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Research Article

Use of Portable Air Cleaners in Washington State Schools: A Qualitative Analysis Based on the Technology Acceptance Model

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ABSTRACT

BACKGROUND: The US government allocated over $2.5 billion in ''Elementary and Secondary School Emergency Relief (ESSER)'' funds to Washington State for COVID-19 response and ventilation improvements. Despite available funding, gaps persist in supporting schools to successfully use portable air cleaners (PACs). We evaluated PAC needs within King County, Washington and characterized factors influencing schools' purchase and use of PACs.

METHODS: Public Health—Seattle & King County (PHSKC) assessed school's ventilation systems and IAQ improvements through a survey (N = 17). Separately, semi-structured interviews (N = 13) based on the technology acceptance model (TAM) were conducted with school personnel. A thematic analysis using inductive and deductive coding was conducted and logistic regression models assessed the predictive capability of the TAM.

RESULTS: The PHSKC survey findings informed our recommendations. Positive attitudes, knowledge, and beliefs in ease of use and effectiveness of PACs were facilitators to PAC use. While barriers included a lack of training, education, and concerns about PAC maintenance and sustainability. TAM constructs of perceived usefulness (PU) and perceived ease of use (PEU) were predictive of having the intention to use PACs in schools.

CONCLUSIONS: There is a critical need for solutions to circumvent challenges to implementing PACs in schools. This characterization provides insight for promoting PAC use in IAQ-impacted schools.

Keywords: school health; indoor air quality; portable air cleaners; ventilation; filtration.

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Emerging studies suggest there is significant wildfire smoke infiltration into elementary and secondary school indoor air.[1] An estimated 7.4 million US children are affected annually by wildfire smoke, especially in the Southeast, Pacific Northwest, and California.[2] Wildfire smoke risk is predicted to increase in central Colorado, southeastern Idaho, southern Montana, and eastern Washington.[1] Given the adverse

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effects of wildfire smoke to children, developing and implementing interventions to reduce exposures, particularly for children in disadvantaged communities is vital.[3,4] The Washington State Department of Health (WA DOH) has recommended using portable air cleaners (PACs) with high efficiency particulate air (HEPA) filters to keep indoor air clean during wildfire events.[5]

PACs purchased and distributed for COVID-19 response strategies can be leveraged to reduce exposures to wildfire smoke in schools. This effort was promoted by the White House-led ''Clean Air Buildings Challenge.''[6] The program is a call to action and offers guidance for building owners and operators to reduce risks from airborne viruses and other indoor contaminants.[6,7] The Biden-Harris Administration and Congress allocated billions of dollars to improve indoor air quality (IAQ) in schools, public buildings, and other settings.[6] The ''American Rescue Plan Elementary and Secondary School Emergency Relief (ARP ESSER)'' fund includes $122 billion for schools.[6,8] To leverage this effort, it is necessary to go beyond funding PACs by supporting schools to maintain PACs obtained during the COVID-19 pandemic.

PACs have been widely used in recent years due to their effective removal of indoor air pollutants.[9] In developed countries, 10% to 30% of homes are have PACs for improving IAQ.[10] PACs with HEPA filters are safer and more effective in removing indoor air particles than electrostatic filter systems, ionizers, and ozone generators.[11] HEPA filters can remove at least 99.97% of dust, pollen, mold, bacteria, and any 0.3 μm sized airborne particles.[12] Particle removal efficiency in a given room depends on the flow through the filter, exchange rate between the room and outdoors, and particle size distribution.[13]

Alternate technologies to PACs with HEPA filtration are available but may produce harmful by-products.[14] Air cleaning technologies such as photocatalytic oxidation may generate by-products such as formaldehyde and acetaldehyde through chemical reactions.[15-17] In addition, plasma air cleaners, ionizers, and electrostatic precipitators (ESPs) may generate ozone[18-22] which is associated with adverse respiratory health effects.[23] A recent analysis aggregating $PM_{2.5}$ reduction statistics from 83 papers including 16 schools reported a mean 49% reduction using PACs of HEPA, non-HEPA, HEPA + ionizer, ESP, or unidentified technologies.[14]

