 639 classroom-years of data. Attendance data was compared for the HEPA treatment and non-HEPA control classrooms over the two academic school years.

3. Analyze individual-level health outcomes

Lastly, parents of asthmatic students from the participating schools were recruited to longitudinally assess asthma and respiratory symptoms in 2024. The panel study, Child's Asthma and Respiratory Events and Symptoms (HIFIVE CARES) enrolled 20 participants and collected data from an initial questionnaire and weekly symptom surveys over 12 weeks to assess the association between the number of symptoms and HEPA intervention. The Strategic Data and Evaluation Branch at LAUSD required study modifications to approve UC Irvine conducting human research which delayed the start of recruitment. Furthermore, UC Irvine researchers could not contact parents directly for recruitment in the HIFIVE CARES study. Instead, researchers were only allowed to send a recruitment flyer to LAUSD administration, who then distributed the flyer to parents via Blackboard Connect messaging. Unfortunately, there was a change in LAUSD administration during the study and communication from LAUSD was not forthcoming. Information to parents was only distributed once or twice, and LAUSD did not provide confirmation that all the schools had sent the message to parents. As a result, participation was low despite additional efforts to recruit parents via a mailed study flyer to residents of the schools' neighborhoods. This impacted researchers' ability to determine a statistically significant health effect associated with HEPA filtration.

Results

For the school year September 2022 through May 2023, the average annual $PM_{2.5}$ level in HEPA treatment classrooms was 0.9 µg/m³, which was 40% lower than the average annual $PM_{2.5}$ of 1.5 µg/m³ in non-HEPA controls classrooms ($p < 0.001$). Similar results were observed for PM_{10} and PM_1. For the school year September 2023 through May 2024, the average annual $PM_{2.5}$ level of 1.4 µg/m³ in HEPA classrooms was 50% lower than the average annual $PM_{2.5}$ level of 2.8 µg/m³ in non-HEPA classrooms ($p < 0.001$). Average $PM_{2.5}$ concentrations for 2022-2024 in classrooms located in permanent buildings was 1.1 µg/m³ and 2.0 µg/m³ for the HEPA treatment group and the non-HEPA control group, respectively. This was significantly higher than the average $PM_{2.5}$ in classrooms located in bungalows/portable buildings by 18% and 20% ($p<0.001$). Average $PM_{2.5}$ concentrations for 2022-2024 in classrooms located in bungalows/portable buildings was 0.9 µg/m³ and 1.6 µg/m³ for the HEPA treatment group and the non-HEPA control group, respectively. The average annual outdoor $PM_{2.5}$ levels from September 2022 to May 2024 ranged from 6.9 to 10.8 µg/m³ and no major wildfires occurred in the region during that time. Ratios of indoor $PM_{2.5}$ to outdoor $PM_{2.5}$ varied depending on the school, and confidence intervals for HEPA classrooms and non-HEPA classrooms overlapped. The rate ratio and 95% confidence interval for the effect of the HEPA filter treatment on annual attendance rates was 1.000 (0.997, 1.003) in the model adjusted for 2021-22 baseline attendance and not statistically significant ($p = 0.98$). The average number of symptoms per week ranged from 1 to 10 symptoms and did not differ significantly by treatment group ($p = 0.85$).

Conclusion

Our findings support the use of portable air cleaners with HEPA filters in classrooms to reduce PM. Few studies have examined HEPA filtration in a classroom environment, and this is one of the first studies since the COVID-19 pandemic to assess PM exposure in the classroom. Using a well powered block randomized crossover trial, it was shown that adding portable HEPA air cleaners to classrooms that already had HVAC systems with MERV 13 air filters resulted in lower measurable PM concentrations. This demonstrates that further improvements in classroom air quality, especially in environmentally burdened communities, can be achieved with additional filtration. However, the study did not find evidence that these improvements in air quality were sufficient for measurable attendance and health benefits. Among children with asthma, use of classroom HEPA filters did not significantly reduce symptoms, but these analyses were underpowered. The lack of a significant association also may have been due to the already low levels of $PM_{2.5}$ in classrooms from using the HVAC systems with MERV 13 filters and the generally good outdoor air quality at the schools during these two years.

1.0 Introduction

The California Air Resources Board's (CARB) Community Incentives 2019 guidelines included an incentive program that provided funds for school districts to improve filtration in their classrooms via the use of standalone High-Efficiency Particulate Air (HEPA) cleaners. These measures aim to reduce the particulate matter $(PM)_{2.5}$ exposures inside classrooms in Assembly Bill (AB) 617 communities and other highly impacted and disadvantaged communities, where in many cases children are already disproportionately exposed to $PM_{2.5}$ compared to children living in other communities. The goal of this study was to provide data on the benefits of HEPA air filtration in elementary schools to fulfill the accountability reporting requirements of the incentive program in a vulnerable AB 617 community.

The study included 17 Los Angeles Unified School District elementary schools located in Carson, Torrance, Harbor City, and Lomita. There were a total of 435 classrooms in these schools. Unlike other health studies with air filters in homes, this is one of the first studies to examine the effects of air filtration interventions implemented in schools, where young students spend a substantial amount of the day in one room. The air filtration school intervention project directly determined the degree to which $PM_{2.5}$ exposure is reduced by air filtration and provided data on classroom attendance and parental report of student health to evaluate the impact of the incentive program.

The priority of this project was to provide air filtration interventions to elementary schools in a way that maximized the benefits to the school community and provided data for understanding benefits associated with the intervention. The study design used a rigorous crossover randomized controlled trial to ensure validity. In this design, each classroom received the intervention, but during different school years.

1.1 Objectives

The objectives of the intervention study were as follows:

1. <u>Monitor $PM_{2.5}$ levels at school locations</u>
   $PM_{2.5}$ sensors were placed inside 200 classrooms of the 17 elementary schools participating in this project. One ambient air sensor was also placed outside the schools. $PM_{2.5}$ data in classrooms with and without the HEPA filters were compared in statistical analyses to determine the effect of the intervention on air quality.

2. <u>Analyze classroom-level attendance</u>
   Classroom-level attendance for children in classrooms with the HEPA filters were compared to those without the HEPA filters in an epidemiologic crossover randomized controlled trial throughout two school years (2022-2023 and 2023-2024).

3. <u>Analyze individual-level health outcomes</u>
   Parents of asthmatic students were recruited for a panel study to assess longitudinally, over a 12-week period in school year 2023-2024, the asthma events and respiratory symptoms via questionnaires and weekly surveys. Statistical analyses were conducted to determine associations between classroom intervention group and reported symptoms.

1.2 Background

1.2.1 Asthma in children

Asthma remains the leading cause of chronic illness among the pediatric population, affecting approximately 1 in 10 children in the United States, and is the leading cause of hospitalizations, emergency department visits, and missed school days (James et al., 2019). Allergic asthma is the most common clinical chronic airway allergic disease and leads to insomnia, daily fatigue, and decreased activity levels (Jin-Ying et al., 2021). Asthma can be exacerbated by environmental factors from particulate matter (PM), environmental tobacco smoke (ETS), household dust, and various allergens (Batterman et al., 2013). Children and infants spend eighty percent of their time in indoor environments which are contaminated by particulate matter from both indoor and outdoor sources, especially particles below 2.5 µg in size ($PM_{2.5}$) from traffic (James et al., 2019). $PM_{2.5}$ is a known asthma trigger in children and adults (Garcia et al., 2021; Mukharesh et al., 2023; Munoz-Pizza et al., 2020); however, an increasing number of studies show associations between coarse PM (i.e., $PM_{10\text{-}2.5}$) and pediatric asthma exacerbations as well (Riederer et al., 2021). Exposure to PM increases oxidative stress and leads to asthma (Jia-Ying et al., 2021).

Studies have shown that portable HEPA cleaners reduce asthma triggers in household air (Riederer et al., 2021; Lanphear et al., 2011). Free-standing HEPA filters reduced particulate matter (PM) levels in nearly all homes and reductions averaged 69% to 80% on days when the filter was used at least 75% of the time (Batterman et al., 2013). While HEPA air purifiers can trap air pollutants, it remains unclear if avoiding exposure to environmental allergens would alleviate asthma patients' symptoms (Jia-Ying et al., 2021). Associations between the use of filters and improved respiratory health have not always been reproducible (Batterman et al., 2013).

1.2.2 Rigor of previous research

The effectiveness of classroom filtration improvements in reducing air pollutant concentrations has been assessed in some California schools (e.g., Polidori et al., 2012) and scientific evidence supports the link between criteria air pollutant exposure and child respiratory dysfunction (Garcia et al., 2021; Mukharesh et al., 2023; Munoz-Pizza et al., 2020; Gilliland et al., 2017; Girguis et al., 2018; Khalili et al., 2018), but there are only a few classroom intervention studies of air cleaners. Most of the studies have been in homes and many found statistically significant results for using HEPA filtration on removing inhalation pollutants and improving asthma symptoms in children who have asthma (Appendix A). James et al. (2019) studied forty-three children with asthma in a double-blind, placebo-controlled crossover study to examine if HEPA filtration improves asthma control in children exposed to traffic-related airborne particles. During the first four weeks, one group was given a HEPA air cleaner, and the other group was given a placebo "dummy" in their homes, followed by a one-month wash-out period, before crossing over to the other treatment arm for another four weeks. Air sampling, including PM2.5, black carbon, and ultraviolet-absorbing particulate matter (UVPM) and health outcomes, including asthma control (ACQ) and quality of life (AQLQ) measures, were taken before and after each treatment arm. Following HEPA treatment, participants with poorly controlled asthma and lower quality of life at baseline, ACQ and AQLQ score were significantly improved (1.3 to 0.9, $p = 0.003$ and 4.9 to 5.5, $p = 0.02$, respectively). There were improvements in indoor concentrations of traffic particles significantly reduced with

HEPA filter treatment but not with the “dummy” treatment. This study shows an association of HEPA filtration with improved clinical outcomes and quality of life measures in children with uncontrolled asthma (James et al., 2019).

Riederer et al. (2021) conducted a randomized intervention trial of indoor endotoxin, PM_{10}, and coarse particulate matter in an agricultural cohort of children, aged 6-12 years, with asthma. All families received asthma education while the intervention family also received two HEPA cleaners (child’s bedroom, living room). Riederer et al. (2021) collected 14-day integrated samples of endotoxin in settled dust, PM_{10}, and $PM_{10-2.5}$ in the air of the children’s bedrooms at baseline and one-year follow-up. Seventy-one families (36 HEPA, 35 control) completed this study. Results show that at follow-up, HEPA families had 46% lower (95% CI, 31%-57%) PM_{10} on average than control families. Using the best-fit heterogeneous slopes model, HEPA families had 49% (95% CI, 6-110%) and 89% lower (95% CI, 28%-177%) PM_{10} and $PM_{10-2.5}$ at follow-up, respectively, at 50th and 75th percentile baseline concentrations. There was no significant difference in endotoxin loadings at follow-up (4% lower, HEPA homes: 95% CI, -87% to 50%). Riederer et al. (2021) demonstrate how HEPA cleaners can effectively reduce by approximately half PM_{10} and $PM_{10-2.5}$ in the bedroom of children with asthma.

Riederer et al. (2020) investigated the effectiveness of portable HEPA air cleaners on reducing $PM_{2.5}$ and anhydrous ammonia (NH_3) in the same agricultural cohort of children. Like the previous study, both families received asthma education while the intervention group received two HEPA cleaners. Fourteen-day integrated samples of $PM_{2.5}$ and NH_3 were measured at baseline and one-year follow-up. Also, seventy-one (36 HEPA, 35 control) families completed the study. At follow-up, HEPA families had 60% (95% CI, 41-72%; $p < .0001$) and 42% (19%-58%; $p = .002$) lower sleeping and living area $PM_{2.5}$, respectively. Reductions in NH_3 were not observed. The results from Riederer et al. (2020) suggest that portable HEPA cleaners, combined with asthma education, source control, and adequate ventilation, may be part of an effective strategy to reduce asthma morbidity in children.

Drieling et al. (2022) also used a randomized trial of a portable HEPA air cleaner to reduce asthma morbidity, specifically among Latino children in an agricultural community. Similar to Riederer et al. (2020 & 2021), seventy-five children with poorly controlled asthma living in non-smoking homes were randomly assigned to asthma education alone or also with HEPA air cleaners placed in their sleeping area and home living room. At baseline, six, and twelve months, the Asthma Control Test (ACT), asthma symptoms in prior 2 weeks, unplanned clinical utilization, creatinine-adjusted urinary leukotriene E4 (uLTE4 [ng/mg]), and additional secondary outcomes, were evaluated. Primary analysis of repeated measures of ACT score did not differ between groups. Secondary analysis showed children with HEPAs were less likely to have an ACT score meeting a clinically defined cutoff for poorly controlled asthma. In Poisson models, intervention participants had reduced risk of ever meeting this cutoff (IRR: 0.45 [95% CI: 0.21 - 0.89]), ever having symptoms in the past two weeks (IRR: 0.71 [95% CI: 0.52-0.98]), and lower risk of any unplanned clinical utilization (IRR: 0.35 [95% CI: 0.13-0.94]) compared to control participants. Although primary analysis did not show statistical significance, Drieling et al. (2022) warn to take caution when interpreting the results, as many of the outcomes were subjective (self-report) in this unblinded study.

Gent et al. (2022) utilized a triple-crossover randomized controlled intervention trial to test whether reduced exposure to household Nitrogen Dioxide (NO_2) or fine particulate matter results in reduced symptoms among children with persistent asthma. There were 126 children, aged 5-11 years, living in homes with gas stoves and levels of NO_2 15 ppb or greater. The children were randomly assigned to 5-week treatment periods using a three-arm crossover design: (1) NO_2 reduction: sham particle filtration and real NO2 scrubbing; (2) particulate matter filtration: HEPA filter and sham NO_2 scrubbing; (3) control: sham PM filtration and sham NO_2 scrubbing. Results showed that NO_2 was lower (by 4 ppb, $p<.0001$) for NO_2-reducing compared to control or PM-reducing treatments. NO_2-reducing treatment did not reduce asthma morbidity compared to the control.

