Evaluating the effectiveness of air purification in the real-world living and learning environment for pupils: a randomized, double-blind, crossover intervention trial [A1]

Abstract[A2]

Air purifiers have ~~s~~ been ~~proved~~ proven to ~~be an effective method to reduce~~reduce $PM_{2.5}$ exposure indoors or simply personal PM2.5 effectively ~~personal $PM_{2.5}$ exposure~~.. To investigate the purification effects of air purifier intervention in ~~living rooms~~homes and classrooms and ~~explore~~ to evaluate~~the~~ potential ~~determinants~~ factors determining (determinants)~~of~~ personal $PM_{2.5}$, we conducted a double-blind trial study ~~–~~with 79 elementary school students in Mengzhou, China. Real-time $PM_{2.5}$ samplers ~~were used to~~ monitored $PM_{2.5}$ concentrations in ~~different~~ various microenvironments, and students'~~'~~ and their parents' data was gathered using structured questionnaires ~~were used to collected basic information of students and their parents~~. ~~T~~Further, we employed time-weighted method ~~was used to calculate personal $PM_{2.5}$~~ to determine personal $PM_{2.5}$ exposure and used the mixed-effects model ~~was used~~ to explore the potential determinants of personal $PM_{2.5}$ exposure. The results showed that~~The~~ the purification efficiencies of air purifiers in the living room and classroom were 32.5%~54.8% and 81.6%~92.4%, ~~in living room and classroom,~~ respectively. ~~Compared to the control groups, the personal $PM_{2.5}$ concentrations in the intervention groups reduced significantly~~The personal $PM_{2.5}$ concentrations in the intervention groups were significantly reduced compared to the control groups. The ~~results of the mixed-effects model~~mixed-effects model results revealed that ~~A~~air purifiers, ambient $PM_{2.5}$, indoor humidity, indoor temperature, ~~difference in temperatur~~temperature difference, and environmental tobacco smoke exposure were significant determinants of personal

$PM_{2.5}$ exposure. The living room intervention and classroom intervention responded to 42.31% [95% confidence interval (95% CI): 45.28%, 39.17%] and 21.34% (95% CI: 24.89%, 17.61%) reductions in personal $PM_{2.5}$, respectively. This ~~e intervention~~ study demonstrated ~~the benefits of~~ multi-scenario interventions among students ~~and the intervention strategy to~~the control $PM_{2.5}$ pollution to decide on the best intervention strategy to overcome the harmful effects of indoor PM2.5 pollution.

Introduction[A3]

Fine particulate matter ($PM_{2.5}$, particulate with aerodynamic diameter ≤ 2.5 μm) pollution has become a ~~widely~~ major~~concerned~~ environmental concern~~issue~~[1, 2] because it has been linked to many ~~and was associated with many~~ adverse health outcomes.[3-7] Many studies have shown that exposure to elevated levels of $PM_{2.5}$ ~~exposure l~~lead to an increased risk of respiratory and cardiovascular diseases.[8, 9] Based on the data from ~~T~~the 2019 Global Burden of Disease (GBD), ~~has reported that~~ ambient levels of $PM_{2.5}$ are responsible for roughly ~~cause approximately~~ 4.1 million deaths per year.[10] Children are particularly susceptible to the effects of air pollution because of their developing immune systems, larger lung surface areas, and 50% higher air consumption per kilogram of body weight than adults.[11] Modern epidemiological studies have shown that elevated levels of $PM_{2.5}$,[12-15] accelerate children's cardiopulmonary dysfunction and cognitive decline. A~~ are accelerated by elevated levels of~~ ~~$PM_{2.5}$,~~~~[12-15]~~ ~~and~~ s a result, health professionals and governments are showing ~~there is widespread~~~~hug~~massive interest in better understanding the effects of air pollution on children.

Considering the adverse health effects of $PM_{2.5}$, identifying ~~the identification of~~ determinants and estimating~~ion of~~ $PM_{2.5}$ exposure concentrations at the personal level ~~are~~ is ~~of vital importance~~crucial to ~~the prevention and control of~~prevent and control $PM_{2.5}$ pollution. ~~A series of~~Several studies have ~~reported~~ found that concentrations of personal $PM_{2.5}$ exposure are influenced by ~~depend on a combinations of~~ various factors, including outdoor $PM_{2.5}$ concentrations, participants' activity patterns, and their behavioral ~~indicators~~markers, ~~such~~ including~~as~~ cooking, environmental tobacco exposure (ETS), use of air purifiers, and frequency of cleaning.[16,-17,18,-19] ~~I~~Individual residential building ~~characteristics~~ specifications have also been reported to be ~~were~~

~~also~~ associated with personal $PM_{2.5}$ exposure as well as ~~. B~~building age and distance from main roads ~~affect personal exposure~~.[20] ~~In addition~~Additionally, many studies have ~~also pointed out~~highlighted how ~~that~~ meteorological conditions play a significant role in ~~are also important~~ determiningants ~~of~~ $PM_{2.5}$ exposure.[21-23]