Home-based studies demonstrated PACs with HEPA filters reduce fungal spores and pollen by 80%,[24] cigarette smoke particulate matter by 30% to 70%,[25] and wildfire smoke particulate matter by 48% to 78%.[26] In a university classroom-based study, PACs with HEPA filters captured over 95% of ultrafine fine particles (UFPs) and coarse particles, and 82% to 88% particles in accumulation range 0.3-2 μm.[27] A school-based study found PACs with HEPA filters were an effective short-term intervention with removal efficiencies for total UFPs (83%), aircraft-originated UFPs (67%), and traffic-originated UFPs (73%).[28] HEPA-filtered PACs can reduce exposure to simulated COVID-19 aerosol particles by up to 65%.[29]

Indoor UFPs measurements in school settings are limited,[30-37] however UFPs are higher in trafficked areas than in rural areas and peaks coincide with rush hours.[37] Outdoor UFP levels directly influence levels in schools.[28,38] Few studies have evaluated the effectiveness of PACs with HEPA filters UFP reduction in classrooms.[28,39] Long duration HEPA filter unit tests report filter airflow decreases slightly after 2-3 months.[25] Research on PAC effectiveness in King County, WA homeless shelters found PAC maintenance and operations are a concern.[40] Recommendations for congregate shelters included planning filter replacement costs and staff capacity for PAC maintenance.[40]

The *Healthy Air, Healthy School* community-engaged study to measure and identify UFP sources in classrooms in WA.[41] The study examined PACs with HEPA filters removal efficiency in classrooms and found UFPs in classrooms dropped to about one-tenth of outdoor levels after deployment.[28] PACs filter effectively for 6 months before a manufacturer-required filter change. Report back meetings found study partners were concerned with PAC deployments. Low participation prompted our research group to explore ways to better understand sentiments raised about school PAC use.

Recent school IAQ challenges, include aging infrastructure, infectious disease prevention, managing outdoor air pollution sources from wildfires and traffic, and adhering to energy efficiency standards.[42] PACs have emerged as a vital interim solution to address these issues[28] but face implementation barriers. This paper discusses findings from 2 initiatives aimed at understanding current and planned PAC use in WA schools. The first initiative involved conducting semi-structured interviews based on the technology acceptance model (TAM)[43] to assess PAC adoption in schools. Semi-structured interviewees included school district administration, facilities, maintenance, and operations personnel. The second initiative, led by Public Health—Seattle & King County (PHSKC), included a comprehensive school ventilation survey to capture current and anticipated ventilation strategies. The goal was to better understand current practices and identify factors influencing schools' decisions to invest and use PACs with HEPA filters. This analysis aims to provide essential insights to inform future strategies promoting PAC use in schools with poor IAQ.

METHODS

Semi-Structured Interview Interviewees

All interviewees were recruited between March and June 2022. We contacted all WA public school district Superintendents (N = 306) via email to invite them to participate in interviews. If initial contact with a school district was unsuccessful after a follow-up email, we emailed additional staff with publicly available email addresses on school district's websites. School district personnel included Directors of Operations, Directors of Facilities, Directors of Maintenance, Maintenance Supervisors, and Directors of Environmental Health and Safety, District Nurses, Health Directors, and Occupational and Physical Therapists. However, some school districts lacked publicly available email addresses for these roles. Our final recruitment effort focused on contacting Parent Teacher Association (PTA) members using publicly available email addresses.

Instrumentation — Semi-Structured Interview

Semi-structured interviews were conducted using an interview instrument. A semi-structured interview is a flexible method allowing the interviewer to follow theory-driven questions while allowing for more open-ended questions exploring a participants' experience.[44] PHSKC guided the development of the interview instrument based on their survey and experience with King County schools. Interviews had 4 main parts: (a) school role and *Healthy Air, Healthy Schools* report evaluation, (b) general IAQ concerns and strategies, (c) PAC perceptions and considerations, and (d) strategies to address air pollution sources (aircrafts, wildfires, and infectious diseases).