Jia-Ying et al. (2021) investigated the efficacy of air purifier therapy for thirty-eight subjects with clinically diagnosed allergic asthma. The intervention group was given home HEPA purifiers for six consecutive months, while the control group was not given air filters. Particulate matter (PM) and dust samples were collected at baseline and each month thereafter. Simultaneously, subjects completed a questionnaire for the Asthma Control Test (ACT) or Childhood Asthma Control Test (C-ACT). Results showed that after using the HEPA purifier, there was a significant decrease in PM indoor/outdoor values. The ACT and C-ACT scores in the intervention group maintained a steady significant upward trend. In sum, Jia-Ying et al. (2021) observed that HEPA air purifiers can decrease indoor PM levels and improve the quality of life for allergic asthma patients.

There are limited school intervention studies and results have been inconsistent. Vesper et al. (2022) conducted a post-hoc analysis of the School Inner-City Asthma Intervention Study 2 (SICAS 2) to analyze the effect of HEPA filtration interventions on mold levels using the Environmental Relative Moldiness Index (ERMI) and possible improvement in the students' asthma using spirometry testing. Pre-intervention and follow-up dust samples were collected from classrooms and 150 corresponding homes of students with asthma. After the HEPA intervention, the average Group 1 mold level (components of the ERMI metric) and ERMI values were significantly lowered, and the average forced expiratory volume at 1 sec (FEV1%) test results significantly increased by an average of 4.22% for students in HEPA compared to sham classrooms. Vesper et al. (2022) concluded that HEPA intervention in classrooms reduced Group 1 and ERMI values, which corresponded to improvements in the students' FEV1% test results.

Phipatanakul et al. (2021) did not find classroom HEPA filter purifiers to significantly reduce symptom-days with asthma. In a blinded intervention, classrooms were randomly assigned portable HEPA filter purifiers with filters that were changed every 3 months or sham HEPA filters that looked and sounded like active HEPA filter purifiers. During the 2-week period, the mean was 1.6 symptom-days with asthma after use of HEPA filter purifiers in the classrooms vs 1.8 symptom-days after use of sham HEPA filter purifiers across the school year (incidence rate ratio, 1.47 [95% CI, 0.79-2.75]), which was not statistically significant. Phipatanakul et al. (2021) focused their study on reducing pest allergens as a strategy for improving asthma symptoms and did not assess classroom level attendance. Their pilot randomized controlled trial study (Jhun et al., 2017) assessed the effect of air cleaners on indoor air particulate matter concentrations in 18 classrooms (9 control, 9 intervention) in 3 urban elementary schools. The baseline classroom level of $PM_{2.5}$ was 6.3 μg/m^3. When comparing the intervention to the control group, classroom $PM_{2.5}$ levels were reduced by 49%.

2.0 Methods

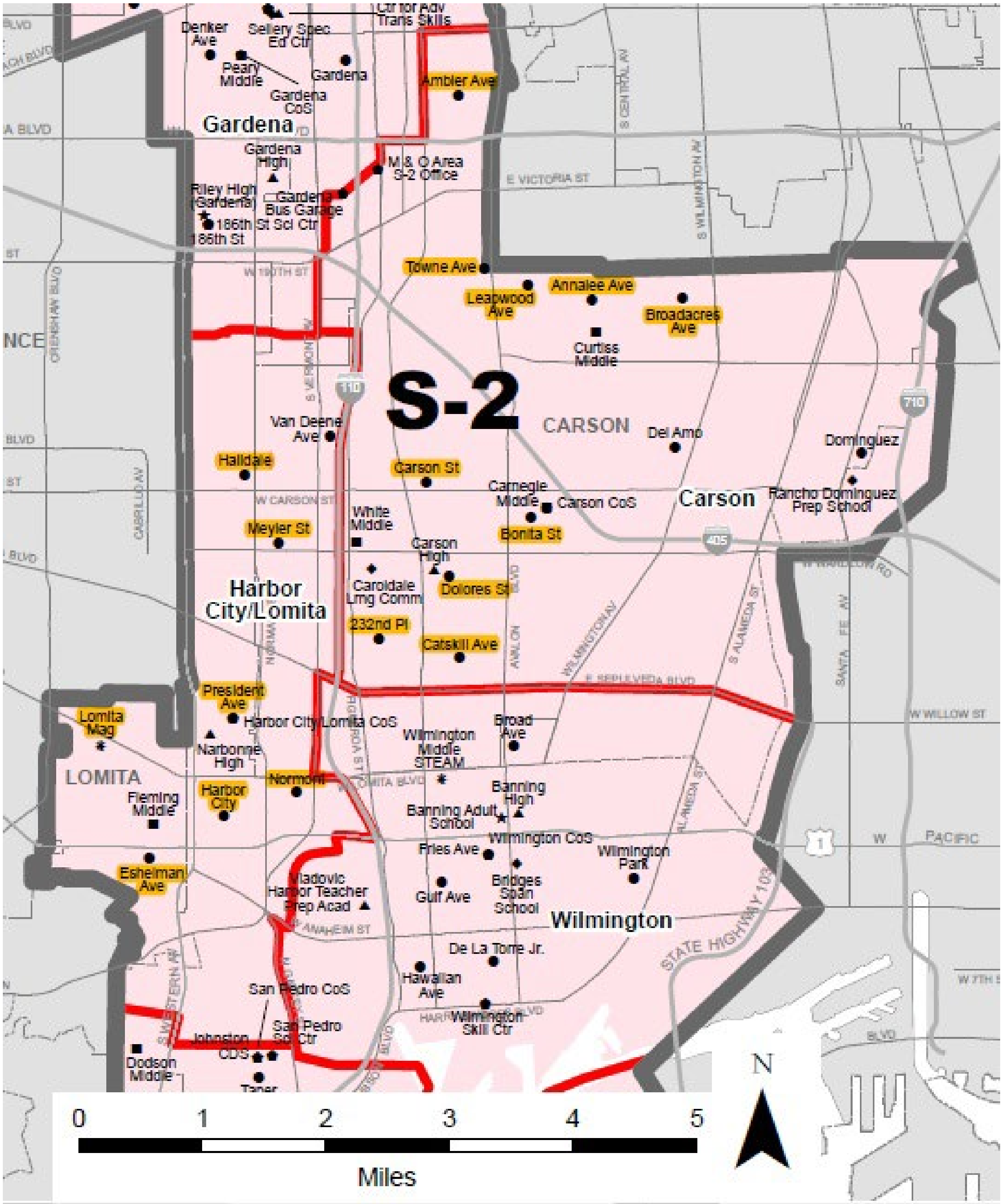
2.1 Overview

The overall goal of this project was to assess the benefits associated with HEPA air filtration in elementary school classrooms. UC Irvine worked with LAUSD Office of Environmental Health & Safety to identify seventeen elementary schools (Table 1) located in Carson, Torrance, Harbor City, and Lomita within the Carson and Harbor City/Lomita Community of Schools (COS, Figure 1) that could benefit from air cleaners in the classrooms. These schools are located in South Los Angeles County, near the Port of Los Angeles, major highways, industries, and oil refineries. In the first year, the project placed air cleaners (n=435) in those schools' classrooms where students spent the majority of their time. These 435 classrooms had been identified by LAUSD in the spring of the 2021-22 school year as instructional classrooms, as opposed to classrooms for Art, Music, Science Lab, Computer Lab, Intervention (Set-Aside), or Specific Learning Disability. During the study, three of the schools (n=85 classrooms) received other air cleaners to use in their classrooms in addition to the study air cleaners, although one of those schools (n=34 classrooms) did not install the new air cleaners until after this study intervention concluded. Because there was additional air filtration beyond the intervention, data from those classrooms could not be included in the air quality analyses. From two schools, 51 classrooms were excluded, leaving a total of 384 classrooms in the study.

Table 1. Participating schools in Carson and Harbor City/Lomita Community of Schools

School name	CoS	Classrooms
Ambler Avenue Elementary	Carson	32
Annalee Avenue Elementary	Carson	16
Bonita Street Elementary	Carson	22
Broadacres Avenue Elementary	Carson	19
Carson Street Elementary	Carson	34
Catskill Avenue Elementary	Carson	23
Dolores Street Elementary	Carson	31
Leapwood Elementary	Carson	16
Towne Avenue Elementary	Carson	17
232nd Place Elementary	Carson	23
Halldale Elementary	Harbor City/Lomita	25
Meyler Elementary	Harbor City/Lomita	35
Normont Elementary	Harbor City/Lomita	19
President Avenue Elementary	Harbor City/Lomita	27
Harbor City Elementary	Harbor City/Lomita	29
Lomita Elementary Math/Science/Technology Magnet	Harbor City/Lomita	43
Eshelman Avenue Elementary	Harbor City/Lomita	24
Total		435

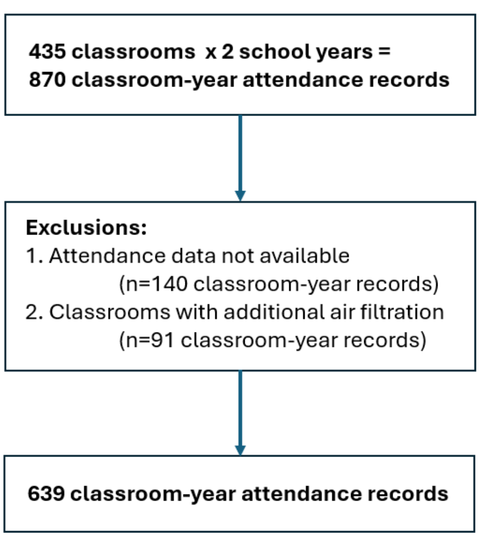
Figure 1. Participating schools in Harbor City/Lomita and Carson COS in South Area 2 (S-2) are highlighted



Before the 2022-23 school year, classrooms were randomized into intervention groups using a crossover randomized controlled trial during the two consecutive school years (2022-23, 2023-24). In this design, each classroom received the intervention, but during different school years. In August 2023, classrooms switched intervention groups so that classrooms with non-HEPA filters in 2022-23 had HEPA filters in academic year 2023-24 and vice versa. This design helps protect against any potential lack of balance in unmeasured confounders across the HEPA treatment and non-HEPA control groups, by allowing investigators to examine and compare the intervention effect across both phases (Thiese, 2014; Chandler et al., 2020). This design also allows comparisons to be made for control versus intervention groups at the same time, and across multiple seasons.

Air quality sensors that measure real-time $PM_{2.5}$ concentrations were also installed at each intervention school, both indoors and outdoors, to monitor air quality. Among the 435 classrooms, there were funds to have IQair monitors placed in 200 of them, and data from those monitors were downloaded every six months. IQair monitors were distributed to classrooms so that air quality was measured in each school building (permanent and portable), each school floor (if more than one story) and each end of the floor. Classroom PM concentrations were compared for the HEPA treatment and non-HEPA control classrooms over two academic school years,. Fourteen of the indoor IQair monitors could not be located for data download, so air quality data was available for 186 classrooms. We also collected outdoor air quality data using PurpleAir monitors successfully installed in 15 of the schools and compared it to indoor classroom data by school. Not all the schools could support the outdoor air monitor because of the lack of available outdoor power outlet needed for operating the monitor. For the 2 schools without PurpleAir monitors, Clarity Node data available from the LAUSD network were used for analyses. For a third school, the PurpleAir monitor stopped collecting data during the summer of 2023, likely due to a loss of power, so data form the nearest Clarity Node at a school 2 km south was used in the statistical analyses.

Figure 2. Attendance data exclusions



Absenteeism data was compared across the HEPA treatment and non-HEPA control groups during the same time period. Absenteeism data was provided by LAUSD for each school year. If all the classrooms with an air cleaner had attendance data available for both years, then 870 classroom-years of attendance records would have been available for analyses (435 classrooms multiplied by 2 years). Attendance was not collected for some classrooms (due to small class size or change from instructional classroom to other type) in each school for one or both schools years (n=140 classroom-year records) and 91 classroom-year records were excluded because additional air filtration was being used in two schools. The final analytic dataset included 639 classroom-years of attendance records. Figure 2 shows a diagram of the attendance data exclusions.

In addition, UC Irvine recruited parents of asthmatic students from the participating schools to longitudinally assess asthma and respiratory symptoms. These students were in classrooms participating in the intervention, either in a HEPA treatment classroom or non-HEPA control classroom. Students of recruited parents were all included in the data analyses. The panel study, entitled Child's Asthma and Respiratory Events and Symptoms (HIFIVE CARES), collected data from an initial questionnaire and weekly symptom surveys over the course of twelve weeks. UC Irvine provided step-by-step written instructions for using the IQAir sensor and in-person training for maintenance of air cleaners so the schools could continue to use the equipment after the intervention was completed.

2.2 Air monitoring

PM concentrations were monitored using IQAir AirVisual Pro sensors (Figure 3), handheld devices that were placed inside 200 study classrooms in July 2022. These sensors measure indoor air pollution from sources such as wildfire smoke and traffic pollution entering the building (https://www.iqair.com/us/air-quality-monitors). AirVisual Pro uses light-scattering to measure particles, converts the signal to a particle mass concentration for PM1, PM2.5, and PM10, and stores the data measured at 10-second intervals on the device memory (https://www.aqmd.gov/aq-spec/sensordetail/iqair---airvisual-pro). The sensor showed very strong correlations with laboratory studies (R2 =0.99) and overall showed 85-92% accuracy compared to reference instruments for concentrations < 300 µg/m^3 (https://www.aqmd.gov/docs/default-source/aq-spec/summary/iqair-airvisual-pro-v1-1683---summary-report.pdf?sfvrsn=18).

