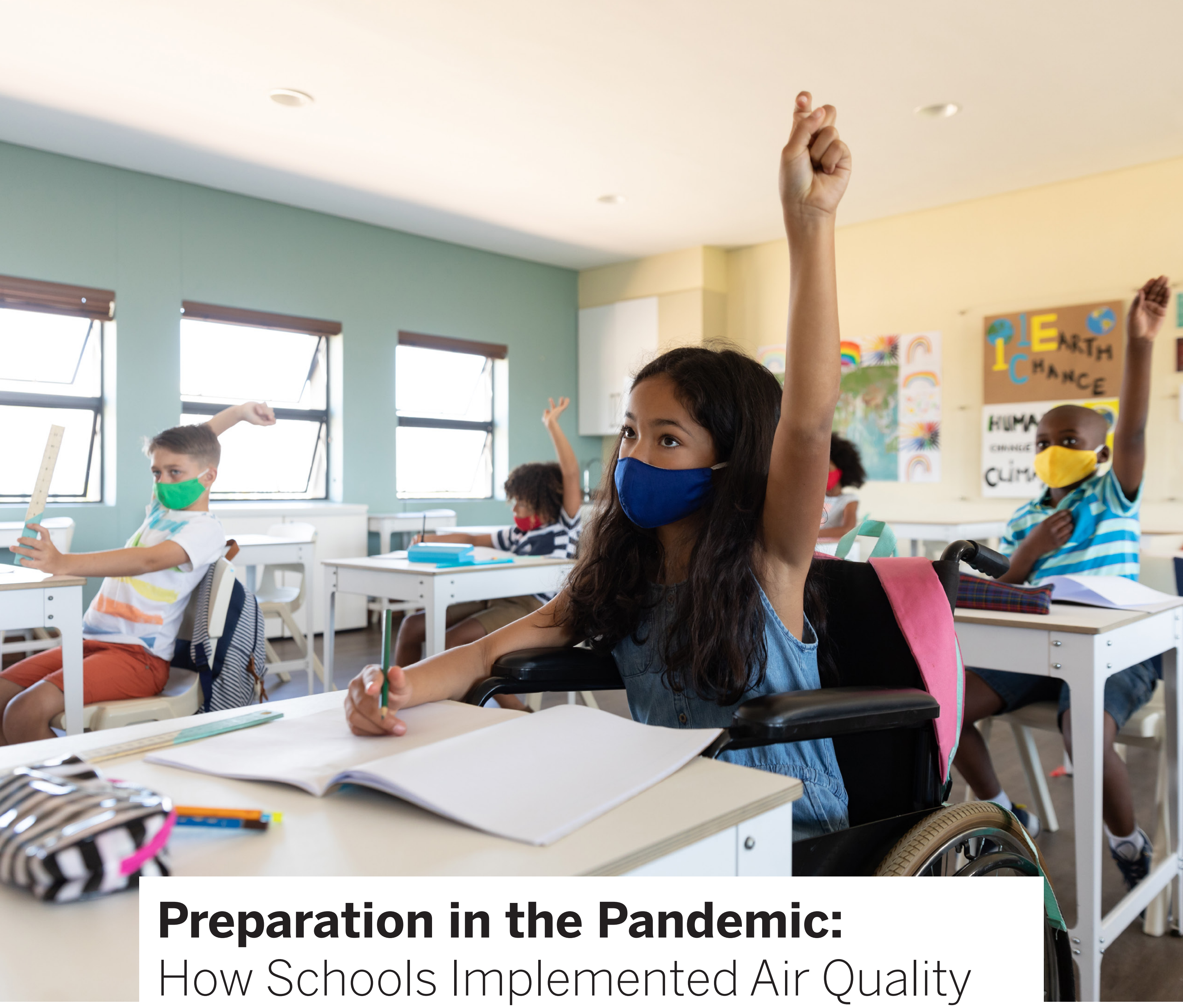

Preparation in the Pandemic: How Schools Implemented Air Quality Measures to Protect Occupants from COVID-19

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Executive Summary

The partial or complete closures of schools nationwide have brought attention to how indoor air quality (IAQ) can play a critical role in curbing the transmission of SARS-CoV-2 in buildings and promoting public health. The evolving science has found that airborne transmission of SARS-CoV-2 is significant and should be controlled. When combined with evidence-based source control practices (i.e., masks, physical distancing, and handwashing), improving air ventilation and filtration through engineering controls provides a comprehensive, layered strategy to protect staff and students from exposure to COVID-19.