Each interview question addressed TAM constructs. Table 1 shows our interview questions in relation to their respective TAM construct. First, we asked questions about external factors impacting PAC use, such as school IAQ concerns, and strategies used to improve IAQ. Second, we asked questions about perceived usefulness (PU) of PACs in schools. Third, we asked questions about the perceived ease of use (PEU) of PACs and feasibility and sustainability concerns. Fourth, we asked questions about their attitude (A) toward using PACs and influencing factors. Fifth, we asked their behavioral intention (BI) to use PACs, if they have recommended their use and their estimated PAC use.

Procedure — Semi-Structured Interview

Interviewees were identified using publicly available contact information from the WA Office of Superintendent of Public Instruction (OSPI) website. Subjects were recruited via email using a standardized contact email. Educational resources and the *Healthy Air, Healthy Schools* Technical Information webpage[45] were provided in the initial contact email and post interview. A pre-interview questionnaire was distributed to learn about the school's PAC use; however, most participants did not complete the questionnaire and it was not used in the final analysis. Interviews were conducted over Zoom and were transcribed using the software's transcription feature, which was reviewed against recordings to ensure transcript accuracy.

Table 1. **Interview Questions Based on Technology Acceptance Model Constructs**

TAM Construct	Interview Question
External variables	Are you concerned with the indoor air quality in schools (or childcare centers)?
	Have you implemented strategies to reduce your exposure to air pollution when indoors?
Perceived usefulness (PU)	What do you think about the use of portable air cleaners in schools (or childcare centers)?
Perceived ease of use (PEU)	What concerns do you have about the feasibility and sustainability of using portable air cleaners in classrooms?
Attitude toward using (A)	What considerations have informed your decisions about whether or not to use portable air cleaners in classrooms (or childcare centers)?
Behavioral intention to use (BI)	When have you used or recommended portable air cleaners in the classroom (or childcare centers)?

Instrumentation — School Ventilation Survey

The PHSKC Environmental Health COVID-19 Recovery Team also administered a School Ventilation Survey to gauge public schools' actions and needs to improve ventilation during the COVID-19 pandemic in King County, WA. The goal was to better inform the county's technical assistance support to schools, including distribution of PACs acquired with ARP funds. The instrument was constructed to better understand schools' ventilation system types, maintenance, needs due to various limitations, and actions taken to improve IAQ to reduce COVID-19 transmission risk. In addition, the survey inquired about schools' plans for applying for ESSER funding, its intended use, and reasons for not applying.

Procedure — School Ventilation Survey

The survey took place earlier in the pandemic prior to semi-structured interviews, in July to November 2021, with follow-up calls in early 2022. No time overlap with follow-up calls and semi-structured interview recruitment occurred. The survey instrument was an electronic self-administered questionnaire with both open- and closed-ended questions.

Participants — School Ventilation Survey

An email explaining the survey purpose and instrument was sent to principals, facilities or operations managers, and all district-level superintendents in King County. School districts received follow-up phone calls to encourage participation, answer questions, and verbally administer surveys if requested.

Data Analysis

Transcripts were qualitatively analyzed using Atlas.ti (Version 8) software.[46] We used a TAM framework to develop a codebook with *a priori* codes based on potential responses. Deductive coding captured emerging concepts. We grouped codes into overarching categories, labeling individual codes as barriers or facilitators to using PACs. We also examined the relationships between barriers and facilitators in urban and rural regions. Rural-urban commuting area (RUCA) codes were used to classify school districts as either an urban or rural census tract.[47]

Group sentiment analysis. We conducted a sentiment analysis to examine the emotional tone associated with TAM constructs. A sentiment analysis classifies sentences into different positive or negative emotion classes.[48] We examined sentiment by factors including school district location (urban or rural) and PAC use levels (no use, limited use, wide use). ''No use'' was defined as never using PACs, ''limited use'' was defined as only using PACs in specific cases, and ''wide use'' was defined as using PACs in many classrooms throughout the school district. We used the R package ''sentimentr'' to calculate scores for positive, negative, or neutral sentiment.[49,50]

TAM predictive capability. We tested the TAM's predictive capability using a logistic regression with independent variables PEU and PU, and dependent variable BI. Sentiment scores were calculated for each individual participant response to the constructs PEU and PU. A score of 0 or 1 was assigned to BI based on responses on their intention to use PACs. We fit a logistic regression between PEU and BI, and PU and BI. We used the R packages ''stats''[51] to conduct the logistic regression and ''emmeans'' to estimate population marginal means.[52]

School ventilation survey. Survey data were analyzed using descriptive statistics in Microsoft® Excel®.[53] Frequencies and proportions were calculated for closed-ended questions, while open-ended questions were analyzed using content analysis to identify recurring themes.