Air monitors were distributed across school campuses so that at least one instructional classroom in each building had a monitor. Once plugged in, the device can be left without any maintenance or intervention. Air monitors were tested by project staff prior to placing them in the classrooms. Teachers could move the air monitor to another location in the same classroom but were instructed to plug the monitor back into an outlet after moving it. The display could be turned off if the teacher preferred. Baseline PM concentrations were measured in July 2022 prior to air cleaner installation. Air quality data were downloaded every six months during winter and summer breaks of the 2022-23 and 2023-24 school years. Over the study period, 14 IQairs could not be located for downloading data.

Figure 3. IQAir air monitors placed in classrooms

The outdoor air quality at the schools were also monitored with an ambient air sensor. PurpleAir SD-II outdoor air monitors to measure ambient PM levels were installed on school building walls outside 15 participating schools by LAUSD maintenance staff. The sensor is an optical particle counter. PM_1, $PM_{2.5}$ and PM_{10} mass concentrations are calculated from the counts (https://www2.purpleair.com/collections/air-quality-sensors/products/purpleair-pa-ii-sd). The monitor also measures temperature and relative humidity, and it has an SD card for internal data storage. Schools did not need to maintain the air sensors, but the units needed to be uninstalled by LAUSD to retrieve the data because LAUSD would not allow the study to access their WI-FI. The sensors were returned to UC Irvine by LAUSD staff in late December 2024 for analysis. Two schools did not have outdoor outlets available to mount the PurpleAir monitor but these schools have existing Clarity outdoor air monitors on the roof (https://achieve.lausd.net/knowyourairnetwork). Indoor and outdoor air quality data were compared to determine how much of an improvement in indoor air quality resulted from filtration.

2.3 HEPA air filter intervention

Figure 4. Blueair Classic 605 air cleaners placed in classrooms

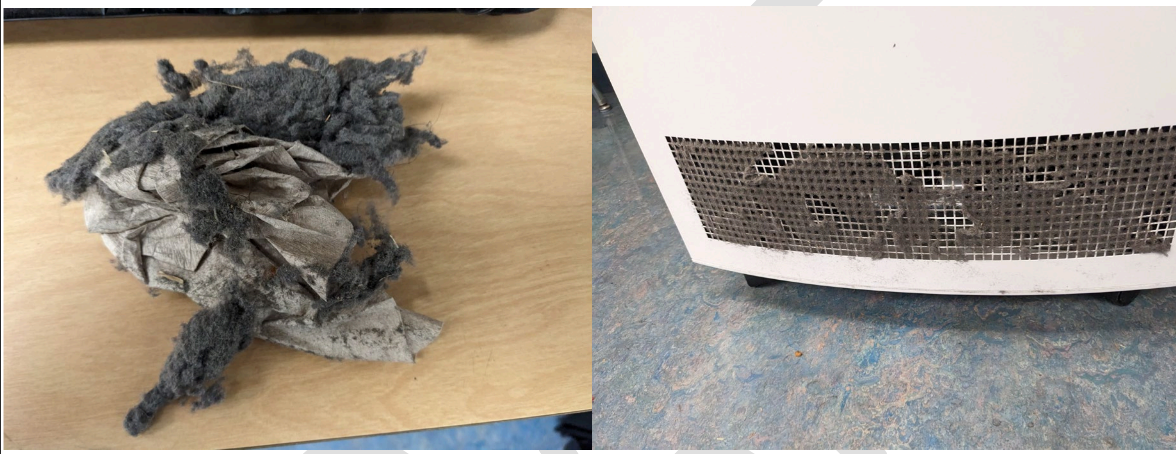
For this intervention, standalone air cleaners were placed in all classrooms where students spent the majority of the school day. The Blueair Classic 605 air cleaner (Figure 4) filters the air in a large classroom every 12.5 minutes and is 26 inches tall, 20 inches wide, and 13 inches deep (https://www.blueair.com/us/air-purifiers/classic-605/1641.html). These air cleaners have been used in other intervention studies to lower particulate concentrations (Carmona et al., 2022). LAUSD EHS approved the unit. Due to COVID-19, schools already had upgraded to MERV13 air filtration in classroom HVAC systems. The standalone air cleaner provided extra filtration, rather than replacing existing filtration.

Air cleaners with HEPA filters were installed in approximately half the classrooms, randomized to treatment, and air cleaners with non-HEPA control filters in the other half of classrooms, randomized to control. The non-HEPA filter was constructed from HDPE (High Density Polyethylene) shade cloth that looked like the HEPA filter when placed in the air cleaner and maintained the same sound when in operation.

The air cleaners were placed in each classroom in mid-August 2022, just before the start of the school year. The units were situated in the classroom away from any windows or obvious PM sources, but placement was restricted by the availability of accessible outlets. Units were turned on at the medium speed as this sound level (44 decibels) was preferable to the highest speed (62 decibels). Teachers were allowed to move the unit to another location in the same classroom but were instructed to turn the air cleaner back on after moving. They were also instructed to leave the unit at the medium or high speed but not decrease to low or turn off the unit. They were also asked to not obstruct the air cleaner vents. The air cleaners did not need any maintenance by teachers or school staff.

The teachers and students were not informed of their randomized assignment. Air cleaners for both treatment groups were sealed with tamper-evident tape after filter installation, to discourage teachers and students from opening the machines and revealing the filter type. Every 6 months, during the winter and summer breaks, air cleaners were dusted and cleaned, and filters were replaced with new clean filters by the project team (Figure 5). At the start of the 2023-24 academic year, classrooms switched intervention groups. At the end of the intervention study, schools kept the indoor air sensors (IQAir AirVisual Pro) and portable air cleaners (Blueair Classic 605). Given the life expectancy of the outdoor air monitors (PurpleAir SD-II) and difficulty in retrieving the SD card, the monitors were removed by LAUSD at the end of the study and returned to UC Irvine for data processing.

Figure 5. Air cleaners at 6 month filter change.



2.4 Outcome data collection

2.4.1 Human subjects approval

UC Irvine investigators submitted a detailed project protocol to the Institutional Review Board (IRB) at University of California, Irvine for review. The project was approved in April 2023. A project sheet for participating in the longitudinal individual-level health assessment was shared with the Principals in the participating schools (Appendix B). Consent forms were developed per UC Irvine IRB guidelines. HIFIVE CARES questionnaire (Appendix C) and weekly survey (Appendix D) were developed in both English and Spanish. UC Irvine investigators completed all necessary human subject's protection training.

The Strategic Data and Evaluation Branch at LAUSD also approved this study with modifications. (1) The questionnaire could not ask for residential address. (2) Researchers could not contact parents directly for recruitment in the HIFIVE CARES study. Instead, researchers were only allowed to send a recruitment flyer to the school principals, who then distributed the flyer to parents. Unfortunately, principals only distributed the flyer once or twice, and participation was low (n=19) despite additional efforts to recruit via a mailed study flyer to residents of the schools' neighborhoods. (3) Researchers were also not allowed to recruit teachers directly to participate in a questionnaire. Instead, a flyer with a QR code for a brief survey (Appendix E) was left when the filters were changed. The participation in the teacher survey was also low (n=34).

2.4.2 Classroom attendance data

At the end of the 2022-23 and 2023-24 school years, LAUSD provided attendance data for instructional classrooms. These data included 371 classrooms in 2022-23 and 359 classrooms in 2023-24. For 140 classroom-years, attendance records were not provides, either because the class size was too small (data suppressed) or they were classrooms without attendance taken (e.g., pre-kindergarten, specific learning disability, resource specialist program, STEP classrooms, set-aside rooms). Attendance data for classrooms with and without the HEPA filter treatment were compared using routinely collected administrative data already available from the schools. These data included the number of students in the class and the percentage attendance, which allowed us to calculate the person-days of absenteeism. The intervention during the 2022-23 and 2023-24 school years provided two years of attendance data for analysis. In addition, administrative data from the previous school year (2021-22) was reviewed to determine baseline differences between the schools in the analyses.

2.4.3 Student symptoms data

Parents of asthmatic students were recruited for a longitudinal assessment of individual health outcomes during the school year 2023-2024 beginning in January 2024. Students with physician-diagnosed non-atopic asthma were eligible. Parents/guardians of the students in the longitudinal assessment were asked to complete an initial questionnaire (Appendix C) at the start of the panel study that collected information on demographics (age, ethnicity, household occupancy, and housing characteristics), sources of residential PM exposures (cooking behaviors, wood burning, smoking, and proximity to outdoor sources like traffic) and allergy and respiratory symptom history. Weekly surveys were completed by parents to assess symptoms occurring for the previous week for a total of 12 weeks (Appendix D). Parents were provided with a stipend for each survey completed to encourage participation and increase retention.

2.5. Statistical Analyses

A block randomized crossover trial was conducted to assess the benefits of portable HEPA air cleaners in elementary school instructional classrooms at 17 elementary schools. Classrooms (n=435) within each school were randomly assigned to a treatment group (HEPA filters) or control group (non-HEPA filters) and air quality was measured in 186 classrooms. Each classroom received the HEPA filter treatment for an entire school year, for two different school years (2022-2023 and 2023-2024). For the first school year, half the classrooms were randomly assigned to receive HEPA filters, and half the classrooms were assigned to receive non-HEPA filters. In the second school year of the study, the classrooms switched intervention groups (i.e., a cross-over randomized design). Each classroom also had an existing HVAC system maintained by LAUSD that used minimum efficiency reporting value (MERV) 13 filters since the COVID-19 pandemic; the portable air purifiers used in this study provided air filtration that was in addition to the existing HVAC filtration. Intention to treat (ITT) analysis of the data was conducted to protect against potential noncompliance, protocol deviations, or anything that might have occurred after randomization. ITT analysis avoids overestimation of treatment effects or bias from post-randomization factors is most likely towards the null (Pendlebury et al., 2023).

2.5.1 Air quality data analyses

The first objective of the study was to assess whether there were any differences in air quality between the HEPA and non-HEPA classrooms. The classrooms were randomized per school and balanced across the two treatment groups, but schools with an odd number of classrooms received an additional HEPA classroom in the first school year. For example, if a school had 31 instructional classrooms, 16 were randomized to receive the HEPA filter treatment in the first school year and 15 were non-HEPA control classrooms. Because there was additional air filtration beyond the intervention in two of the study schools, those classroom data could not be included in the statistical analyses.

PM data were downloaded from classroom IQAir AirVisual Pro monitors during winter and summer breaks. Monthly and school-year (September – May) averages and standard deviations of the continuous PM concentrations were calculated for HEPA treatment and non-HEPA control groups and compared using the Welch Two Sample t-test. $PM_{2.5}$ levels were also compared stratified by classrooms in permanent buildings or bungalow/portable buildings. A linear mixed effects (LME) model with a random effect for school was also fit to the data to account for any within-school correlation. The model estimated the effect of the intervention on average monthly $PM_{2.5}$ levels in the classroom by comparing the change of exposure from baseline in the HEPA treatment group to the non-HEPA control group. The LME model was restricted to data for the school-year months of the intervention and was adjusted for baseline PM concentrations. The interclass correlation coefficient (ICC) for schools and the adjusted effect estimate for HEPA intervention on $PM_{2.5}$ are reported.

The outdoor PurpleAir monitors were mounted on the exterior of the schools by LAUSD staff during the summer of 2022, prior to the start of the intervention study, and returned to UC Irvine researchers at the end of December 2024. Given the delay in the retrieval of the air monitors, a secondary analysis was completed first, using the existing LAUSD air monitoring system. Indoor classroom $PM_{2.5}$ was compared to outdoor $PM_{2.5}$ collected at five schools with Clarity Node-S air monitors that were already in place prior to and independent of the intervention study. The sensors use light scattering to size and count particles and then convert them to a mass fraction and have performed well in field and lab evaluations (https://www.aqmd.gov/docs/default-source/aq-spec/summary/clarity-node---summary-report.pdf?sfvrsn=18). Data from the outdoor air monitoring network are measured every 5-6 minutes and available online for download from the school district (https://www.lausd.org/knowyourairnetwork). The $PM_{2.5}$ data collected by the both the PurpleAir and Clarity air monitors were averaged for school months September 2022 through May 2024 for each school. In addition, we calculated the ratio of the average indoor to outdoor $PM_{2.5}$ (I/O ratio) for school months September 2022 through May 2024 for each classroom within each school by dividing the average classroom indoor $PM_{2.5}$ concentrations by the average outdoor $PM_{2.5}$ concentration (Carmona et al., 2022). We then averaged those classroom ratios by treatment group and calculated the standard deviations and confidence intervals for HEPA treatment and non-HEPA control classrooms. This calculation accounts for variation across each classroom by first averaging the classroom data, rather than simply dividing the average school indoor $PM_{2.5}$ concentration by the average outdoor $PM_{2.5}$ concentration We performed these analyses separately for the outdoor data from the Clarity Nodes and the PurpleAir monitors.

2.5.2 Classroom attendance data analyses
Within each elementary school, classrooms were randomized into HEPA treatment and non-HEPA control groups at the beginning of the first intervention school year (2022-23). In the

second school year (2023-24), classrooms switched treatment groups, so that the classrooms that were randomized to the non-HEPA control group at the beginning of the study received the HEPA filter treatment for the second half of the study (second school year), and vice versa. Within 17 schools over two years, 730 classroom-year attendance records for instructional classrooms were available for analyses. Two schools (n=91 classroom-years of attendance data) were excluded because of these schools had received another air cleaner unrelated to the current study and had been using those in addition or instead of the intervention air cleaners. With this exclusion, the final analytic dataset included 639 classroom-years of attendance data for the two academic years, providing a substantial sample size for statistical comparisons. Attendance data were also collected for 2021-22 to determine if there were any baseline differences between classrooms. LAUSD provided the monthly percentage attendance and number of students by school classroom for each school year.