Reducing personal exposure to $PM_{2.5}$ can be achieved by reducing indoor sources of pollution and outdoor pollution source exposure. Such interventions include ~~(e.g.,~~ no smoking or burning incense indoors, reducing fuel burning for heating and cooking, wearing masks~~)~~,[24, 25] reducing the ~~amount~~ concentration of outdoor $PM_{2.5}$ into the indoor environment, ~~(~~e.g., by using ~~better~~ better-sealed rooms ~~)~~[26] and removing indoor $PM_{2.5}$ by ~~(e.g.,~~using air purifiers, and~~,~~ plants~~)~~.[27-30] Nowadays, proactive measures to reduce personal exposure have become the ~~predominant~~ effective ~~approaches~~ methods to ~~reduce~~ reduce personal $PM_{2.5}$, including ~~, including:~~ air purifiers,[29] fresh air systems[31], and N95 masks[32].

Since ~~Most people spend~~ 90% of a typical person's life is spent ~~their lives~~ indoors,[33] and there is a need for effective and efficient ~~-~~interventions to ~~reduce~~ lower the levels of~~indoor~~ indoor $PM_{2.5}$ exposure~~.~~. One of the latest technological interventions is ~~concentrations are particularly important to reduce personal exposure.~~ High-efficiency particulate air (HEPA) purifiers. HEPA is ~~with~~ an integrated multi-layer filter-based equipment that captures the airborne particles ~~,~~when the air flows through it, using the processes of ~~the filter, airborne particles are captured by~~ impaction, interception, and diffusion, and finally achieving a micron-level filtration effect.[34] Reducing indoor $PM_{2.5}$ levels by using HEPA air purifiers has been shown to be very effective.~~The use of HEPA air purifiers has been proven to be an effective method to reduce the concentrations of indoor $PM_{2.5}$.~~[27, 28] In Shanghai, ~~A two-week crossover intervention of~~ 43 asthmatic children participated in a cross-intervention study over two weeks, leading to a ~~with asthma conducted in Shanghai showed a~~ significant reduction of $PM_{2.5}$ concentrations (from 34 ± 17 to 10 ± 8 μg/m^3) in living rooms after using portable air cleaners with HEPA ~~and the indoor $PM_{2.5}$ concentrations reduced from 34 ± 17 to 10 ± 8 μg/m^3~~.[35] In another ~~A t~~two-week randomized crossover intervention study in Beijing ~~of~~ involving 35 non-smoking elderly people ~~in Beijing found~~showed significant reductions of residential $PM_{2.5}$, from 60 ± 45 to 24 ± 15 μg/m^3.[36]

Information about the ~~The~~ determinants of personal $PM_{2.5}$ exposure and the effects of air purifier interventions on personal $PM_{2.5}$ exposure in children are scar~~ce~~cely reported in the literature, especially studies that provide the best strategy option using ~~for~~ multi-scenario purifier intervention-based analysis~~s~~. In this context, this study aimed to ~~Therefore, we~~ conduct ~~conducted~~ a double-blind experimental design of 79 children (aged ~~d from~~ 9 to 13 years) ~~in~~ from Mengzhou City, Henan Province, China, ~~which is~~ an area with severe air pollution, to explore the determinants of personal $PM_{2.5}$ and the assess the effects of air purifier interventions on personal $PM_{2.5}$ levels. Further, we also ~~assess~~evaluated the effectiveness of air purifier interventions in various microenvironments[A4]. ~~Moreover, we further investigated the effectiveness of air purifier interventions in different microenvironments.~~

Method[A5]

2.1 Study population and design

To achieve the objectives of this study, aA double-blind crossover study was conducted from April 2021 to December 2021 in a primary school in Mengzhou city, Henan province, China, which is an area with serious severe air pollution, participated in a double-blind crossover study conducted from April 2021 to December 2021. We chose recruited a total of 79 students from 2 fourth-grade classes based on with the the followingfollowing - specific criteria: r:1) Living esiding in Mengzhou city for more than 2 two years and having no intention plans to leave during theto move within the study period, and ; 2) Wwillingness, having no plans to leave during the study period, and being willing to participate in the study. We installed aAir purifiers were installed iin the classrooms and children's living rooms. In addition, we also installed a fresh air handling unit in each classroom to reduce the concentrations of indoor CO_2. Two types of air purifiers were used in this double-blind experiment, The real and sham purifiers - - were used throughout the experimental period, "real" (with HEPA for $PM_{2.5}$) and "sham" (without HEPA for $PM_{2.5}$). Figure S1 depicts the study''s timeline, which entails four visits between 11 April and 15 December 2021. The study details are displayed in Figure S1, including 4 visits from April 11, 2021 to December 15, 2021. We placed installed real purifiers in the classrooms and living rooms of students in Class 1 and sham purifiers in Class 2, respectively, from April 1111 April, 2021 to July 11 July, 2021. After a washout period, we exchanged switched the intervention class and conducted the intervention study from September 2828 September, 2021 to December 1515 December, 2021. Only the second, third, and fourth visits in July, September, and December were included since the Because of the absence of exposure data was unavailable for earlier months, we only included the second, third and fourth visits