RESULTS

Interviewees

Potential interviewees were individuals who responded ''interested in participating'' to an initial contact email. We established contact with 24 potential interviewees but lost 11 to follow-up, including non-response to subsequent emails or missing scheduled interviews. Interviews were conducted with 13 individuals, each lasting 30-60 minutes. One interview was conducted with 2 concurrent participants. Table 2 describes participant characteristics. Most interviewees were male (62%) with roles including school administration, facilities, and maintenance and operations. Participating school districts (N = 11) were distributed throughout WA with 7 districts in rural counties. All school districts interviewed received ESSER funds.[54] Most interviewees (54%) held district-level positions, making decisions for 45,502 WA students. Out of 11 school districts in 8 counties, 5 were urban and 3 were rural.

Table 2. **Description of Interviewees**

Variable	(Total N = 13), N (%)
Gender	
Male	8 (62)
Female	5 (38)
Role	
Administration	3 (23)
Facilities	3 (23)
Maintenance and operations	3 (23)
Health professional	1 (8)
PTA	1 (8)
Other	2 (15)
Location (county level)	
Rural	7 (54)
ESSER funds I/II	
Received funding	11 (100)

Other roles included Health and Environmental Investigator, and Environmental Safety Coordinator.

Thematic analysis. Table 3 summarizes facilitators and barriers to uptake and continued PAC use in schools. Facilitators included having a positive attitude about PACs, knowledge of PACs or similar instruments, believing PACs are easy to use and improve indoor air quality. In contrast, barriers included perceiving PACs having negative features, insufficient training or education on PAC use, insufficient education on PAC effectiveness, and concerns about maintenance and sustainability required to continue using PACs.

Barriers and facilitators to using PACs in schools differed by urban or rural category. While staff from rural schools believed PACs were desirable and worthwhile to improve IAQ, funding was a major barrier. Urban schools reported fewer funding barriers but were less willing to use PACs due to prioritizing upgrading heating, ventilation, and air conditioning (HVAC) systems. A Superintendent who also served as Principal in an urban school said:

> *It's one more thing to manage. If it can be managed [through] the HVAC system, [then] I don't feel the need*

Table 3. **Descriptions of Themes of Interviews with School Participants**

Impact on PAC Use at Schools	Theme	Definition	Codes	Prototypical Example
Facilitators	Positive attitude about PACs	Participants feel that PACs are good and have positive feelings toward them	Good attitude and positive feelings toward PACs	I think they serve a great purpose. It's something that has not been taken very seriously until the pandemic has come along and they're great, I think that they just serve a great purpose *Director of Operations*
	Knowledge on PACs or similar instruments	Participants feel their ability to determine the ease of use of PACs is determined by their past experiences with similar systems and have knowledge and experience necessary to use PACs	Past experience with similar items; knowledge and experience	Speaking for our school that didn't have an HVAC system and we bought a lot of air filters that were properly ready for the classrooms and didn't have any harmful by products. Those staff members were all very satisfied with that and I'm happy with that solution for that school *Environmental Safety Coordinator*
	Belief that using PACs is easy	Participants believe that using PACs is clear and understandable	Using PAC is clear and understandable; using PAC is easy to use	They have been pretty easy to use, and they actually have air filtration gauges on them to tell you whether the filters need to be changed or not. Which is something that's pretty handy *Maintenance Supervisor*
	Belief that PACs improve air quality	Participants believe that PACs improve indoor air quality and are very desirable and worthwhile to use for improving indoor air quality	Using PAC is desirable and worthwhile; improve air quality	One of the things I was impressed about was again taking my handy dandy meter around to all the sites and I would actually walk into a room and they happen to have one, and I would read you know the different levels and kind of just do a couple samples of the room . . . I was pleasantly surprised to find out how much those things really knock things out of the air *Director of Maintenance and Operations*
Barriers	PACs have negative features	Participants perceive PACs have negative features such as producing noise which negatively impacts students	Noise; special needs	For certain kids I'll turn it off because of the noise. I'm not too bothered by that normally, but with some kids I'll turn the fan level down *Occupational and Physical Therapist*
	Lack of training or education on how to use PACs	Participants reported a lack of training on how to use PACs resulting in misuse of instruments	Room capacity; instrument being misused; uncomfortable using PACs; no training; stresses out; education on use	My concern is that when people buy them as they obviously they're like "oh I'm going to buy this off Amazon and it's only $50" and I'm like yeah it only covers 100 square feet your classrooms 850 square feet. Yeah and so it's not so, I think, once again it comes down to an education piece, and because of that it also gives a false sense of security to folks *Facilities Planning Manager*
	Lack of education on PAC effectiveness	Participants reported a lack on education on PAC effectiveness	Education on effectiveness; not sure effective	My thoughts are just questions right now. How effective are they? How are we measuring the effectiveness? *Principal*
	PAC maintenance and sustainability	Participants reported being concerned with maintenance and sustainability of using PACs in schools	Maintenance and sustainability	It's a little worrisome to think about, are teachers gonna notice when it's time to change? *PTA*