Monthly percentage attendance was averaged to calculate an annual percentage attendance for 2021-22, 2022-23, and 2023-24. The number of person-days per school month was calculated by multiplying the number of students in each classroom by the number of school days in each month. The annual person-days was the sum of the monthly person-days. The monthly attendance count was calculated by multiplying the monthly percentage attendance by the monthly person-days. The annual attendance count was the sum of the monthly counts for the school year. A weighted annual average attendance rate was calculated as the annual attendance count divided by the annual person-days. The weighted annual average attendance rate was calculated for each school year.

For the classroom-level data, Poisson models were used to compare person-days of absenteeism. Teacher survey data (n=34 teachers) were checked for randomization balance, to determine if any important covariates differed between the HEPA treatment and non-HEPA control groups despite randomization. Although participation in the teacher survey was low, the use of the portable air cleaners, HVAC system, and external ventilation (doors and windows) was similar between the two groups, so the statistical analyses did not include additional covariates..

Poisson models included the weighted annual attendance for either 2022-23 or 2023-24 for each classroom as the outcome and log of the classroom annual person-days as an offset. The unadjusted model included only a term for the intervention group (HEPA or non-HEPA). In the adjusted model, the classroom annual attendance rate for 2021-2022 was included to account for any baseline differences in classroom attendance independent of the intervention. Effect estimates and standard errors were exponentiated to determine the rate ratios for the effect of HEPA filter treatment for 2022-2024. The average annual attendance rate per intervention group per year was also calculated.

2.5.3 Student symptoms data analyses

The individual-level longitudinal data examined the association between the presence or absence of asthma or allergy symptoms reported the week prior and average weekly $PM_{2.5}$ levels in the classroom. Experiencing “any symptom” day in the week prior is a dichotomous metric that has been used in other asthma intervention studies (Phipatanakul et al., 2017; Eggleston et al., 2005). To determine whether the average number of symptoms per week differed by treatment groups, a negative binomial Generalized Additive Mixed Models (GAMMs) stratified by treatment groups was used. GAMMs allow for the inclusion of a thin-plate smoothed term of calendar week to account for seasonal fluctuations of the symptoms while simultaneously estimating a random intercept per participant to account for unbalanced repeated measures. A negative binomial GAMMs was used to account for the overdispersion on the total number of symptoms data. In each stratified model, other covariates besides the smooth term were not adjusted for because the covariates were balanced across participants due to the random assignment to treatment groups. To test whether the average number of symptoms per week differed by treatment groups, a Cochran's Q statistic was calculated based on estimates of the intercepts and the corresponding standard errors in the stratified models.

As an exploratory analysis, the permuted mean squared difference (PMSD) test (Tang et al., 2020) was adapted to test whether the two splines in the stratified models were different. A mean squared difference statistics was calculated by first fitting separate splines for each treatment group, then making predictions on a common grid of calendar weeks for each treatment group and calculating the average of the squared differences between the treatment groups at each grid point. First the mean squared difference was calculated for the original dataset on a prediction grid of weeks ranges from 4 to 25, which was the range of calendar weeks in the study sample. For each iteration of 1000 permutations, the assignment of treatment groups was shuffled across all participants and a permuted dataset was generated. Two separate splines were fit by the treatment groups using the permuted dataset. A permuted mean squared difference was then calculated on a prediction grid ranges from 4 to 25 weeks. A permutation p-value was calculated by ranking the original mean squared difference with the permuted mean squared differences.

All analyses were conducted in R (R development Core Team, 2019; Venables & Ripley, 2002; Wickham et al., 2019; Wickham et al., 2022). GAMMs were fit using "gamm4" package and model checking was performed using "DHARMa" package(Hartig, 2018; Wood et al., 2017).

3.0 Results

3.1 Air quality data analyses

3.1.1 Linear mixed effects (LME) models

The primary analysis examined the difference between indoor $PM_{2.5}$ concentrations in classrooms with and without HEPA filters in portable air cleaners. Results of the LME model for the academic school year 2022-23, adjusting for baseline $PM_{2.5}$ concentrations (July 2022), show that HEPA treatment classrooms were lower than control classroom by 0.4 $\mu g/m^3$ on average with a standard error of 0.1 $\mu g/m^3$. The ICC for school was low (0.15), supporting the approximate independence assumption of the t-tests, and indicating substantial variation in $PM_{2.5}$ concentrations across classrooms within each school, compared to differences across schools. Many of the schools consist of a combination of main building classrooms and portable trailer classrooms with different proximity to roadways and other PM sources. When data for school year 2023-24 were included in the analysis, the HEPA treatment classrooms were lower than control classroom by 0.7 $\mu g/m^3$ on average with a standard error of 0.1 $\mu g/m^3$. The ICC for school remained 0.15.

3.1.2 Welch two sample t-tests

Table 2 shows the monthly and school year means and standard deviations (SD) for $PM_{2.5}$ levels ($\mu g/m^3$) by treatment group and the corresponding p-values from the t-tests. For the school year

September 2022 through May 2023, the average $PM_{2.5}$ level in treatment classrooms was 0.9 µg/m³, which was 40% lower than the average $PM_{2.5}$ of 1.5 µg/m³ in controls classrooms ($p < 0.001$). Compared to baseline values in July 2022 (prior to the start of the intervention), $PM_{2.5}$ levels were reduced on average by 31% for HEPA treatment classrooms, compared to only 12% for non-HEPA control classrooms. The difference between average $PM_{2.5}$ concentrations in HEPA treatment and non-HEPA control groups in July 2022 was not statistically significant (p=0.27). Months with extended student breaks, when some air cleaners were turned off, also did not show statistically significant differences: January 2023 (p=0.14), March 2023 (p=0.41), and May 2023 (p=0.12). For the school year September 2023 through May 2024, the average $PM_{2.5}$ level of 1.4 µg/m³ in treatment classrooms was 50% lower than the average $PM_{2.5}$ level of 2.8 µg/m³ in controls classrooms ($p < 0.001$). For all months of the second school year, $PM_{2.5}$ concentrations in HEPA treatment classrooms were statistically significantly lower than in non-HEPA control classrooms. This may be due to the study emphasizing that the air cleaners should never be turned off, even during school breaks. Similar results were observed for PM_{10} and PM1 (Appendix F). Indoor $PM_{2.5}$ concentrations were significantly higher during the 2023-24 school year compared to the 2022-23 school year. This may be due to differences in outdoor PM levels between years.

For the two school years, average $PM_{2.5}$ concentrations for classrooms in permanent buildings was 1.1 µg/m³ and 2.0 µg/m³ for the HEPA treatment group and the non-HEPA control group, respectively. This was significantly higher than the average $PM_{2.5}$ in classrooms located in bungalows/portable buildings by 18% and 20% ($p<0.001$). Average $PM_{2.5}$ concentrations for classrooms in bungalows/portable buildings was 0.9 µg/m³ and 1.6 µg/m³ for the HEPA treatment group and the non-HEPA control group, respectively. These differences may be due to differences in the HVAC systems in these building types.

Table 2. Average monthly and annual $PM_{2.5}$ (µg/m³) during the 2022-23 and 2023-24 school years by treatment group

$PM_{2.5}$ (µg/m³)	**HEPA**	**Non-HEPA**	
Month	**Mean (SD)**	**Mean (SD)**	**p-value**
July 2022 (Baseline)	1.3 (1.2)	1.7 (3.9)	0.273
August 2022	0.9 (0.8)	1.8 (2.7)	0.003
September 2022	0.8 (0.8)	1.7 (2.5)	0.001
October 2022	1.1 (0.9)	2.2 (3.3)	0.005
November 2022	0.8 (0.9)	1.3 (1.0)	0.001
December 2022	1.3 (1.2)	1.7 (1.2)	0.007
January 2023*	0.9 (1.5)	1.3 (1.5)	0.142
February 2023	0.6 (0.6)	1.1 (1.7)	0.014

March 2023*	0.6 (1.5)	0.9 (3.3)	0.413
April 2023	1.1 (1.0)	1.9 (2.2)	0.004
May 2023*	0.8 (1.0)	1.1 (1.6)	0.117
June 2023	0.6 (0.7)	0.9 (0.8)	0.011
Sep 2022 - May 2023	0.9 (1.1)	1.5 (2.2)	< 0.001
August 2023	1.4 (1.1)	2.3 (1.7)	< 0.001
September 2023	1.6 (1.4)	2.6 (1.9)	<0.001
October 2023	1.3 (1.3)	2.0 (1.5)	0.007
November 2023	1.0 (1.2)	1.6 (1.3)	0.007
December 2023	1.5 (1.5)	2.5 (1.8)	0.001
January 2024*	1.7 (1.2)	3.0 (2.1)	< 0.001
February 2024	1.0 (0.8)	1.8 (1.6)	< 0.001
March 2024*	1.0 (0.7)	1.8 (1.3)	< 0.001
April 2024	1.4 (1.0)	2.9 (1.7)	< 0.001
May 2024*	1.7 (1.3)	3.6 (2.0)	< 0.001
June 2024	2.0 (1.5)	3.8 (1.9)	< 0.001
Sep 2023 - May 2024	1.4 (1.2)	2.8 (1.9)	< 0.001
Permanent buildings	1.1 (1.3)	2.0 (2.4)	< 0.001
Bungalow/portable buildings	0.9 (0.9)	1.6 (1.2)	< 0.001

** Months with extended school breaks*

3.1.3 Ratio of indoor to outdoor air

PurpleAir SD-II outdoor air monitors were installed at most of the schools. The air monitoring data is being stored on SD cards. Given the difficulty in accessing the units, the monitors were not accessed during the intervention study. LAUSD was able to uninstall the air monitors and return them to UC Irvine researchers in December 2024. As an alternate strategy while waiting for the SD cards, ambient air data were first analyzed from networked Clarity air monitors mounted on the roofs of several LAUSD schools, including five schools in the current project. After PurpleAir monitors were returned to UC Irvine, those data were subsequently analyzed in addition to the Clarity air data analyses.

Table 3 presents the monthly outdoor $PM_{2.5}$ levels from the Clarity air monitors along with the indoor treatment and control classrooms $PM_{2.5}$ levels in those schools. The average annual outdoor $PM_{2.5}$ levels from September 2022 to May 2024 ranged from 7.8 to 10.4 µg/m³ and were higher than the classroom levels. In addition, the annual average outdoor $PM_{2.5}$ concentrations increased from 2022-23 to 2023-24. The ratio of indoor $PM_{2.5}$ to outdoor $PM_{2.5}$ (I/O ratio) was similar in the HEPA and non-HEPA classrooms, with overlapping confidence intervals. The difference between I/O ratios for HEPA treatment and non-HEPA control classrooms varied by school, with HEPA classrooms up to 80% lower than non-HEPA classrooms in 2023-24. Appendix G presents a comparison of classroom and PurpleAir outdoor $PM_{2.5}$ (µg/m³) annual averages and I/O ratos by treatment group for all schools by year. For two of the schools (A and D), PurpleAir monitors could not be installed because there was no power outlet available, but these schools did have Clarity monitors, so those data were used for Appendix G calculations. The correlation between the three schools (B, C, E) with both Clarity and PurpleAir monitors was high (0.8). Results for the data from PurpleAir monitors were similar to the Clarity monitors. The average annual outdoor $PM_{2.5}$ levels from September 2022 to May 2024 ranged from 6.9 to 10.8 µg/m³ and no major wildfires occurred in the region during that time.

Table 3. Comparison of classroom and Clarity outdoor $PM_{2.5}$ (µg/m³) annual averages and ratio of indoor to outdoor air by treatment group and school for years 2022-23 and 2023-24

		$PM_{2.5}$ (µg/m³)			I/O ratio	
		HEPA	Non-HEPA	Outdoor	HEPA	Non-HEPA
School Year	School ID	Mean (SD)	Mean (SD)	Mean (SD)	Average Ratio (95% CI)	Average Ratio (95% CI)
2022-23	A	1.7 (1.5)	2.2 (1.1)	10.1 (2.1)	0.2 (0.1, 0.2)	0.2 (0.2, 0.3)
	B	0.5 (0.3)	0.5 (0.4)	9.2 (1.9)	0.1 (0.0, 0.1)	0.1 (0.0, 0.1)
	C	0.4 (0.2)	2.0 (1.6)	8.2 (1.9)	0.0 (0.0, 0.1)	0.2 (0.2, 0.3)
	D	0.9 (0.9)	1.4 (1.0)	9.9 (2.3)	0.1 (0.1, 0.1)	0.1 (0.1, 0.2)
	E	0.5 (0.3)	1.0 (0.5)	7.8 (1.9)	0.1 (0.0, 0.1)	0.1 (0.1, 0.2)
2023-24	B	1.2 (0.5)	4.3 (4.8)	9.5 (2.5)	0.1 (0.1, 0.1)	0.5 (0.2, 0.7)
	C	1.0 (0.6)	3.0 (2.3)	8.1 (2.0)	0.1 (0.1, 0.2)	0.4 (0.2, 0.5)
	D	2.0 (1.1)	2.2 (1.1)	10.4 (2.9)	0.2 (0.2, 0.2)	0.2 (0.2, 0.3)
	E	0.9 (0.4)	1.1 (0.5)	8.1 (1.8)	0.1 (0.1, 0.1)	0.1 (0.1, 0.2)

3.2 Classroom attendance data analyses

3.2.1 Overview of data

LAUSD provided monthly data on absenteeism numbers by classroom for 2021-2024 school years. In addition, the number of instructional days per school month were obtained from the online LAUSD school calendars. There were noticeable differences by month for attendance in

January 2022 when the omicron variant of SARS-CoV-2 was prevalent (Figure 6). In contrast, monthly attendance for the 2022-23 and 2023-24 school years were stable (Appendix H and I).