~~conducted in July, September and December in this study, respectively~~. A total of 205 person~~-~~ visits were included in the analyses. During each visit, the 24-h activity patterns of the students were also collected for 4-5 days before the health examination. The operation time of air purifiers in different microenvironments is shown in Table S1. The ~~study protocol was approved by the Ethical Review Committee~~Ethical Review Committee approved the study protocol of this research conducted by ~~of~~ the National Institute of Environmental Health, Chinese Centers for Disease Control and Prevention (No.202031). All participants and their guardians provided written informed consent~~s~~.

2.2 $PM_{2.5}$ monitoring

For both indoors and outdoors, the concentration of $PM_{2.5}$ was measured using ~~During the study periods, we used~~ online Hike industrial air quality monitors (B3-L2, Beijing Hike Intelligent Technology Development Co., Ltd., BJ, China) ~~to measure the $PM_{2.5}$ concentrations in indoor and outdoor environments~~.[37] All Hike devices were brought into the lab to take parallel samples before the PM2.5 measurements began, and the ones with an RSD of less than 10% were chosen ~~to be used~~ for subsequent $PM_{2.5}$ monitoring. Every 5 minutes, readings were taken for temperature, humidity, and PM2.5 concentrations. To calibrate the online instruments, we monitored the $PM_{2.5}$ concentrations in the living rooms of 12 selected participants using ~~Before the start of the $PM_{2.5}$ measurements, all Hike devices were placed in the laboratory for parallel samples, and the instruments with relative standard deviation (RSD) of less than 10% were selected for subsequent $PM_{2.5}$ monitoring. The $PM_{2.5}$ concentrations, temperature and relative humidity were measured every 5 minutes. In parallel with the Hike B3 monitors, we used the~~ MicroPEM (RTI International, Research Triangle Park, NC, USA) ~~to monitor the~~. ~~$PM_{2.5}$ concentrations of 12 selected participants' living rooms at~~ during each study period to calibrate the online instruments. A 40 cm plastic sampling tube with a flow rate of 500 mL/min was attached to the MicroPEM sampler, and a 25 mm Teflon filter (Pall Corporation, Mexico, USA) was used to collect $PM_{2.5}$ particles. During each sampling phase, we additionally collected data from In addition, two field blankblank field filtersWe collected data from two blank field filters during each sampling phase. were also collected during each sampling period. After sampling, all filters were stored at −20 °C to reduce the loss of organic compounds. Before and after sampling, eEach filter was weighed twice in a chamber with using a microbalance (UMX2 Mettler, Switzerland), microbalance (in a chamber (25 ± 1°C, 50 ± 5%), once before and once after the sampling process. The average of the two weights was utilized as the weight of the filter, and . Tthe difference between the two weights of each filter did not exceed 0.004 mg, and the average of the two weights was used as the weight of the filter.

2.3 Covariates

In each visit, face-to-face questionnaires interviews were conducted to collect the basic essential personal characteristics of students, including age, gender, and levels of physical activity. All students' Information on daily time-activity dairies (TADs) were analyzed using of all students was obtained by 24-hour questionnaires. Electronic parent questionnaires also collected information about the specifications of The houses, i characteristics specifications and living environments, including building area, floor level, distance from the home to the nearest main road, exposure to ETS exposure, cleaning activitiesroutines, cooking activities, and time of opening windows., were also collected by electronic parents' questionnaires. The questionnaires were double-checked daily by professional staff to ensure the quality of the data collected.To ensure the accuracy of the collected data, the trained personnel checked the questionnaires every day.

2.4 Statistical analysis

We merged data about the environment with survey responses and carried outal data and information from questionnaires by the time. dDescriptive statistics were performed for all participants' characteristics and time-activity patterns. Spearman's correlation analysis was used to The explore the relationship between MicroPEM and Hike samplers was analyzed statistically using Spearman's correlation. To ensure the accuracy of $PM_{2.5}$ exposure, we used $PM_{2.5}$ from MicroPEM samplers to construct a linear regression model to calibrate the online Hike B3 monitors. The method for this calibration methodology can be, and more detailed correction information could be f found elsewhere[38-40]. The calibrated $PM_{2.5}$ data were used for further analysis. Based onWe calculated $PM_{2.5}$ concentration in various microenvironments and participants' TADs, we determined a 24-h time-weighted average concentration of $PM_{2.5}$ as personal daily exposure., based on $PM_{2.5}$ concentrations in different microenvironments and participants' TADs. Spearman correlation analysis was used to describe the relationship between personal and ambient $PM_{2.5}$, as well as the correlation between all the variables (, including ambient $PM_{2.5}$, indoor temperature, outdoor temperature, the difference in temperature, indoor humidity, outdoor humidity, the difference in humidity, use of air conditioning, time of opening windows, burn incense, use of mosquito coil, use of air freshener, use of insecticide, ETS exposure, cooking, use of range hood, cleaning, air purifier intervention, time spent outdoors, and survey period). [A6]We applied a two-stage data analysis strategy using a linear mixed-effects (LME) model to investigate the influencing factors of personal $PM_{2.5}$ exposure.e by using linear mixed-effects (LME) model. Due to skewed distributions of Ppersonal $PM_{2.5}$ and ambient $PM_{2.5}$ concentrations, a were log- transformation was performeded due to their skewed