to use them. If you don't have the funds, I get that. Or if it's just not structurally feasible at the time, then portable makes sense, but if you have another option I wouldn't.

Superintendent/Principal

School districts, particularly urban counties, utilized state and federal funding to purchase PACs. Urban school staff applied for federal funding while their rural counterparts noted they did not have the capacity to apply. A Director of Operations in a large urban county said:

We came to this purchase because of the pandemic. [We had] to spend money that became available, but we prioritized air cleaners as one of our initiatives to take advantage of those funds.

Director of Operations

Similarly, rural school staff reported lacking knowledge and experience necessary to use PACs, while urban schools reported having necessary knowledge and experience to use PACs. However, urban school interviewees expressed concerns about PACs misuse due to limited guidance or knowledge on using them. A Facilities Planning Manager in a large urban county said:

They obviously serve a purpose. My concern is that when people buy them . . . they're like ''oh I'm going to buy this off Amazon and it's only $50'' and I'm like ''yeah it only covers 100 ft^2 your classrooms 850 ft^2, so it's not [sufficient].'' I think, once again it comes down to an education piece. I think, because of that, it also gives a false sense of security to folks.

Facilities Planning Manager

We found additional education was needed on determining the number of PACs for classroom sizes. A Director of Facilities and Sustainability said:

Most of the research I have done on portable air cleaners is that they do not provide that much efficacy in [a room] the actual size of a classroom.

Director of Facilities and Sustainability

Findings from inductive coding illuminated IAQ disparities at children's homes. An emerging theme was concern about poor air quality at children's homes versus school buildings with higher filtration capacity. A Director of Operations said:

We are in a lower socioeconomic area, 93% of our kids qualify for free or reduced lunch and, honestly, for many families, school is the best place for them. That goes for air quality, for food nutrition services, you name it. School is the best place for a lot of these kids and if it's unhealthy for them to be outside then it's going to be unhealthy for them to probably be at their house . . . They're probably not going to have air purifiers, are probably not going to even have AC, sometimes they have the door open because it's just too hot, it's just a reality, so school is best. Closing school would be a detriment, in most cases, to their health.

Director of Operations

Sentiment analysis. We analyzed positive and negative PU and PEU construct sentiment. Overall, positive sentiment for PU was higher than PEU. Participants in urban school districts had a slightly higher mean positive PU sentiment score (0.20 [SD: 0.09]) than participants in rural school districts (0.15 [SD: 0.13]) (Figure 1A). School districts showed slight differences in sentiment with varying PAC use levels, but no clear relationship (Figure 1B). School districts with limited PAC use had the highest mean positive PU sentiment score (wide use: 0.11 [SD: 0.05], limited use: 0.24 [SD: 0.10], no use: 0.15 [SD: 0.16]). Selective use included rooms requiring more filtration from lacking HVAC systems or rooms with high COVID-19 exposure potential such as band rooms.