3.2.2. Poisson models

Based on the model results, there was no effect of HEPA filters on attendance in 2022-2024 school years. The rate ratio and 95% confidence interval for the HEPA filter treatment in the unadjusted model was 1.000 (0.997, 1.002). The p-value was 0.73. Analyses were also adjusted for 2021-22 data to account for baseline differences between classrooms (Table 4). The results for HEPA treatment in the model adjusted for 2021-22 baseline attendance was also null with an adjusted rate ratio and 95% confidence interval of 1.000 (0.997, 1.003) and p = 0.98. Anecdotally, informal conversations with some teachers suggested that parents often sent children to school even if sick because they did not have the ability to stay home from work or find alternative childcare. The analyses were also not able to assess whether a child was absent due to illness or another reason, but in elementary schools, truancy and suspensions are uncommon. Although school nurse visits and medication use would have been a more sensitive outcome, LAUSD did not allow access to those data due to privacy concerns.

Figure 6. Average Attendance by Classroom in 2021-22

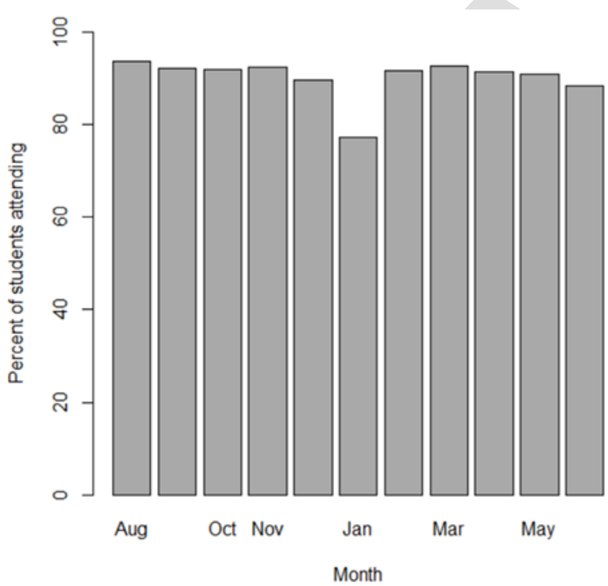


Table 4. Average Annual Classroom Attendance % by Group

	2021-22	2022-23	2023-24
HEPA	90.4%	91.7%	92.8%
Non-HEPA	90.8%	91.9%	92.4%

3.3 Student symptoms data analyses

3.3.1 Recruitment

Once participants confirmed eligibility and provided informed consent, they were sent a link to complete the initial questionnaire in REDCap (Research Electronic Data Capture), a secure, HIPAA compliant web-based survey application that is managed by UC Irvine Health Information Technology, and subsequently, the weekly surveys at specified times each week. REDCap sent participants their unique survey link through SMS text message or email. REDCap has the feature to send survey links to participants via email or text messages integrated within. REDCap uses a third party, Twilio, for their SMS text messaging services. Twilio did not have access to any personally identifiable information other than phone numbers. The initial questionnaire collected information on demographics (age, ethnicity, household occupancy), housing characteristics and sources of residential air exposures (cooking behaviors, wood burning, smoking) and child's respiratory symptom history. Weekly online surveys were completed by parents/guardians assessing symptoms occurring for the previous week for 12 weeks. For Spanish-speaking participants, all study material were also available in Spanish, using standard back-translation procedures through a professional translation service.

The Strategic Data and Evaluation Branch at LAUSD required study modifications to approve UC Irvine conducting human research which delayed the start of recruitment. Furthermore, researchers could not contact parents directly for recruitment in the HIFIVE CARES study. Instead, researchers were only allowed to send a recruitment flyer to LAUSD administration, who then distributed the flyer to parents via Blackboard Connect messaging. Unfortunately, there was a change in LAUSD administration during the study and communication from LAUSD was not forthcoming. Information to parents was only distributed once or twice, and LAUSD never provided confirmation that all the schools had sent the messaging to parents. As a result, participation was low despite additional efforts to recruit via a mailed study flyer to residents of the schools' neighborhoods. This impacted researchers' ability to determine a statistically significant health effect associated with HEPA filtration from the symptoms questionnaire.

3.3.2 Sample demographics

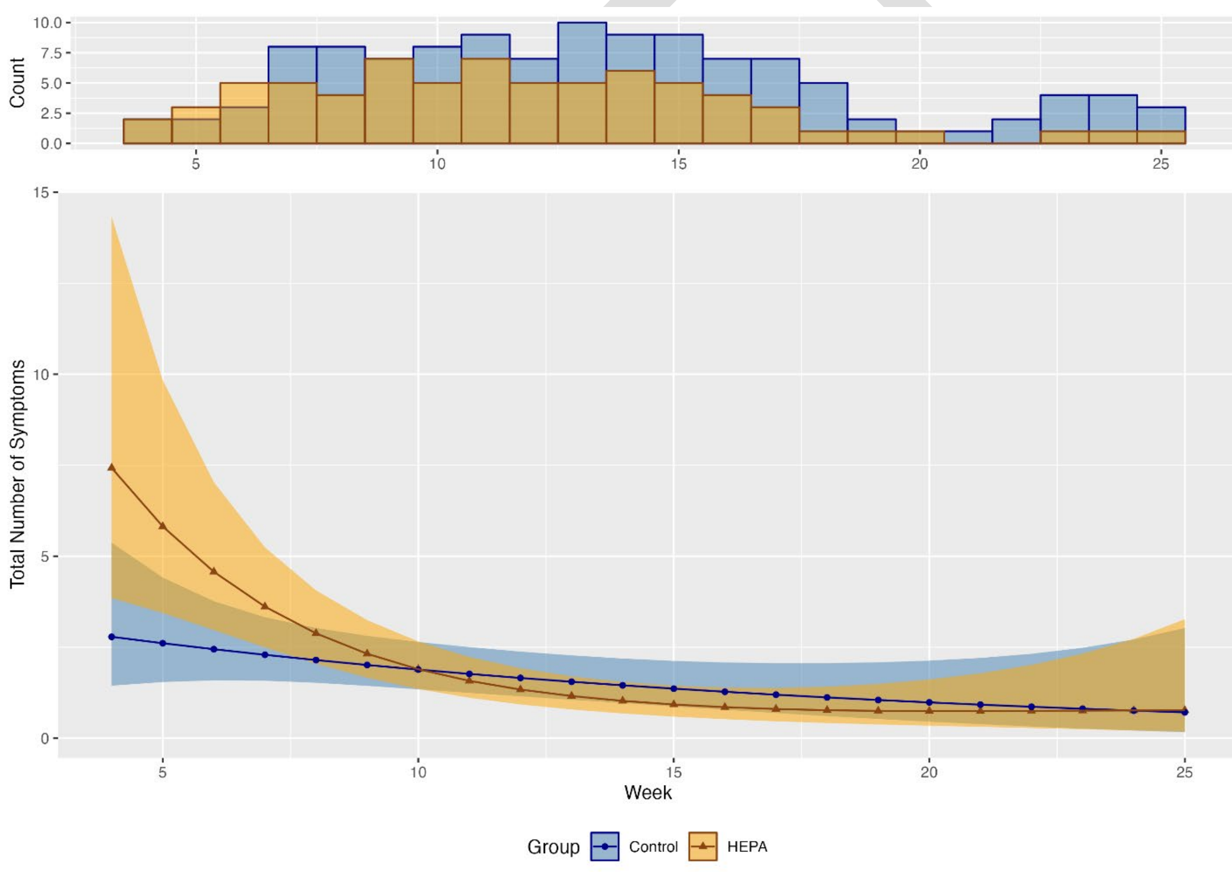
Among the 20 participants enrolled in the study, one did not complete the surveys and was excluded; 12 were in the non-HEPA control group, while 7 were in the HEPA treatment group. The two groups did not differ in sex of the student (21% female, 68.4% male, and 10.5% preferred not to answer, $p = 0.82$), age (M (SD) = 8.84 years (1.95), $p = 0.83$), race (26% African American, 21.1% White, 52.6 % Other, $p = 0.14$), ethnicity (47.4% Hispanic, $p = 0.23$), parent insurance type ($p = 0.76$), parent education ($p = 0.50$), household income ($p = 0.29$), or week of enrollment ($p = 0.43$) and the duration of participation ($p = 0.80$). The average duration of participation was 9 weeks (SD = 3.65) and the average enrollment week in calendar weeks was 9.90 (SD = 7.14, range: 4 – 23).

3.3.3 Generalized additive mixed models (GAMMs)

The average number of symptoms per week ranged from 1 to 10. After stratifying by treatment groups and fitting a spline per group in the GAMM, the average number of symptoms per week was observed to not differ significantly by treatment group (Cochran's Q: χ_1^2= 0.035, p = 0.85). Residual analysis showed mild deviations for the HEPA stratified group.

3.3.4 Permuted mean squared difference (PMSD) test
Results of the PMSD test showed that the HEPA treatment group and the non-HEPA control group had different predicted number of symptoms over weeks based on the stratified spline models (permutation p = 0.008). The HEPA group had a steeper drop of the number of symptoms per week in the first quarter of the year, and the slope tapered over time (Figure 7). In contrast, the non-HEPA control group showed a steady decline of average number of symptoms over time.

Figure 7. Frequency of symptoms by intervention group and predicted number of symptoms over study weeks. The top panel shows the frequency of symptoms reported for calendar weeks 4-25 among students in HEPA treatment classrooms (orange bars) and non-HEPA control classrooms (blue bars). The bottom panel shows the number of symptoms for both groups predicted by applying the stratified spline model parameters to each calendar week.



4.0 Discussion
Few studies have examined HEPA filtration in a classroom environment. This study aimed to assess if air cleaners using HEPA filters reduced classroom indoor air pollution exposure using a block randomized crossover trial in elementary schools in Los Angeles County. In July 2022 before the placement of portable air cleaners, there was no statistically significant difference between PM concentrations in the treatment and control classrooms, indicating successful

randomization with regard to baseline PM concentrations. These findings show that HEPA classrooms had 39.6% lower average annual $PM_{2.5}$ than non-HEPA classrooms (0.9 $\mu g/m^3$ compared to 1.5 $\mu g/m^3$) during the 2022-2023 school year, and 48.5% lower (1.4 $\mu g/m^3$ compared to 2.8 $\mu g/m^3$) during the 2023-2024 school year. The averages of the two school years were significantly different. This may be due to higher outdoor air concentrations and possible differences in HVAC usage.

A previous study that used a similar study design was conducted from April to December 2021, in Mengzhou city, Henan Province, China (Jiang et al., 2023). $PM_{2.5}$ concentrations were measured in classrooms, living rooms, and outdoor environments during the study period. MicroPEM samplers were also used in the students' living room. The living room and classroom interventions resulted in 42.31% and 21.34% reductions in personal $PM_{2.5}$ exposure, respectively. Participants with living room and classroom air purification interventions had the lowest $PM_{2.5}$ levels, with an average of 45.9 ± 44.4 $\mu g/m^3$, followed by participants with only living room intervention (62.0 ± 51.5 $\mu g/m^3$), participants with only classroom intervention (73.4 ± 54.1 $\mu g/m^3$), and participants with no intervention (89.0 ± 61.4 $\mu g/m^3$). $PM_{2.5}$ levels in the Mengzhou study were much higher than levels in Los Angeles for the HIFIVE study.

Another air filtration intervention study conducted from 2015 to 2020 in urban elementary schools located in the Northeastern United States utilized a factorial randomized trial with a four-arm design (Phipatanakul et al., 2021). This study examined treatment with and without air cleaners with HEPA filters and with and without school-wide integrated pest management (IPM). The median $PM_{2.5}$ classroom exposure at prior to the intervention starting was 5.5 $\mu g/m^3$ in the group with HEPA filtration and no IPM and 6.1 $\mu g/m^3$ with control filtration. After the intervention, the median $PM_{2.5}$ in classroom exposures were 3.1$\mu g/m^3$ and 5.3 $\mu g/m^3$ for HEPA and control filtration, respectively. These PM levels are closer to those measured in the current study and the control classrooms were 70% higher than HEPA treatment classrooms, similar to what we observed (65%). This study did not find classroom HEPA filters to significantly reduce symptom-days with asthma. During the 2-week period, the mean was 1.6 symptom-days with asthma after use of HEPA filter purifiers in the classrooms vs 1.8 symptom-days after use of sham HEPA filter purifiers across the school year (incidence rate ratio, 1.47 [95% CI, 0.79-2.75]), which was not statistically significant. Phipatanakul et al. (2021) focused their study on reducing pest allergens as a strategy for improving asthma symptoms and did not assess classroom level attendance.

A third study also examined urban elementary schools from the Northeastern United States from 2013 to 2014, using a pilot randomized controlled trial (Jhun et al., 201). Treatment classrooms received HEPA filtration while control classrooms had the filters replaced by a sound device to mimic the noise from the air filtration. Prior to randomization, baseline mean classroom levels of $PM_{2.5}$ were 6.3 $\mu g/m^3$ with no statistically significant differences between the control and treatment classrooms. In the control group, mean $PM_{2.5}$ concentrations decreased from 6.4 $\mu g/m^3$ at baseline to 4.8 $\mu g/m^3$ and 5.0 $\mu g/m^3$ at the first and second follow-up visits, respectively. In the treatment group, mean $PM_{2.5}$ concentrations decreased from 6.2 $\mu g/m^3$ at baseline to 2.4 $\mu g/m^3$ and 2.6 $\mu g/m^3$ at the first and second follow-up visits, respectively. The intervention group had greater reductions in $PM_{2.5}$ levels compared to the control group, corresponding to a 49% and 42% reduction, respectively. This is similar to the reduction of 39.6% observed in the current study, even though the classroom $PM_{2.5}$ levels we observed were much lower. Like the previous results, portable HEPA filter air cleaners were effective in improving short-term air quality in classroom environments. It is unclear whether the classrooms in any of the three previous air cleaner studies had pre-existing HVAC filtration.