~~distributions~~. The participant's identity number was introduced into the LME model as random effects intercept~~s~~ to account for correlations between repeated measures within participants. First, the relationship between ~~trivariate models were used to assess the relationship between~~ personal $PM_{2.5}$ exposure and potential influencing factors was evaluated using trivariate models~~, with the and the potential variables~~. The potential variables were ~~were~~ incorporated one at a time as the fixed-effect terms (~~with the in the model, exception of~~except ~~for~~ ambient $PM_{2.5}$ measurements and air purifier intervention). Second, to further explore the factors that influence personal $PM_{2.5}$~~we~~exposure, we developed ~~constructed a~~ a comprehensive ~~full~~ model that incorporated all ~~including all~~ variables ~~identified~~ revealed by backward stepwise regression~~, to investigate the determinants for personal $PM_{2.5}$.~~ The model's partial R-squared (R^2_β) ~~of the models~~ and Marginal R-squared (R^2_M) were also calculated. The contribution of each determinant in the full model was calculated by $R^2_\beta / R^2_M \times 100\%$.

Finally, we estimated individual $PM_{2.5}$ concentrations in four scenarios, including the use of an air purifier, on four days (28 June 2021, 29 June 2021, 9 December 2021, and 10 December 2021). (intervention group I: classroom and living room interventions, intervention group II: living room intervention only, intervention group III: classroom intervention only, control group: without intervention). ~~Finally, we selected 4~~ four ~~days (28 June 2021, 29 June 2021, 9 December 2021, and 10 December 2021) with air purifier intervention and calculated personal $PM_{2.5}$ levels in four scenarios (intervention group I: classroom and living room interventions, intervention group II: living room intervention only, intervention group III: classroom intervention only, control group: without intervention).~~ T~~We also used t~~he LME model was also used to analyze the effects of interventions in ~~different~~ various microenvironments on personal $PM_{2.5}$ levels, with~~and~~ the air purifier intervention ~~was~~ set as two binary variables: classroom air purifier intervention and living room air purifier intervention. All analyses were conducted with R (version 3.5.1) with the “lme4” and “lmerTest” packages[A7].

Results[A8]

3.1 Characteristics of participants

The individual and household characteristics of all participants are shown in Table 1. ~~Mean~~ The mean age of 79 participants ~~were~~ was 11.3 years, and about half (38) ~~of participants~~ were boys. The average of the houses was 142.7 ± 68.6 square meters. ~~A total of~~ 35.4% of the participants lived on ~~6~~ six or higher floors, and 50.6% ~~of the participants~~ lived in houses within 100 m ~~from~~ of the main road. Table S2 provides ~~The~~ the descriptive statistics on ~~of~~ time- participants' activity patterns ~~of participants~~, house characteristics, and living environments. ~~are presented in Table S2.~~ According to the questionnaires in 205 person-visits, 72.7% of data reported cleaning at home~~.~~ , and ~~About~~ ETS impacted around 22% of data~~22% of data were exposed to ETS~~. Indoor cooking (reported by 94.6% of respondents) and range hood use (reported by ~~and~~ 88.8% of respondents) were relatively common ~~of data reported indoor cooking and use of range hood, respectively~~. On ~~The average~~ average, ~~hours of~~ participants spent 16.40 h in ~~in~~ houses, 1.39 hours outdoors, and 6.21 hours in~~in the~~ the classroom ~~per da~~daily ~~were 16.40, 1.39, and 6.21 h, respectively~~.

3.2 $PM_{2.5}$ concentrations in various microenvironments

As shown in Table S3, we used the calibration equation to adjust Hike $PM_{2.5}$ measurements, and the coefficient of determination (R^2) was 0.91 in 10-fold ~~cross~~ cross-validation. ~~As shown in Figure S2, the~~On average, ~~ratios of~~ raw Hike to MicroPEM measurements were 1.13 ± 0.40, while ~~and~~ calibrated Hike to MicroPEM measurements were ~~1.13 ± 0.40 and~~ 1.03 ± 0.37, as shown in Figure S2~~respectively~~.