Participants in rural school districts had a slightly higher mean positive PEU sentiment score (0.13 [SD: 0.09]) than participants in urban school districts (0.08 [SD: 0.15]) (Figure 2A). We found minor differences in PEU sentiment between school districts with varying PAC use levels, but no clear relationship (Figure 2B). School districts with limited PAC use had the highest mean positive sentiment score (wide use: 0.10 [SD: 0.09], limited use: 0.13 [SD: 0.15], no use: 0.09 [SD: 0.11]). Although these results are not statistically significant using a Wald test with a p-value $>.05$, they reveal patterns in participating school districts.

School ventilation survey. Seventeen participants at district or school level completed the PHSKC survey. Schools throughout rural, suburban, and urban King County responded, representing about half of all county school districts. Participants represented 11 public school districts, 2 also participated semi-structured interviews. Most school districts (73%) reported actively planning ventilation system improvements with set plans to apply to ESSER (or other) funding for IAQ improvements. School districts reported using strategies to improve IAQ including opening doors and windows when conditions allow (73%), HVAC system routine maintenance (82%), routine filter replacement (82%), and using PACs (64%). However, cost or lack of funding (64%) and inadequate infrastructure for a better HVAC system (27%) remained a barrier for some school districts. Most school districts (91%) have in-house HVAC professionals or contracts with HVAC management companies.

TAM predictive capability. We fit logistic regression models to determine the odds of having positive BI to use PACs based on PU or PEU sentiment. We selected the 25th (−0.02) and 75th (0.23) percentiles of PU and PEU sentiment scores to estimate odds in our models.

Figure 1. **Perceived Usefulness (PU) of PAC Sentiment by School District Location and PAC Use Level (A) PU by school district location. (B) PU by PAC use level.**

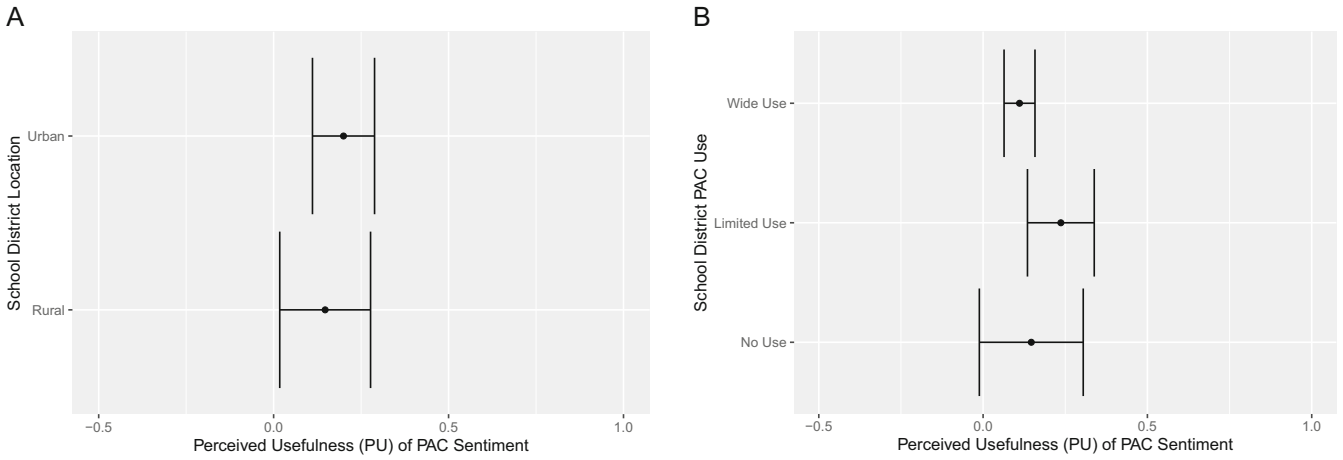
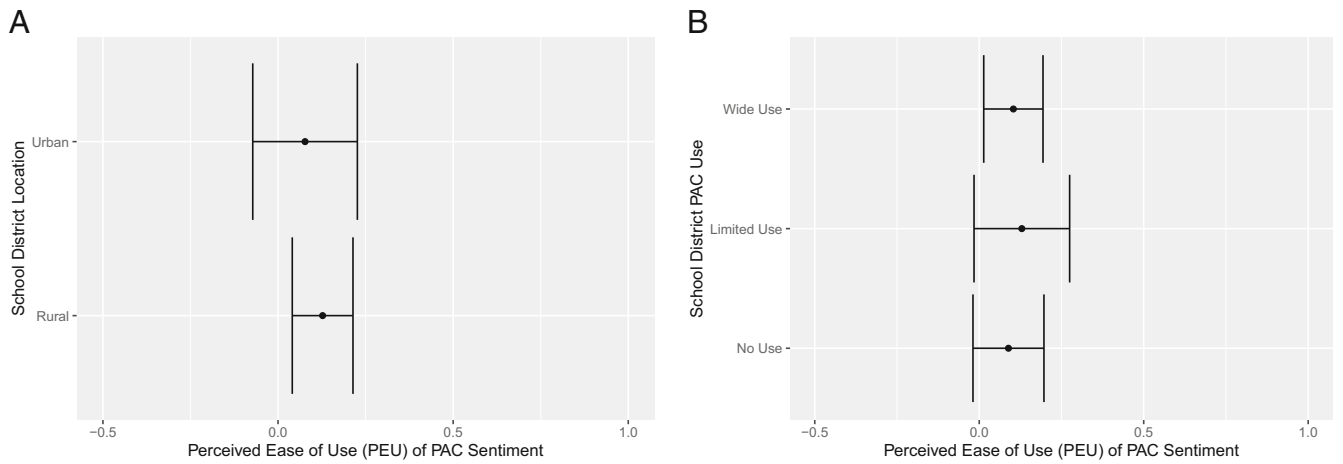