We launched a study to understand how school districts prioritized and implemented six IAQ recommendations for ventilation and filtration to help reduce coronavirus transmission in schools. The six IAQ strategies focused on increasing fresh air and cleaning recirculated air. This study detailed the experiences and challenges of 47 school districts and independent schools, representing over 4000 schools and 2.5 million students in 24 states.

We found that school districts relied heavily on their mechanical systems to implement air quality measures. Using mechanical ventilation to increase fresh air was most commonly adopted by schools, followed by filtration measures to remove airborne contaminants from recirculated air. The most frequently cited challenge to implementing protective air quality measures at schools was that school buildings were not designed to support the strategies that were being recommended.

Guidance from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and Centers for Disease Control and Prevention (CDC) were the most commonly referenced resources. However, there was a consistent wish for straightforward information that could be customized, depending on the school districts' unique circumstances and climate zone. Overwhelmingly, where they saw success, participants credited prompt leadership, a cache of pre-existing wealth (for well-funded districts), and/or past investments in infrastructure.

This report is the first known national effort to collect school district-level data on experiences and challenges in implementing IAQ measures in response to the COVID-19 pandemic. The results suggest that school districts still have unmet needs in addressing indoor air quality, in particular, when faced with cost constraints and outdated building infrastructure in the face of changing conditions. Our study fills a critical gap in informing how policymakers and non-profits can better serve schools' needs as they continue to face uncertainty during the COVID-19 pandemic and will continue to face in future ones.

Introduction

The coronavirus disease 2019 (COVID-19) pandemic has forced Americans and institutions to make many profoundly tough choices. One of the most controversial decisions communities have had to make concerns when and how schools serving students in grades K-12 should re-open. Schools have faced many difficult decisions about how to best reduce the risk of exposure to SARS-CoV-2 (the virus that causes COVID-19) for staff and students.

The partial or complete closures of schools nationwide have brought attention to how indoor air quality (IAQ) can play a critical role in curbing the transmission of SARS-CoV-2 in buildings and promoting public health. The evolving science has increasingly supported the notion that SARS-CoV-2 spreads substantially through airborne transmission.[1-4] SARS-CoV-2 viral particles spread between people more readily indoors than outdoors through respiratory aerosols exhaled from infected individuals.[1, 2, 4] More importantly, these respiratory aerosols can be small enough to remain suspended in the air for hours and travel distances farther than the recommended social distance of six feet.[2-4]

When combined with evidence-based source control practices (i.e., masks, physical distancing, and handwashing), ensuring enhanced air ventilation and filtration through engineering controls provides a comprehensive, layered strategy to protect staff and students from exposure to COVID-19.[1-7] Buildings can integrate IAQ measures such as ventilation and filtration to maximize fresh air and clean recirculated air to reduce the risk of coronavirus transmission by factors ranging from 8.5 to over 500.[8] Yet, before the pandemic, less than half of school districts in the country had an IAQ management program.[10]

Prominent professional societies and public health institutions published educational materials about addressing IAQ in response to COVID-19 in buildings and schools. The organizations include but are not limited to the: American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Centers for Disease Control and Prevention (CDC), Environmental Protection Agency (EPA), American Institute of Architects (AIA), U.S. Green Building Council (USGBC), World Health Organization (WHO), and Healthy Buildings Program at the Harvard T.H. Chan School of Public Health (HSPH).1, 6, 7, 11-16 The published guidance converged on six major IAQ strategies:

Increase fresh air through mechanical ventilation.