Figure S3 showed the ~~The~~ $PM_{2.5}$ concentrations in various microenvironments during the study period ~~are presented in Figure S3~~. Class 1 and ~~Class~~ 2 individuals saw significantly varying $PM_{2.5}$ concentrations across environments~~The $PM_{2.5}$~~

concentrations of participants between Class 1 and Class 2 were significantly different in different environments during the study period. In July, the $PM_{2.5}$ levels of participants in Class 2 in living rooms and classrooms were higher than that of participants in Class 1. In September and December, the levels of $PM_{2.5}$ of participants in Class 2 in living rooms and classrooms were lower than that of participants in Class 1. The class 1 participants' December living rooms had PM2.5 concentrations of 120.9 ± 52.0 μg/m^3, while their July classrooms had concentrations of The highest and lowest concentration of $PM_{2.5}$, with the levels of 120.9 ± 52.0 μg/m^3 and 2.0 ± 3.9 μg/m^3, were observed in Class 1 participant's living rooms in December and classrooms in July, respectively.. In living rooms, air purifiers had a 32.5%~54.8% purification efficiency, and in the classroom, 81.6%~92.4%C compared to the control group, the purification efficiencies of air purifiers were 32.5%~54.8% and 81.6%~92.4% in living rooms and classrooms, respectively.

3.3 Personal $PM_{2.5}$ exposure

The descriptive statistics of the personal $PM_{2.5}$ exposure of participants in the three survey periods are presented in Table 2. Personal $PM_{2.5}$ concentrations were significantly reduced in the intervention group compared to were significantly lower than those in the control group. In the intervention groups, The personal $PM_{2.5}$ concentrations dropped in the intervention groups were reduced by 63.2% in July and 38.5% in July and December, respectively. For example, pPersonal $PM_{2.5}$ levels of Class 1 participants– in July ranged from 1.7 to 25.3 μg/m^3, with an average of 12.1 μg/m^3, which was lower than that of Class 2 participants (control group). As shown in Figure S4, there waFigure S4 shows a strong correlation between personal and ambient $PM_{2.5}$, with Spearman's r of 0.86 and 0.77 in the control and intervention groups, respectively.

The contributions of $PM_{2.5}$ in different microenvironments to personal $PM_{2.5}$ are illustrated in Figure S5. Moreover, about 60% of the total personal $PM_{2.5}$ in both control and intervention groups came from their ~~$PM_{2.5}$ in l~~living rooms~~ accounted for more than 60% of the total personal $PM_{2.5}$, both in the control and intervention groups~~. The contributions of $PM_{2.5}$ in classrooms and outdoors to personal $PM_{2.5}$ were 21.7% ± 8.2% and 9.8% ± 3.7%, respectively.

3.4 Determinants of personal $PM_{2.5}$ exposure

~~The correlations between all variables are shown in~~ Figure S6 shows the correlations of all the variables. ~~There was a strong positive correlation between a~~Ambient $PM_{2.5}$, temperature difference~~ in temperature,~~ and the survey period were positively correlated (Spearman's *r*: 0.74). There were negative correlations between ~~O~~outdoor~~ temperature~~ and indoor temperature ~~showed negative correlations~~ with ambient $PM_{2.5}$ and survey period (Spearman's *r*: −0.56~−0.93). In addition, there was a positive correlation between cooking and using~~a positive correlation between cooking and use of~~ a range hood (Spearman's $r = 0.50$).

~~To explore the determinants of personal $PM_{2.5}$, t~~Trivariate models that account for both ~~adjusted for~~ ambient $PM_{2.5}$ concentration and air purifier intervention were developed so that the factors that determine personal $PM_{2.5}$ exposure can be investigated.~~.~~ Table 3 shows the ~~The results of the~~ relationship between personal $PM_{2.5}$ and all potential variables.~~ are presented in Table 3.~~ Personal $PM_{2.5}$ concentrations were significantly correlated with ~~I~~indoor humidity, outdoor humidity, ETS exposure, cooking, use of range hood, time spent outdoors, and survey period~~ were significantly associated with personal $PM_{2.5}$ concentrations~~. The concentration of $PM_{2.5}$ was elevated both by exposure to ETS and by time spent outdoors. Personal exposure was inversely related to ~~ETS exposure and time spent outdoors increased $PM_{2.5}$ levels. I~~indoor humidity, outdoor humidity, cooking, and use of range hood were negatively associated with personal exposure.

3.5 Multivariate LME model for personal $PM_{2.5}$ exposure[A9]

Table 4 shows the summary of results from The results in the final multivariate LME model for personal $PM_{2.5}$ exposure. are summarized in Table 4. UThe final LME model, which was developed using a stepwise method, incorporated ambient $PM_{2.5}$, purifier use, interior humidity, indoor temperature, the change in temperature, and ETS exposure, and it explained 73.0% of the variance in personal $PM_{2.5}$. The contribution of sing stepwise approach, ambient $PM_{2.5}$, use of purifier, indoor humidity, indoor temperature, difference in temperature, and ETS exposure were included in the final LME model, which explained 73.0% of the variance of personal $PM_{2.5}$. Among all these variables, ambambient $PM_{2.5}$ to personal was found to be the most important determinants of personal $PM_{2.5}$, was 85.76%, thus becoming the most critical variable among all the determinants with contributions of 83.76%,, followed by the effect of air purifier intervention (45.83%). Personal exposure was higher when ambient $PM_{2.5}$ levels were higher and lower when indoor humidity, indoor temperature, and temperature differential levels were higher. Increased ambient $PM_{2.5}$ was associated with increased personal exposure, whereas indoor humidity, indoor temperature, and the difference in temperature were associated with decreased personal exposure. The air purifier intervention can can reduce personal $PM_{2.5}$ by 55.51% (95% confidence interval (95% CI): 58.67%, 52.11%), whereas . ETS exposure led to a 15.03% (95% CI: 4.35%, 26.80%) increase of in personal $PM_{2.5}$.