Figure 2. **Perceived Ease of Use (PEU) of PAC Sentiment by School District Location and PAC Use Level (A) PEU by school district location. (B) PEU by PAC use level.**



Having positive PU or PEU sentiment was predictive of having the intention to use PACs in schools. PEU had a stronger relationship with BI than PU. The odds ratio (OR) of having positive BI to use PACs in schools was 1.77 (SE: 1.68) when comparing individuals with high PU sentiment vs. low PU sentiment. The OR of having positive BI to use PACs in schools was 28.6 (SE: 84.7) when comparing individuals with high PEU sentiment vs. low PEU sentiment.

DISCUSSION

The present study was conducted to characterize current practices and factors influencing schools' intention to purchase and continue using PACs with HEPA filters. Concerns that emerged during *Healthy Air, Healthy Schools* report back activities prompted development of the present study. Positive attitudes and beliefs in PACs ease of use and effectiveness facilitated their use, while barriers included insufficient training, education, and sustainability concerns. PU and PEU were predictive of having the intention to use PACs in schools.

Public schools provide equitable interventions[55] making it crucial to prioritize schools in disadvantaged communities for school-based interventions. However, several obstacles hinder schools from being safe and healthy locations during wildfire smoke events.[3] PACs are a solution for improving IAQ recommended by WA DOH,[5] White House,[56] and US EPA.[57] More resources for maintenance, education, and training are needed for this intervention to be successful. Additional funding should address ongoing filter replacement

costs and staff time needed for cleaning and changing filters regularly.

The Centers for Disease Control and Prevention (CDC) conducted a telephone ventilation improvement survey among 8410 US K-12 public school districts (62% enrolled US public school students) between August and December 2022.[58] Among ventilation improvements examined, 51% of school districts maintained continuous airflow in classrooms, 34% had ongoing or completed HVAC system improvements, and 28% used HEPA-filtered in-room air cleaners.[58] High-poverty school districts (using US Census Bureau Small Area Income Poverty Estimates [SAIPE]) reported more ventilation improvements than low- and mid-poverty school districts.[58] Rural school districts infrequently reported replacing or upgrading HVAC systems and using HEPA-filtered in-room air cleaners.[58] Limited resources and contractor availability may hinder capital improvements.[59]