1. Increase outdoor air supply through the building's heating, ventilation, and air conditioning (HVAC) system.
2. Implement a flushing process between occupancy periods where the HVAC system runs for a pre-specified duration or until a target of clean air changes has been reached.

Increase outdoor air through the use of operable windows.

3. Open windows to increase the outdoor flow.
4. Place fans in windows to exhaust room air to the outdoors.

Remove airborne contaminants through filtration.

5. Upgrade to filters with higher minimum efficiency reporting values (MERV) ratings, with MERV 13 or better as a target for removing airborne viral particles in recirculating systems (MERV ratings range from 1-16, with 16 being the most efficient filtration).
6. Install air cleaners with high-efficiency particulate air (HEPA) filters (HEPA filters are no less than 99.97% efficient at capturing human-generated viral particles).

School districts have had to make customized decisions about how best to implement these six IAQ measures during the pandemic, depending on their current building infrastructure, financial and human resources, competing priorities, and local politics. Given the pressing need to address IAQ to ensure safe in-person learning, we surveyed school districts to understand their experiences and challenges in implementing these six IAQ recommendations on the ground. These insights will inform what support school districts need to respond to this public health crisis and, inevitably, future similar crises.

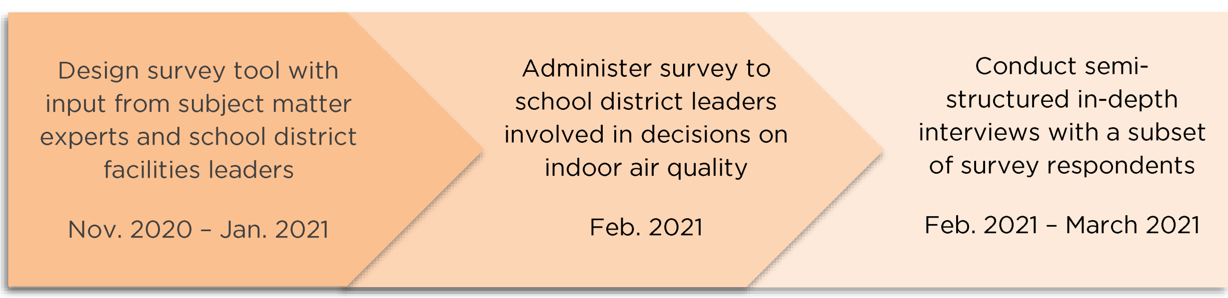
Methodology

We implemented a mixed methods research design using a sequential explanatory strategy in which a quantitative protocol was followed by a qualitative component.[17] The quantitative phase consisted of an online survey distributed to participants whose responses directly informed the guided questions used for the in-depth interviews. Survey and interview questions were developed in an iterative fashion with the consultation of experts and leaders in air quality, public health, school district facilities, and sustainability. Figure 1 details the study design and timeline.

To maximize recruitment of school district participants, we utilized a multi-modal, internet-mediated recruitment strategy to disseminate a web-based questionnaire on the following platforms: email listservs in the Center for Green Schools' and ASHRAE's networks, the Center for Green Schools' website, Twitter, Facebook, and networking events. The online survey asked participants to provide their emails if they were interested in being invited for an in-depth interview. This subset of participants was subsequently emailed for confirmation. Participants provided written consent via email and did not receive monetary compensation. The individual semi-structured interviews were conducted on Zoom, ranging from 30 to 60 minutes in length.

Demographic and funding data for each school district were acquired from the National Center for Education Statistics (NCES) and the U.S. Department of Education. Locale classifications were based on the NCES framework (Appendix A). The survey was administered using Wufoo by Survey Monkey Inc. Descriptive statistics, frequency calculations, and interquartile ranges (IQR) were calculated using GraphPad Prism 9. Fisher's exact tests were calculated with Stata version 16.1 for Mac. In-depth interviews were recorded and transcribed using Otter.