3.5 Evaluation of purification effects in various microenvironments

Figure 1 shows the The concentrations of personal $PM_{2.5}$ in concentrations observed in various various air purifier intervention scenarios are presented in Figure

~~1~~. The participants with living room and classroom interventions had the lowest $PM_{2.5}$ levels, with an average of 45.9 ± 44.4 μg/m^3, followed by participants with living room intervention (62.0 ± 51.5 μg/m^3), participants with classroom intervention (73.4 ± 54.1 μg/m^3), and participants with no intervention (89.0 ± 61.4 μg/m^3). Table 5 shows the personal $PM_{2.5}$ ~~The results of~~ effects of air purification interventions in various microenvironments ~~on personal $PM_{2.5}$ are shown in Table 5~~. We found that living room interventions result in a 42.31% (95% CI: 45.28%, 39.17%) and classroom interventions result in a 21.34% (95% CI: 24.89%, 17.61%) reductions in personal $PM_{2.5}$ after ~~After~~ controlling for ambient $PM_{2.5}$, indoor humidity, indoor temperature, the difference in temperature, and ETS exposure in the LME model.~~, we found that living room intervention and classroom intervention respond to 42.31% (95% CI: 45.28%, 39.17%) and 21.34% (95% CI: 24.89%, 17.61%) reductions in personal $PM_{2.5}$, respectively.~~

Discussion[A10]

To the best of our knowledge, this is the first study~~To the best of our knowledge,~~ that has assessed the ~~this is the first study to evaluate the~~ effects of air purifier interventions on personal $PM_{2.5}$ exposure in various microenvironments~~ on personal $PM_{2.5}$ exposure~~. Results from this showed that ~~In this study, we found~~participants in the intervention group had significantly lower~~ that~~ personal $PM_{2.5}$ concentrations ~~in intervention group were significantly lower~~ than that in the control group. Further, we observed that personal $PM_{2.5}$ was affected significantly by various determinants such as ~~Apart from air purifier intervention, we also found that~~ ambient $PM_{2.5}$, indoor humidity, indoor temperature, the difference in temperature, and ETS~~ exposure were important determinants for personal $PM_{2.5}$~~. This study has crucial implications for policymakers seeking to establish successful interventions, as it suggested that interventions implemented in the home can have a greater impact on reducing individual $PM_{2.5}$ concentrations than those implemented in the classroom.~~Personal $PM_{2.5}$ concentrations were reduced more by living room interventions than by classroom interventions, and this finding has important implications for policymakers to consider when developing effective interventions.~~

~~In our study, we~~Our study found that air purifier interventions significantly reduced $PM_{2.5}$ concentrations in participants' living rooms and classrooms. ~~A report by the~~ U.S. EPA report on ~~residential~~ home air purifiers ~~found~~ indicated that PM exposure could be cut by at least 50% when using ~~high~~ high-efficiency portable air purifiers~~ can reduce PM exposure by at least 50%~~.[41] Indoor PM levels were studied by Park et al. ~~investigated indoor PM levels~~ in 102 classrooms ~~in~~ across 34 Korean elementary schools in ~~Korea during~~ 2017-2018, and they ~~found~~ observed that indoor PM levels in classrooms with air purifiers were ~~approximately~~ about 35% lower than those in classrooms without air purifiers.[42] Barn et al. investigated indoor $PM_{2.5}$ levels in 32 homes and found that air purifiers with HEPA were 55% effective in winter (19 homes) and 65% effective in summer (13 homes).[43] Similarly, Cox et al. ~~found~~ observed that HEPA air purifiers significantly ~~with HEPA~~ reduced indoor $PM_{2.5}$ exposure ~~significantly~~ in 41 homes, compared with 38 control homes.[44] Our study also showed that over the same intervention periods, ~~We also found that~~ classrooms with the fresh air handling unit installed had reduced ~~had lower~~ $PM_{2.5}$ concentrations compared to ~~than~~ living ~~rooms during the same intervention periods, which could be attributed to the addition of the fresh air handling unit to the classrooms~~ rooms. ~~Several~~ Various previous studies have demonstrated that fresh air handling units could increase indoor/outdoor gas exchange rates and replenish indoor air quality.[45, 46]