Although ESSER funds supported school ventilation improvements, funding records do not provide information on PAC purchases and deployments. PAC use in schools is uncertain since COVID-19 transmission focus has declined. Additional knowledge is necessary to provide guidance on funding and resource allocation for PAC maintenance. Campaigns are needed to characterize PAC usage amidst staff time and maintenance cost barriers. Future trainings and PAC selection should consider noise impacts, as decreasing fan speed may not meet optimal air changes per hour (ACH). School teachers have noted being strongly or somewhat disturbed by PAC noise.[60] Currently, we lack understanding of how public schools utilize PACs and whether they could benefit from supplemental filtration. PACs are a potential intervention for a wide range of uses including removing pollution from wildfires,[26,61] traffic-related air pollution,[28,39] and COVID transmissibility.[29]

PHSKC survey results aligned with findings from semi-structured interviews. Through follow-up conversations throughout the COVID-19 pandemic, school facilities managers expressed concerns about staff capacity and funding needed to maintain PACs. One recurring theme was PAC maintenance hindering PAC use in schools. PHSKC learned many school personnel felt interventions would be more effective if they received guidance on how to select, use, and maintain PACs before purchasing them.

School staff also expressed concerns with classroom noise and time needed to check units were kept on, plugged in and on correct settings. A common concern was determining the number of units to place in a space to achieve effective air filtration. PHSKC recommendations align with semi-structured interview findings. Recommendations include screening classrooms using IAQ testing instruments to prioritize interventions where needed, and evaluate if IAQ improvement interventions worked. IAQ testing can include pollutants such as PM and carbon dioxide (CO_2). IAQ interventions can include installing PACs, upgrading HVAC systems, opening windows for natural ventilation, and developing a maintenance plan for sustainable use, cleaning, and changing PAC filters.

Limitations

Due to our sampling approach, our results may not be generalizable to all WA schools. Systematic differences between participating and non-participating schools may impact the study representativeness. COVID-19 pandemic demands on schools likely caused poor participation in both initiatives. Preexisting concerns about school IAQ may lead to selection bias. Future research is needed to understand unequal exposure to wildfire smoke and barriers to protective action among school health professionals and parents, particularly low-income families.

PHSKC faced limitations in their survey and PAC distribution to schools. The survey sample may not represent all schools in King County. Participating districts may have more interest or concern about ventilation systems than non-participants or more staff capacity to respond during the pandemic peak. Self-reported data may have overestimated or underestimated ventilation system status. The survey was limited to schools in King County, WA, and results may not be generalizable. Finally, the survey indirectly assessed IAQ by utilizing information about ventilation systems as a proxy.

Conclusions

Our findings reveal gaps remain between funding and resources to improve school IAQ. PACs are underutilized and school districts lack access to funding, education, and training for effective implementation and maintenance. With new funding for school IAQ improvements, we encourage PACs with HEPA filters as a supplemental strategy to existing HVAC systems. Risk assessments should also be utilized when deploying this intervention to determine the appropriate size, and placement, filter types.

IMPLICATIONS FOR SCHOOL HEALTH POLICY, PRACTICE, AND EQUITY

The study's findings provide a detailed qualitative lens exploring factors influencing PAC use and school IAQ improvements. Despite the study's limitations, our findings can provide guidance to groups approaching PAC use in schools nationwide. Large urban school districts utilize a ''ticket system'' for IAQ issues and QR codes to manage HVAC systems. A similar system

could be implemented to manage PACs, integrating PACs into existing centralized management, creating more capacity for facilities staff, and removing the need for assistance from non-facilities staff.

Suggested areas for future interventions include: .

1. Improve HVAC systems by upgrading filters within the system's capacity and implementing centralized control systems.
2. Implement effective information management such as a ticket system for tracking IAQ concerns for both PACs and HVAC.
3. Routinely test IAQ and provide financial support for air quality monitoring instruments, personnel, and research. Accompanied with technical assistance to facilitate schools in identifying and acquiring the best options for their needs.
4. Increase reliable IAQ information availability and facilities staff education.
5. Implement management systems for PACs including tracking, maintenance, and filter supply.
6. Provide financial support for maintaining PACs including scheduled filter replacements.

Human Subjects Approval Statement

Preparation of this paper did not involve primary research or data collection involving human subjects, and therefore, no institutional review board examination or approval was required. The University of Washington's Institutional Review Board determined the study to have exempt status.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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