There are several strengths of this study, most notably the rigorous study design. Classrooms were randomized into intervention groups using a crossover randomized controlled trial during the two consecutive school years (2022-23, 2023-24). In this design, each classroom received the intervention, but during different school years. In August 2023, classrooms switched intervention groups so that classrooms with non-HEPA filters in 2022-23 had HEPA filters in academic year 2023-24 and vice versa. This design helps protect against any potential lack of balance in unmeasured confounders across the HEPA treatment and non-HEPA control groups, by allowing investigators to examine and compare the intervention effect across both phases. This design also allows comparisons to be made for control versus intervention groups at the same time, and across multiple seasons. The interclass correlation coefficient (ICC) for school in the $PM_{2.5}$ linear mixed effects model was low (0.15), supporting the assumption of approximate independence assumption of the t-tests, and indicating variation in $PM_{2.5}$ concentrations across classrooms within each school, compared to differences across schools.

Another strength was the large number of classrooms in the attendance data analysis. The 639 classroom-year attendance records available across the 17 schools and two years of the study provided sufficient data to assess whether there were improvements in attendance due to additional HEPA filtration in classrooms. Attendance data from 2021-22 was also collected to provide a baseline in case there were differences across schools. Although we did not observe a meaningful effect of the HEPA filter intervention on classroom attendance, this is not because of a lack of power. Based on informal conversations with some teachers, students often attended school even when ill. Unfortunately, schools did not have nurse/clinic data available by classroom to allow for more sensitive analyses of student wellbeing.

Compliance limits the effectiveness of the air cleaners. Since the current study used intention-to-treat analysis, its treatment effect estimates are more conservative (i.e., likely to be underestimated if there is imperfect compliance with treatment assignments, such as teachers installing their own HEPA filters in non-HEPA air purifiers). Although it was noted that nearly all of the air cleaners remained powered on with the correct assigned filters in place when the filters were replaced, continuous operation of the units throughout the entire year was not monitored, making ITT analysis the most appropriate choice. However, heterogeneity of results is more likely from mixing non-compliant and compliant data into the final analysis. Another limitation of the study was the low recruitment of parents in the symptom survey due to restricted contact by LAUSD. When the project was started, LAUSD leadership was very supportive, but changes in staff resulted in limited engagement from principals to reach out to parents. Ultimately, the symptom data analysis was underpowered and showed no statistically significant differences between intervention groups.

5.0 Summary and Conclusions

The overall goal of this project was to assess the benefits associated with HEPA air filtration in elementary school classrooms. UC Irvine worked with LAUSD Office of Environmental Health

& Safety to identify seventeen elementary schools located in South Los Angeles County, near the Port of Los Angeles, major highways, industries, and oil refineries. In the first year, the project provided air cleaners (n=435) in those schools' classrooms where students spent the majority of their time. Classrooms were randomized into intervention group using a crossover randomized controlled trial during the two consecutive school years (2022-23, 2023-24). In August 2023, classrooms switched intervention groups so that classrooms with non-HEPA filters in 2022-23 had HEPA filters in academic year 2023-24 and vice versa. This design helps protect against any potential lack of balance in unmeasured confounders across the HEPA treatment and non-HEPA control groups and allows comparisons to be made for control versus intervention groups at the same time, and across multiple seasons. Air quality sensors that measure real-time $PM_{2.5}$ concentrations were also installed at each intervention school, both indoors and outdoors, to monitor air quality.

Classroom PM concentrations were compared for 186 study classroom by intervention group over the two academic school years. Data for 639 classroom-years of attendance records were compared across the intervention and non-intervention groups during the same time period. In addition, UC Irvine recruited 20 parents of asthmatic students from the participating schools to longitudinally assess asthma and respiratory symptoms. Of note, each classroom also had an existing HVAC system maintained by LAUSD that used minimum efficiency reporting value (MERV) 13 filters since the COVID-19 pandemic. Furthermore, ambient air quality during the study time period was generally good, with no wildfire smoke events.

The study findings support the use of portable air cleaners with HEPA filters in classrooms to reduce PM. Few studies have examined HEPA filtration in a classroom environment, and this is one of the first studies since the COVID-19 pandemic to assess PM exposure in the classroom. Using a well powered block randomized crossover trial, we showed that adding portable HEPA air cleaners to classrooms that already had HVAC systems with MERV 13 air filters resulted in lower measurable PM concentrations and lower ratios of indoor to outdoor $PM_{2.5}$ compared to control classrooms with non-HEPA filters. This demonstrates that further improvements in classroom air quality, especially in environmentally burdened communities, can be achieved with additional filtration. However, the study did not find evidence that these improvements in air quality were sufficient for measurable attendance and health benefits. Among children with asthma, the use of classroom HEPA filters did not significantly reduce symptoms. Although the analysis was limited by the small numbers of participants, differences in health symptoms may be difficult to detect given the already low levels of $PM_{2.5}$ in classrooms from using the HVAC systems with MERV 13 filters and the generally good outdoor air quality at the schools during these two years.

6.0 Recommendations

This project would not have been possible without the support and collaboration of Carlos Torres, Director, Office of Environmental Health & Safety (OEHS), and Dennis Bradburn, Regional Facilities Director, Maintenance & Operations (M&O) Region South. They and their staff worked closely with UC Irvine researchers to place and maintain the 435 air cleaners throughout 17 elementary schools over two years. The project results suggest that the portable air cleaners reduce PM levels in classrooms, even with existing MERV 13 filters in their HVAC systems. While this study did not include a cost benefit analysis, it may be more financially feasible for LAUSD to operate portable air cleaners in all classrooms in the future if continuing with MERV13 filters in the HVAC system is not an option. Future research may include a cost-benefit analysis. Furthermore, the current study did not observe data during wildfire events so unfortunately cannot provide any recommendations for how effective additional air filtration would be during extreme air pollution days. However, LAUSD should consider having HEPA filtration available as a precaution. While the LAUSD OEHS and M&O staff were consistent with their support of the project, there was turnover in the School Operations Office (SOO) and a change in the Administrator of Operations (AOO) overseeing the schools in the study. The lack of engagement by the AOO and school principals limited the recruitment of parents and reduced the impact of the project's third objective to assess student asthma symptoms. With the air cleaners already in the classrooms, there was little incentive for the new AOO or principals to put in much effort in reaching out to parents. It is recommended that for any future projects with school districts, CARB also work with the SOO to get project support.

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Appendix A. Summary of articles from literature review

Author(s)/Date	Research Question(s)/ Hypotheses	Methodology	Analysis & Results	Conclusions	Implications for Future Research
Phipatanakul et al. (2021)	Does use of a school-wide integrated pest management (IPM) program or HEPA filter purifiers in the classrooms reduce asthma symptoms in students with active asthma?	Randomized clinical trial at 41 urban elementary schools. HEPA vs sham filters. Measure the # of symptom-days with asthma during a 2-week period. Assessed every 2 months during the 10 months after randomization	2 week period: the mean was 1.6 symptom-days with asthma after use of HEPA in the classrooms vs. 1.8 symptom-days after use of sham HEPA across the school year	HEPA filter purifiers did not significantly reduce symptom-days with asthma.	May need to consider allergen levels, particle exposures, and asthma symptoms at baseline
James et al. (2019)	Is HEPA filtration, in comparison to placebo-control, associated with improved asthma control and quality of life measures in children?	Double-blind, placebo-controlled crossover design with 43 children with asthma. A HEPA filter or 'dummy' placebo was placed in participant homes for 4-weeks followed by a one-month washout period before switching over to other treatment arm.	In participants with poorly controlled asthma and lower quality of life at baseline, asthma control (ACQ) and quality of life (AQLQ) scores were significantly improved following HEPA treatment	HEPA filtration is associated with improved clinical outcomes and quality of life measures in children with uncontrolled asthma.	Future larger parallel placebo-controlled trials in uncontrolled asthmatic participants will be needed to confirm these results.
Riederer et al. (2021)	What is the effectiveness of the HEPA cleaners at reducing indoor levels of endotoxin in settled dust, and PM10 and PM10-2.5 concentrations?	Randomized trial of HEPA air cleaners in homes of children. All 71 families received asthma education; intervention families received 2 HEPA cleaners (child's bedroom, living room). 14-day integrated samples of endotoxins in settled dust and PM10 and PM 10-2.5 in the air of the children's bedrooms at baseline and one-year follow-up.	HEPA families had 46% lower PM10 on average than control families at follow-up	HEPA cleaners can effectively reduce by approximately half PM10 and PM10-2.5 in the bedrooms of children with asthma	Need to evaluate effect of HEPA cleaners on airborne endotoxin in homes.
Riederer et al. (2020)	What is the effectiveness of the HEPA cleaners at reducing indoor levels of NH3 and PM2.5 concentrations?	Randomized trial of HEPA air cleaners on reducing indoor PM2.5 and NH3 in homes of children. All 71 families received asthma education; intervention families received 2 HEPA cleaners (child's bedroom, living room). 14-day integrated samples of endotoxins in settled dust and PM10 and PM 10-2.5 in the air of the children's bedrooms at baseline and one-year follow-up.	HEPA cleaners effectively reduced Pm2.5 levels in the child's bedroom and living room by 60% and 42% respectively, compared to control. Reductions in NH3 were not observed.	When combined with asthma education, source control, and adequate ventilation, portable HEPA cleaners may be part of an effective overall strategy to reduce pediatric asthma morbidity.	On understanding and enhancing compliance with air cleaner use alongside asthma education and medication access.
Jia-Ying et al. (2021)	Is there a long-term efficacy of HEPA air purifiers for reducing PM and HDM allergens and to evaluate the effect of air purifier use on subjects' asthma symptoms?	38 subjects were under two groups: (1) treatment using HEPA air purifiers for 6 consecutive months, and (2) control who did not use the air filters. PM data and dust samples were collected before treatment and each month after. Subjects completed a questionnaire for the Asthma Control Test (ACT) or Childhood Asthma Control Test (C-ACT).	After using air purifier, the concentrations of house dust mite (HDM) allergens in the dust samples decreased. PM indoor/outdoor values significantly decreased. ACT and C-ACT scores in the treatment group maintained a steady significant upward trend.	HEPA air purifiers can decrease indoor HDM allergen and PM levels and improve the quality of life for allergic asthma patients.	Include a placebo to further explore the effectiveness of air purifiers as a method of environmental intervention.
Drieling et al. (2022)	What is the effectiveness of HEPA air cleaners on asthma morbidity among a cohort of rural Latino children?	75 children with poorly controlled asthma and living in non-smoking homes were randomly assigned to asthma education alone or along with HEPA air cleaners placed in their sleeping area and home living room.	The Asthma Control Tests (ACT) did not differ between groups.	Primary analysis did not show statistical significance but many outcomes were subjective (self-report) in this unblinded study	Child asthma health where traditional asthmagens (traffic, tobacco smoke) are not prominent factors but larger studies with more statistical power and blinded designs

Lanphear et al. (2011)	Children with asthma who were exposed to second hand smoke (SHS) would benefit by using air cleaners.	Double-blind, randomized trial with 225 children who had physician-diagnosed asthma and were exposed to at least or equal to 5 cigarettes per day. Children were randomly assigned to received 2 active or inactive HEPA air cleaners.	During the trial, there were 42 fewer unscheduled asthma visits among children in the intervention group compared to the control group.	There is promise for using HEPA air cleaners as part of a multi-faceted strategy to reduce asthma morbidity.	Finding ways to reduce the sources of exposure further
Gent et al. (2022)	Does reduced exposure to household NO2 or fine particles result in reduced symptoms among children with persistent asthma?	Triple-crossover randomized controlled intervention with 126 children with persistent asthma living in homes with gas stoves and levels of NO2 15 ppb or greater. 5-week treatment (1) NO2 reduction: sham particle filtration and real NO2 scrubbing; (2) particle filtration: HEPA filter and sham NO2 scrubbing; (3) Control: sham particle filtration and sham No2 scrubbing. 5-week treatment periods using a three-arm crossover design.	NO2 was lower for NO2-reducing compared to control or particle-reducing treatments. NO2-reducing treatment did not reduce asthma morbidity compared to control. There were 1.8 fewer symptom days out of 14 in the particle-reducing treatment compared to control	Remains unknown if using an air cleaner alone can achieve levels of NO2 reduction large enough to observe reductions in asthma symptoms.	Interventions that targets and removes the source. An intervention targeting exposures to NO2 and fine particles is complicated; future research is warranted.
Vesper et al. (2022)	Students with higher mold exposures in their classrooms than homes, the use of HEPA filtration interventions in their classrooms might improve their forced expiratory volume at 1 sec (FEV1%) test results compared to students who received Sham intervention treatments.	Pre-intervention at the beginning of the school year and follow-up at the end of the intervention dust samples were collected. Environmental Relative Moldiness Index (ERMI) values and the Group 1 & 2 mold levels were quantified. Each student's lung function was evaluated by spirometry testing (FEV1%) before and at the end of the intervention.	After the HEPA intervention, the average Group 1 and ERMI values were significantly lowered, and the average FEV1% test results significantly increased by an average of 4.22% for students in HEPA compared to Sham classrooms.	HEPA intervention in classrooms reduced Group 1 and ERMI values, relating to improvements in the students' FEV1% test results.	