As reported by various other studies, we ~~We f~~found that personal $PM_{2.5}$ exposure levels were significantly lower in the intervention group ~~were significantly lower~~ than ~~that~~ in the control group~~, which was consistent with previous studies~~.[47, 48] A randomized, double-blind, crossover study on outpatient cardiac rehabilitation patients (N=20) at Michigan Medicine found that using portable air purifiers at home significantly reduced 24-hr personal $PM_{2.5}$ exposures by 43.8% (−12.2 μg/m^3; 95% CI, −24.2 to −0.2).[47] Maestas et al. assessed the efficiency of two commercially available high-efficiency (HE: true-HEPA) and low-efficiency (LE: HEPA-type) air purifiers placed indoors to reduce personal $PM_{2.5}$ exposures for 40 participants. They ~~and f~~found that the concentrations of personal $PM_{2.5}$ were reduced by 53% and 31% with HE and LE filters, respectively, compared to the control scenario.[49] However, Zhan et al. monitored personal $PM_{2.5}$ concentrations in six residences in Beijing and found that the average personal ~~concentrations of~~ $PM_{2.5}$ concentrations were 67.8 and 51.1 μg/m^3 using true and sham purifiers, respectively.[50] Purification efficiencies were affected by~~Ind~~ indoor

$PM_{2.5}$ sources, ~~such as~~including wood burning and cleaning, traffic-related air pollution, and ETS exposure.~~, had an impact on purification efficiencies,~~ [51] ~~which affected personal $PM_{2.5}$ exposure .~~ In addition, ~~time~~ time-activity patterns are associated with personal $PM_{2.5}$ levels.[50, 52]

This study found that ~~A~~ambient $PM_{2.5}$ is the ~~was found to be the most~~ most important contributor to personal $PM_{2.5}$, accounting for 83.76% of ~~personal~~ exposure, and was ~~. This was~~ consistent with the findings of previous studies.[20, 53, 54] For example, Fang et al. ~~found~~ observed that an increase in 1 μg/m^3 of ambient $PM_{2.5}$ resulted in 1.07% (95% CI: 0.98%, 1.17%) increase in ~~were the strongest predictors of~~ personal $PM_{2.5}$~~; with each 1 μg/m^3 increase in ambient $PM_{2.5}$ triggered 1.07% (95% CI: 0.98%, 1.17%) increase in personal $PM_{2.5}$~~.[53] Possible explanations of this phenomenon include the ~~The~~ strong relationships between personal and ambient $PM_{2.5}$ in ~~other~~ various other Chinese cities[55-57] ~~might explain the reason~~. However, some ~~other~~ studies have revealed that ~~found that~~ exposure to ~~indoor~~ $PM_{2.5}$ is mainly a problem in homes~~dominated personal $PM_{2.5}$ exposure~~.[58, 59] In one of the studies conducted by Sarnat et al., it was observed that when the rate of air exchange between indoors and outdoors was low, the ~~discovered that indoor $PM_{2.5}$ sources contributed the most~~exposure to personal $PM_{2.5}$ was primarily governed by indoor sources~~exposure when the indoor-outdoor air exchange rate was low~~.[53] Besides ambient measurement, we found that meteorological conditions (e.g., indoor humidity, indoor temperature, and difference in temperature) significantly affected personal $PM_{2.5}$. Many studies reported that the ~~effects~~ influence of meteorology on $PM_{2.5}$ varies with geographic location and seasons~~d by region and time period~~.[56, 60, 61] The results of our investigation are ~~S~~similar to those of ~~our study,~~ Mu et al. who found a negative correlation between ambient relative humidity and personal $PM_{2.5}$.[52] High relative humidity (R~~R~~H) can promote the hygroscopic growth of the particulate matter, resulting in increased PM diameter and accelerated PM settlement.[62] ThisFurther, our– study observed a negative correlation between indoor temperature and personal $PM_{2.5}$, which was contrary to the findings of Meng et al. [63], which can perhaps be explained on the basis of . We thought it might be people's varying lifestylesbecause of the different individual lifestyles.

Our findings that ETS exposure was a critical contributor to personal $PM_{2.5}$ and increased personal $PM_{2.5}$ are consistent with those of earlier studiesSimilar to previous research,[64-66] we found that ETS exposure was a crucial contributor to personal $PM_{2.5}$ and increased personal $PM_{2.5}$ exposure. According to the finding of Semple et al.,; found that –$PM_{2.5}$ concentrations in Scottish smoking homes houses werewere approximately almost ten times higher than that in non-smoking homes.[65] Although previous studies have found that cooking at home has been identified as anis an important indoor source of $PM_{2.5}$,[67, 68] indoors, we did not observe find anythe correlation between the two cooking and $PM_{2.5}$ exposure in this study. This may be because a positive correlation was found between cooking and the use of range hoods, and these hoods may mitigate the increase in $PM^{2.5}$ that occurs as a result of cooking. Further, these results may also be partly explained by the fact that weThis could be because there was a positive correlation between cooking and use of range hoods and the use of range hood might offset the increase in $PM_{2.5}$ caused by cooking. In addition, we conducted the air purifier interventions and $PM_{2.5}$ monitoring in student's students' living rooms, which may be partly explain the findings.

Comparing our results to those of prior studies, Wwe found that the removal efficiencies of air purifiers on $PM_{2.5}$ in classrooms were higher and than that in previous publications, rangededing from 35% to 49%.[42, 69, 70] This study found that the fresh air handling unit and air purifiers in classrooms were successful in lowering $PM_{2.5}$

levels.~~The fresh air handling unit and air purifiers in classrooms were proved to be effective to reduce $PM_{2.5}$ concentrations in this study.~~ This study found that ~~T~~the efficiency of ~~purification efficiencies of a~~air purifiers in the living room ranged from ~~in this study (~~32.5%~~~~~ to 54.8%, which is in line with prior research ~~) were similar to previous studies~~ (43%~75%).[71, 72] In this study, we conducted the air purifier interventions in ~~student's~~ students' living rooms and classrooms, and the purification effects were ~~better~~ superior to those of studies using~~than that in~~ single scenario interventions.[47,–73] For example, a study by ~~For example,~~ Barkjohn et al., who conducted an air purifier intervention ~~study~~ experiment, in 7 living rooms in Beijing, China, ~~and~~ found that personal $PM_{2.5}$ exposure was –reduced by 28%.[73] However, the intervention effects in this study were relatively lower than ~~that~~ observed in a study carried out by ~~in~~ Chen et al.~~,'s study~~,[70] in which all participants were requested to stay in their dormitory room with the windows and doors closed throughout each intervention period. The intervention ~~We conducted the intervention~~ study carried out in this study was conducted in ~~the~~ an actual natural scenario without affecting the student's time-activity patterns and thus had ~~. The findings in this study had~~ a ~~strong~~ substantial practical value regarding policy and decision-making. We also discovered that purification in the living room contributed more to individual $PM_{2.5}$ than purification in the classroom, suggesting that household intervention is the best intervention strategy. ~~We also found that the contribution of purification in living room to personal $PM_{2.5}$ was higher than that in class room, indicating that household intervention is the optimal intervention measure.~~ In addition, considering the economic benefits, implementing purifier interventions in classrooms is an intelligent strategy when health-related policies and their impact on the country's GDP are also considered. ~~it is a very good measure to carry out purifier intervention in the classroom.~~

Our research has various advantages.There are several strengths in our study . First, this study was based on a double-blind crossover study design with multiple numerous follow-up visits, which allowed for increasing statistical power in the analyses and addressed many potential confounding effects by usingboosted statistical power in the analyses and addressed many potential confounding effects by utilizing the student's own measurements as controls. Second, we evaluated the –carried out ppurifier interventions in students' living rooms and classrooms, providing insights into the role of to better evaluatelocations in –purification efficiencies in different places, which has important guiding significance forto offer valuable guidance for decision decision-makers in carrying out interventions more effectively.s to carry out interventions more effectively.

It is essential to mention that our has some Some importantsignificant limitations. of our study should be noted. [A11]First, there may be inconsistencies between the calculated and actual personal $PM_{2.5}$ values because we used the time-activity patterns to determine personal $PM_{2.5}$ rather than actual monitored personal $PM_{2.5}$ concentrations. First, we calculated personal $PM_{2.5}$ using the time-activity patterns instead of actual monitored personal $PM_{2.5}$ concentrations, and there may be discrepancies between the calculated and actual personal $PM_{2.5}$ values. Second, all the participants in this study werewe only recruited primary school children as the participants in this study. Therefore, Oone should be cautious when exploring air purifier intervention strategies to with other populations. F, and further researches focusing on other population subgroups are is needed. Third, while our although our final models did account for explained 73.0% of the variation in personal $PM_{2.5}$, the remaining 27.0% may have been influenced by other, equally, or more could be influenced by other unaccounted

~~important~~relevant factors.

Conclusions

This study's main results indicated that ~~The major findings of this study confirmed that~~exposure to ambient $PM_{2.5}$ and the use of air purifiers are critical ~~intervention are important~~ factors in determining the concentration of ~~determinants of~~ personal $PM_{2.5}$. Air purifier interventions in different places may help lessen people's exposure to ~~could effectively reduce pepe~~rsonal $PM_{2.5}$ ~~exposures~~. Further, it was found that personal exposure to $PM_{2.5}$ among students in Mengzhou city, Henan province, China, was significantly affected ~~Aside from these two factors,~~by meteorological conditions and activity patterns such as ETS exposure. ~~were significant determinants of personal exposure to $PM_{2.5}$ among students in Mengzhou city, Henan province, China.~~ Our findings shall improve the ~~our~~ understanding of efficient strategies~~y~~ for air purifier interventions and are of great significance for ~~decision~~ decision-makers to consider when developing targeted intervention measures. Future studies are needed to confirm our findings in other populations.[A12]