Appendix B. HIFIVE CARES study information sheet

University of California, Irvine

Study Information Sheet

HIFIVE CARES –

Child's Asthma and Respiratory Events and Symptoms

Lead Researcher
Verónica Vieira
Environmental and Occupational Health
Phone: (949) 824-7017
Email: vvieira@uci.edu

- Please read the information below and ask questions about anything that you do not understand. The lead researcher listed above will be available to answer your questions.

- You are being asked to participate in a research study. Participation in this study is voluntary. You may choose to skip a question or a study procedure. You may refuse to participate or discontinue your involvement at any time without penalty or loss of benefits. You are free to withdraw from this study at any time. **If you decide to withdraw from this study, you should notify the research team immediately**.

- We would you to participate in a study to learn more about the possible health benefits directly associated improved air filtration in elementary school classrooms. The initial questionnaire will last about 20-30 minutes. The weekly surveys will take between 5 and 10 minutes per week to complete for a total of 12 weeks. The total time of participation should not exceed 2.5 hours.

- Possible risks/discomforts associated with the study are a potential for a breach of confidentiality; and fatigue in completing the surveys.

- There are no direct benefits from participation in the study. However, you are contributing to the gain in knowledge about a topic that is not well understood.

- We appreciate your participation in this study. You will receive $20 for every week of the study you complete. Total compensation for participation in this study is $240. You will receive a gift card at the end of the study. If you decide to withdraw from the study or are withdrawn by the research team, you will receive compensation for the weeks that you have completed.

- All research data collected will be stored securely and confidentially stored on a secure network in an encrypted file. Access to the network is password protected.

- Researchers will use your information to conduct this study. Information gathered during this research study will only be used for this study. They will not be shared with other researchers.

- Questions? If you have any comments, concerns, or questions regarding this study please contact the researcher listed at the top of this form.

- If you have questions or concerns about your rights as a research participant, you can contact the UCI Institutional Review Board by phone, (949) 824-6662, by e-mail at IRB@research.uci.edu or at **160 Aldrich Hall, Irvine, CA 92697-7600**.

  What is an IRB? An Institutional Review Board (IRB) is a committee made up of scientists and non-scientists. The IRB's role is to protect the rights and welfare of human subjects involved in research. The IRB also assures that the research complies with applicable regulations, laws, and institutional policies.

Appendix C. HIFIVE CARES initial questionnaire

Initial Questionnaire for HIFIVE CARES - Child's Asthma and Respiratory Events and Symptoms
Thank you for participating in our research study! This questionnaire is broken up into multiple sections. We would appreciate it if you would answer, to the best of your ability, as many questions as possible. We will first ask you questions about yourself and then we will ask questions about your child and home.

This questionnaire will take approximately 15 to 20 minutes to complete. All answers will be kept confidential. If you are unsure about a question and would like us to contact you afterwards, please make a note in the comments box with the question number at the end of the survey. Thank you.

A: Demographic Background Information

For questions, A1 – A4, we will be asking a few background questions.

A.1) What race do you consider yourself?

- o American Indian/Alaska Native
- o Asian
- o Pacific Islander
- o Black/African-American
- o White/Caucasian
- o Mixed race
- o Other______________________________
- o Prefer not to answer

A.2) Do you consider yourself Latina(o)/Hispanic?

- o Yes
- o No
- o Prefer not to answer

A.3) What type of health insurance do you currently have?

- o Private Insurance (for example: Kaiser Permanente, Anthem, Blue Cross Blue Shield, Health Net)
- o Medi-Cal
- o MediCare
- o No insurance
- o Other ___________________________

A.4) What is the highest level of education that you have completed?

- o Less than high school graduate
- o High school graduate/ GED (or equivalent)
- o Some college (1-4 years, no degree)
- o Associate's degree (including occupational or academic degrees)
- o Bachelor's degree (BA, BS, AB, etc.)
- o Master's degree (MA, MS, MENG, MSW, etc.)
- o Professional school degree (MD, DDC, JD, etc.)
- o Doctorate degree (PhD, EdD, etc.)

A.5) Which of these comes closest to your household income for the last calendar year before taxes?

- Less than $23,000
- Between $23,000 and $46,000
- Between $46,000 and $70,000
- More than $70,000
- Don’t know
- Prefer not to answer

B: Your Child’s Background

The next section asks questions about your child.

B.1) What year was your child born in?

- 2010
- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019
- Other ______

B.2) What grade is your child currently in?

- Pre-school
- Kindergarten
- 1st grade
- 2nd grade
- 3rd grade
- 4th grade
- 5th grade
- Other __________

B.3) What is the name of the school your child attends? _________________________

B.4) What is the name of your child’s teacher? _________________________

B.5) Is this your first child?

- Yes [Skip to Question B.7]
- No

B.6) How many siblings does your child have?

- None
- 1
- 2
- 3 or more

B.7) What was your child's assigned sex at birth?

- Female
- Male
- Don't know
- Prefer not to answer

B.8) What race do you consider your child to be?

- American Indian/Alaska Native
- Asian
- Pacific Islander
- Black/African-American
- White/Caucasian
- Mixed race
- Other______________________________
- Prefer not to answer

B.9) Do you consider your child to be Latina(o)/ Hispanic?

- Yes
- No
- Prefer not to answer

B.10) Is your child currently covered by any health insurance?

- Yes
- No
- Don't know

B.11) Was your child born early (before your child's due date)?

- Yes
- No
- Don't know/ remember

B.12) If your child was born early, how early was your child?

- My child was not born before the due date
- Less than 1 week before your child's due date
- 1 week to 3 weeks before your child's due date
- More than 3 weeks and less than 8 weeks before your child's due date
- 8 weeks or more before your child's due date
- Don't know/ remember

B.13) What was your child's birth weight in pounds?

- Less than 5 lbs.
- Between 5 lbs. and less than 5 lbs. 8 oz.
- Between 5 lbs. 8 oz. and less than 7 lbs.
- Between 7 lbs. to less than 8 lbs., 8 oz.
- Between 8 lbs. 8 oz. to less than 10 lbs.
- 10 lbs. or more
- Don't know/ remember

B.14) In general, would you say your child's health is …

- Excellent
- Very good
- Good
- Fair
- Poor

B.15) Have you ever been told by a doctor or other health care provider that your child has or has had any of the following medical conditions?

- Allergies ____Yes ____No ____Don't Know
- Atopic dermatitis/eczema ____Yes ____No ____Don't Know
- Asthma ____Yes ____No ____Don't Know
- Chronic stuffy/ runny nose (rhinitis/sinusitis) ____Yes ____No ____Don't Know
- Otitis media ____Yes ____No ____Don't Know
- Pneumonia ____Yes ____No ____Don't Know
- Varicella (chicken pox) ____Yes ____No ____Don't Know
- Respiratory syncytial virus infection (RSV) ____Yes ____No ____Don't Know
- COVID ____Yes ____No ____Don't Know
- Diabetes ____Yes ____No ____Don't Know
- Celiac disease ____Yes ____No ____Don't Know
- Crohn's disease ____Yes ____No ____Don't Know
- Lupus ____Yes ____No ____Don't Know
- Attention deficit hyperactivity disorder (ADHD) or attention deficit disorder (ADD) ____Yes ____No ____Don't Know

C: Home Environment

Questions C1-C20 are about your child's home environment.

C.1) Do you and your child live in the same home as each other?

- Yes
- No

C.2) Is there carpeting or a rug in the room your child spends most of their time in?

- Yes
- No [Skip to C.5]

C.3) What type of carpeting is in the room your child spends most of their time in?

- Low pile (examples: Berber carpet, Saxony carpet)
- Medium pile
- High pile (frieze carpet, shag carpet)
- None
- Don’t know

C.4) On average, how often is the carpet vacuumed in the room that your child spends most of their day in?

- Never
- Less than once a month
- 1-2 times a month
- 1-2 times a week
- 3-4 times a week
- 5 more times a week

C.5) Does your vacuum have a HEPA filter?

- Yes
- No
- Don’t know

C.6) Does anyone smoke cigarettes inside your child’s home?

- Yes, frequently (more than 1-2 days a week)
- Yes, occasionally (less than 1-2 days a week)
- Not anymore, but someone used to smoke there
- No
- Don’t know

C.7) On average, in your child’s home, how often is food cooked using a stovetop?

- Never
- Less than once a month
- 1-2 times a month
- 1-2 times a week
- 3-4 times a week
- 5 more times a week

C.8) Please indicate below what type of stovetop is in your child’s home:

- Gas
- Electric
- None
- Don’t know

C.9) On average, in your child’s home, is an exhaust fan used in the kitchen when cooking with the stove?

- Yes
- No

- Don’t know

C.10) Is a wood-burning fireplace used in your child’s home?

- Yes
- No
- Don’t know

C.11) Are scented candles or incense burned in your child’s home?

- Yes
- No
- Don’t know

C.12) Are there any pets in your child’s home?

- Yes
- No [skip to C.14]
- Don’t know [skip to C.14]

C.13) If yes, what type of pets are in your child’s home? [check all that apply]

- Dog
- Cat
- Bird
- Fish
- Other furry pet (for example hamster, gerbil, or rabbit)
- Other _________

C.14) How many bedrooms are there in your child’s home?

- None
- 1
- 2
- 3
- 4 or more

C.15) How many people live in your child’s home (including your child)?

- 2
- 3
- 4
- 5
- 6 or more

C.16) Is an air cleaner used in your child’s home?

- Yes
- No
- Don’t know

C.17) Is an HVAC system used in your child's home?

- Yes
- No [Skip to C.20]
- Don't know

C.18) If yes, how often is the HVAC system used?

- ______________

C.19) If yes, what filter is in the HVAC system?

- ______________

Thank you for completing this questionnaire!

Appendix D. HIFIVE CARES weekly survey

Weekly Survey of HIFIVE CARES - Child's Asthma and Respiratory Events and Symptoms
Thank you for your continued participation in our research study! The following questions are about your child's asthma and respiratory symptoms in the past 7 days.

1) The following list pertains to your child's asthma. Please select if your child experienced any of these events because of asthma. Mark all that apply. If your child did not experience any, select none.
   - ☐ Wheezing
   - ☐ Tightness in the chest
   - ☐ Shortness of breath
   - ☐ Cough
   - ☐ Disturbed sleep
   - ☐ Had to slow down or discontinue play activities
   - ☐ Missed school
   - ☐ Other _____________
   - ☐ None

2) For each asthma-related event selected, how many days did your child experience that event in the past 7 days? Please select a number between 1 and 7. Selecting 1 means that your child experienced that event one day in the last week and 7 means your child experienced the event every day.
[Selected symptoms will propagate – example below]

	1 days	2 days	3 days	4 days	5 days	6 days	7 days
Wheezing	O	O	O	O	O	O	O
Disturbed Sleep	O	O	O	O	O	O	O

3) From the following list, please select which respiratory symptoms unrelated to asthma your child had in the past 7 days. Mark all that apply. If your child did not have any symptoms, select none.
   - ☐ Fever
   - ☐ Stuffy/blocked nose
   - ☐ Runny nose
   - ☐ Itchy nose
   - ☐ Cough
   - ☐ Wheezy or whistling breathing
   - ☐ Shortness of breath
   - ☐ Itchy runny eyes
   - ☐ Common cold
   - ☐ Other _____________
   - ☐ None

4) For each symptom selected, how many days did your child have the symptom in the past 7 days? Please select a number between 1 and 7. Selecting 1 means that your child had the symptom for one day in the last week and 7 means your child had the symptom every day.
[Selected symptoms will propagate – example below]

1 days	2 days	3 days	4 days	5 days	6 days	7 days

Cough	O	O	O	O	O	O	O
Common cold	O	O	O	O	O	O	O

5) In the last 7 days, did your child miss school because of any respiratory illness or medical condition unrelated to asthma, such as the cold, flu, or COVID?

- Yes
- No

6) If yes, what illness or medical condition? ____________

7) In the last 7 days, has your child visited a doctor or healthcare provider because of asthma or any respiratory symptoms?

- Yes
- No

Appendix E. Teachers survey

Air Cleaner Survey

Please complete this survey based on the school year that just ended.

* Indicates required question

1. Did you ever lower the air cleaner filter speed from medium to low during the school day?

   Mark only one oval.

   - Yes
   - No

2. If yes, how often was it on low speed?

   Mark only one oval.

   - 1-2 weekdays
   - 3-5 weekdays
   - Always on low speed
   - Never on low speed
   - Other: ______________________

3. Did you ever turn off or unplug the air cleaner during a school day?

   Mark only one oval.

   - Yes
   - No

4. If yes, how often was it turned off/unplugged?

Mark only one oval.

- ( ) 1-2 weekdays
- ( ) 3-5 weekdays
- ( ) Always turned off
- ( ) Never turned off
- ( ) Other: ____________________

5. Did you, on average, keep objects on top of the air cleaner?

Mark only one oval.

- ( ) Yes
- ( ) No

6. On average, how many of the side vents were blocked?

Mark only one oval.

- ( ) 0
- ( ) 1
- ( ) 2
- ( ) 3

7. Do you ever keep a classroom door or window open during the school day?

Mark only one oval.

- ( ) Yes
- ( ) No

8. If yes, how often was a door or window open?

Mark only one oval.

- ( ) 1-2 weekdays
- ( ) 3-5 weekdays
- ( ) Always closed
- ( ) Never closed
- ( ) Other: ____________________

9. Did you ever turn off the HVAC (heating, ventilation, air conditioning) system?

Mark only one oval.

- ( ) Yes
- ( ) No

10. If yes, how often did you turn off the HVAC system?

Mark only one oval.

- ( ) 1-2 weekdays
- ( ) 3-5 weekdays
- ( ) Always turned off
- ( ) Never turned off
- ( ) Other: ____________________

11. What is the name of your Elementary School? This is required in order to receive your gift card. *

____

12. What is the room number of your classroom? This is required in order to receive your gift card. *

____

13. Do you have any comments you would like to share about the air cleaner?

____
____
____
____
____

14. If you would like a $40 Amazon Gift Card, please provide an email address to receive it:

____

Appendix F. Average monthly and annual PM_{10} (µg/m³) and PM_1 (µg/m³) during the 2022-2023 and 2023-24 school years by treatment group

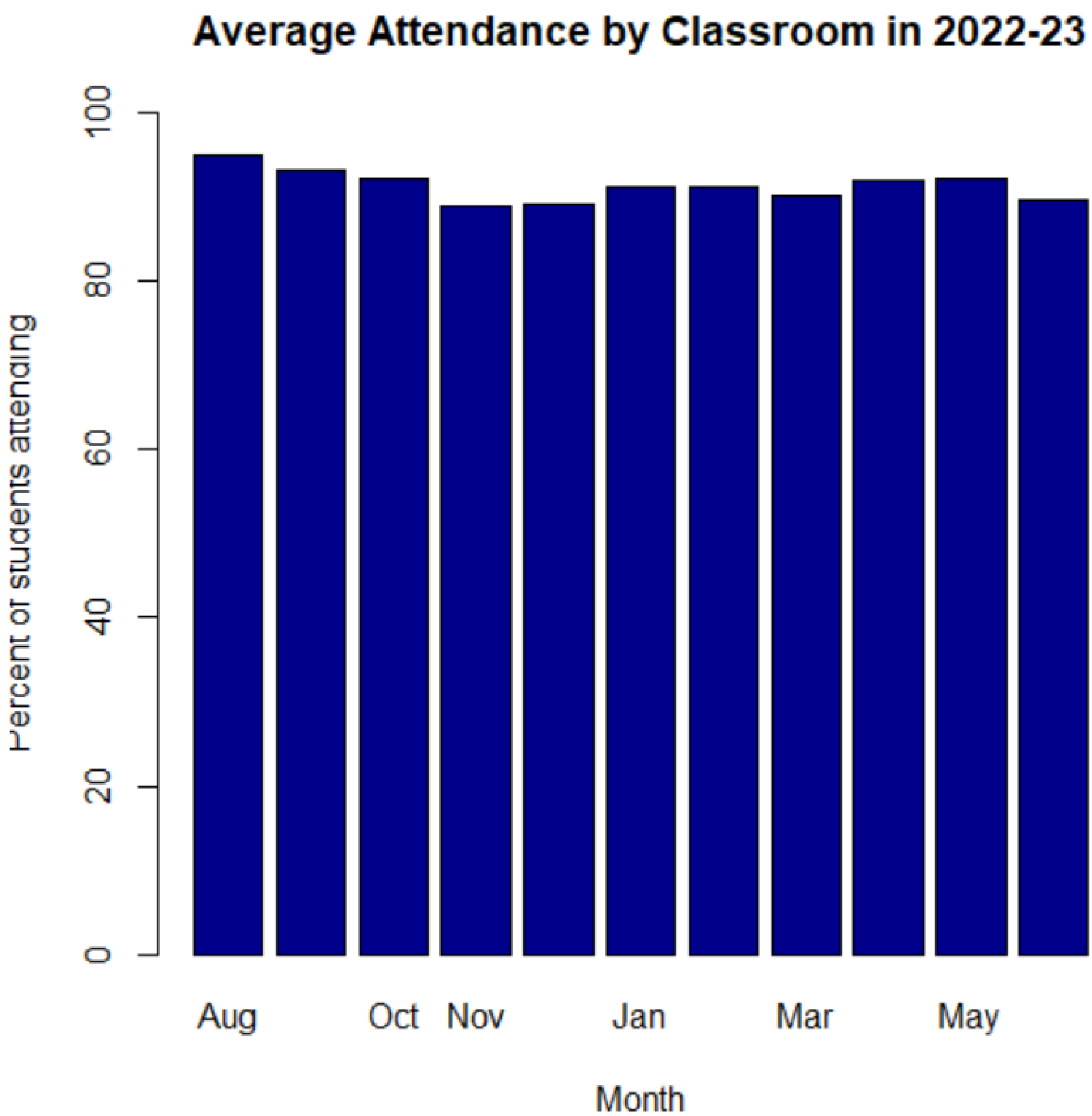
	PM_{10} (µg/m³)			PM_1 (µg/m³)		
	HEPA	**Non-HEPA**		**HEPA**	**Non-HEPA**	
Month	**Mean (SD)**	**Mean (SD)**	**p-value**	**Mean (SD)**	**Mean (SD)**	**p-value**
Jul 2022	1.3 (1.3)	1.8 (4.2)	0.293	1.2 (1.2)	1.7 (3.9)	0.256
Aug 2022	1.0 (0.8)	1.9 (2.9)	0.004	0.8 (0.8)	1.7 (2.6)	0.003
Sep 2022	0.9 (0.9)	1.9 (2.7)	0.002	0.7 (0.8)	1.6 (2.4)	0.001
Oct 2022	1.3 (1.0)	2.4 (3.5)	0.007	1.0 (0.9)	2.1 (3.2)	0.004
Nov 2022	0.9 (0.9)	1.4 (1.1)	0.001	0.7 (0.8)	1.2 (1.0)	0.001
Dec 2022	1.3 (1.2)	1.8 (1.2)	0.008	1.2 (1.2)	1.7 (1.1)	0.008
Jan 2023	1.0 (1.6)	1.4 (1.7)	0.161	0.8 (1.5)	1.1 (1.4)	0.149
Feb 2023	0.7 (0.6)	1.2 (1.8)	0.014	0.5 (0.5)	0.9 (1.6)	0.018
Mar 2023	0.8 (2.4)	1.0 (3.6)	0.604	0.4 (0.9)	0.8 (3.3)	0.294
Apr 2023	1.2 (1.2)	2.0 (2.4)	0.010	0.9 (0.9)	1.7 (2.2)	0.003
May 2023	0.9 (1.2)	1.2 (1.6)	0.165	0.6 (0.8)	1.0 (1.6)	0.071
Jun 2023	0.7 (0.8)	1.0 (0.8)	0.017	0.5 (0.7)	0.8 (0.8)	0.009
Sep 2022 - May 2023	1.0 (1.3)	1.6 (2.4)	< 0.001	0.8 (1.0)	1.4 (2.2)	< 0.001
Aug 2023	1.5 (1.1)	2.4 (1.8)	< 0.001	1.3 (1.1)	2.1 (1.7)	0.001
Sep 2023	1.6 (1.5)	2.7 (2.0)	< 0.001	1.5 (1.3)	2.5 (1.9)	< 0.001
Oct 2023	1.5 (1.5)	2.1 (1.6)	0.017	1.2 (1.1)	1.8 (1.4)	0.003
Nov 2023	1.2 (1.5)	1.8 (1.4)	0.034	0.9 (1.0)	1.5 (1.3)	0.003
Dec 2023	1.7 (1.8)	2.7 (2.0)	0.003	1.3 (1.3)	2.2 (1.7)	< 0.001
Jan 2024	1.8 (1.3)	3.2 (2.3)	< 0.001	1.5 (1.1)	2.7 (1.8)	< 0.001
Feb 2024	1.1 (0.9)	2.1 (1.9)	< 0.001	0.8 (0.6)	1.5 (1.2)	< 0.001
Mar 2024	1.2 (0.9)	2.0 (1.7)	< 0.001	0.8 (0.5)	1.4 (0.9)	< 0.001
Apr 2024	1.7 (1.4)	3.4 (2.4)	< 0.001	1.0 (0.8)	2.2 (1.1)	< 0.001
May 2024	2.1 (1.6)	4.3 (3.0)	< 0.001	1.3 (1.0)	2.8 (1.3)	< 0.001
Jun 2024	2.2 (1.7)	4.2 (2.3)	< 0.001	1.7 (1.3)	3.4 (1.5)	< 0.001
Sep 2023 - May 2024	1.7 (1.4)	3.2 (2.5)	< 0.001	1.2 (1.0)	2.3 (1.5)	< 0.001

Appendix G. Comparison of classroom and PurpleAir outdoor $PM_{2.5}$ (µg/m³) annual averages and ratio of indoor to outdoor air by treatment group for all schools, 2022-23 and 2023-24						
		$PM_{2.5}$ (µg/m³)			I/O ratio	
		HEPA	Non-HEPA	Outdoor	HEPA	Non-HEPA
School Year	**School ID**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Average Ratio (95% CI)**	**Average Ratio (95% CI)**
2022-2023	**A***	1.7 (1.5)	2.2 (1.1)	10.1 (2.1)	0.2 (0.1, 0.2)	0.2 (0.2, 0.3)
	B	0.5 (0.3)	0.5 (0.4)	8.5 (1.3)	0.1 (0.0, 0.1)	0.1 (0.1, 0.1)
	C	0.4 (0.2)	2.0 (1.6)	8.0 (1.2)	0.0 (0.0, 0.1)	0.2 (0.2, 0.3)
	D*	0.9 (0.9)	1.4 (1.0)	9.9 (2.3)	0.1 (0.1, 0.1)	0.1 (0.1, 0.2)
	E	0.5 (0.3)	1.0 (0.5)	9.1 (1.4)	0.1 (0.0, 0.1)	0.1 (0.1, 0.1)
	F	0.8 (0.2)	0.9 (0.5)	9.4 (1.6)	0.1 (0.1, 0.1)	0.1 (0.0, 0.2)
	G	0.6 (0.1)	0.6 (0.3)	7.2 (1.3)	0.1 (0.1, 0.1)	0.1 (0.0, 0.1)
	H	0.6 (0.9)	1.4 (0.9)	8.3 (1.3)	0.1 (0.0, 0.1)	0.2 (0.1, 0.2)
	I	0.8 (0.5)	1.3 (0.9)	10.8 (1.6)	0.1 (0.1, 0.1)	0.1 (0.1, 0.2)
	J	1.4 (1.4)	1.7 (1.1)	7.4 (1.1)	0.2 (0.1, 0.2)	0.2 (0.2, 0.3)
	K	0.9 (0.6)	1.4 (0.4)	8.8 (1.4)	0.1 (0.1, 0.1)	0.2 (0.1, 0.2)
	L	0.8 (0.4)	1.1 (1.1)	7.9 (1.3)	0.1 (0.1, 0.1)	0.1 (0.1, 0.2)
	M	1.7 (0.7)	2.2 (0.6)	9.6 (1.6)	0.2 (0.2, 0.2)	0.2 (0.2, 0.2)
	N	0.6 (0.4)	0.8 (0.3)	7.1 (1.3)	0.1 (0.1, 0.1)	0.2 (0.1, 0.1)
	O	0.8 (0.9)	3.3 (5.5)	6.9 (1.1)	0.1 (0.1, 0.2)	0.5 (0.3, 0.6)
	P	0.4 (0.4)	1.4 (0.5)	9.4 (1.3)	0.0 (0.0, 0.1)	0.2 (0.1, 0.2)
	Q	0.8 (0.1)	1.0 (0.6)	9.0 (1.7)	0.1 (0.1, 0.1)	0.1 (0.1, 0.2)

2023-2024	**B**	1.2 (0.5)	4.3 (4.8)	8.4 (1.2)	0.1 (0.1, 0.2)	0.5 (0.2, 0.8)
	C	1.0 (0.6)	3.0 (2.3)	7.7 (0.9)	0.1 (0.1, 0.2)	0.4 (0.2, 0.5)
	D*	2.0 (1.1)	2.2 (1.1)	10.4 (6.0)	0.2 (0.2, 0.2)	0.2 (0.2, 0.3)
	E	0.9 (0.4)	1.1 (0.5)	9.6 (0.9)	0.1 (0.1, 0.1)	0.1 (0.1, 0.1)
	F	0.7 (0.7)	3.0 (1.5)	8.9 (1.3)	0.1 (0.1, 0.1)	0.3 (0.3, 0.4)
	G	1.2 (0.5)	2.0 (0.8)	7.3 (1.0)	0.2 (0.1, 0.2)	0.3 (0.2, 0.4)
	H	0.9 (0.8)	2.4 (0.7)	8.3 (0.8)	0.1 (0.1, 0.2)	0.3 (0.3, 0.3)
	I**	1.0 (1.0)	3.0 (1.8)	10.4 (6.0)	0.1 (0.1, 0.1)	0.3 (0.2, 0.3)
	J	1.9 (1.6)	3.2 (2.1)	7.3 (0.8)	0.3 (0.2, 0.4)	0.4 (0.3, 0.5)
	K	1.7 (1.4)	3.8 (1.9)	8.4 (1.2)	0.2 (0.1, 0.3)	0.4 (0.3, 0.5)
	L	0.9 (0.7)	1.4 (0.3)	8.1 (0.9)	0.1 (0.1, 0.1)	0.2 (0.2, 0.2)
	M	1.8 (0.4)	3.4 (0.6)	9.0 (1.2)	0.2 (0.2, 0.2)	0.4 (0.3, 0.4)
	N	1.0 (0.5)	1.8 (0.8)	7.0 (0.8)	0.1 (0.1, 0.2)	0.2 (0.2, 0.3)
	O	1.9 (0.8)	2.1 (1.2)	6.9 (0.8)	0.3 (0.2, 0.3)	0.3 (0.3, 0.4)
	Q	1.1 (0.3)	2.4 (1.0)	10.1 (2.8)	0.1 (0.1, 0.1)	0.3 (0.2, 0.3)

*** Missing PurpleAir data because no power outlet available.**
**** PurpleAir was unplugged July 2023 so data from the closest from closest Clarity Node (School D) was used for 2023-24 outdoor air analyses.**

Appendix H. Average monthly classroom attendance for school year 2022-23



Appendix I. Average monthly classroom attendance for school year 2023-24