Figure 1. Survey Design Timeline



Results: An Overview

Profile of the K-12 School District Respondents

The survey was completed by 47 school districts, independent schools, and charter schools in 24 states (Figure 2). Four participants redacted their identities. Overall, we obtained complete demographic and socioeconomic data on 41 school districts (Tables 1 and 2). The school districts in our cohort represented 4124 schools serving over 2.5 million students, of which 344,582 (14%) were English language learners (Table 1). The median student body was majority white (61%), but 27% of school districts in our cohort were majority non-white (Table 1). Half (51%) of the total respondents were located in cities, followed by 41% in suburbs and towns.

The median household income of parents in the school districts was $68,523 (Table 2). Notably, one in five families in the school districts used Electronic Benefits Transfer (EBT) (Table 2). The majority (84%) of households had broadband access. However, in 17% of the school districts, only 60%-76% of households had broadband access.

We interviewed 13 school districts and 1 independent, private school, representing 34% of the total number of schools and students in our cohort. The interviewee group was demographically and socioeconomically similar to the overall cohort (Tables 1 and 2, Figure 3). Approximately 72% of school districts responded that they received federal funding through the Education Stabilization Fund from the Coronavirus Aid, Relief, and Economic Security (CARES) Act. At the time of our analysis, it was difficult to assess this revenue stream's financial impact and significance on IAQ measures in schools.

Table 1. Demographics of K-12 School District Respondents

Characteristics	Survey respondents (n=41[a])	Interviewees (n=13[b])
Total # of schools	4124	1286
Total # students	2,535,258	797,896
Total # English Language Learners	344,582 (14%)	117,281 (15%)
	Median (25th, 75th)	Median (25th, 75th)
# of schools in district	61 (16, 109)	53 (19, 99)
# of students in district	36,888 (10,736, 62,232)	26,395 (9,355, 50,601)
Student teacher ratio	16 (15, 18)	15 (14, 18)
% White students	64% (45%, 77%)	61% (18%, 69%)
% English Language Learners	7% (4%, 14%)	6% (1%, 16%)
% Students with a disability	4.3% (3.8, 5.9)	4.2% (3.8%, 5.2%)
Total population in community	263,148 (78,022, 577,839)	233,750 (76,540, 537,061)
% Year building structures were built		
• Before 1970	17% (11%, 26%)	15% (11%, 21%)
• Between 1970-1999	50% (39%, 58%)	47% (32%, 53%)
• 2000 and beyond	30% (18%, 52%)	37% (27%, 53%)

[a] Out of 47 respondents, 4 participants redacted their identities, 1 participant was an independent, private school, and 1 participant was an independent charter school already accounted for in a school district.

[b] Out of 14 participants interviewed, 1 was an independent private school.

Table 2. Socioeconomic Profile of K-12 School District Survey Respondents

Characteristics	Survey respondents (n=41[a]) Median (25th, 75th)	Interviewees (n=13[b]) Median (25th, 75th)
Amount per student	$13,632 ($12,153, $17,354)	$17,283 (13,598, 18,666)
Median Household Income (Parents)	$68,523 ($57,782, $68,523)	$67,699 ($53,732, $101,271)
Median Household Income (Community)	$63,793 ($53,927, $77,597)	$65,529 ($56,906, 77,597)
% Household with broadband internet	84% (81%, 88%)	83% (76%, 89%)
% Families below the poverty level	16% (8%, 20%)	16% (7.8%, 21%)
% Families with EBT[c]	20% (8.8%, 24%)	20% (8.5%, 31%)

[a] Out of 47 respondents, 4 participants redacted their identities, 1 participant was an independent, private school, and 1 participant was an independent charter school already accounted for in a school district.

[b] Out of 14 participants interviewed, 1 was an independent private school.

[c] EBT or Electronic Benefits Transfer refers to the card-based system similar to a debit card that allows recipients of government assistance to pay retailers directly for their purchases.

Figure 2. Map of states with one or more K-12 school district participants (n=24 states)

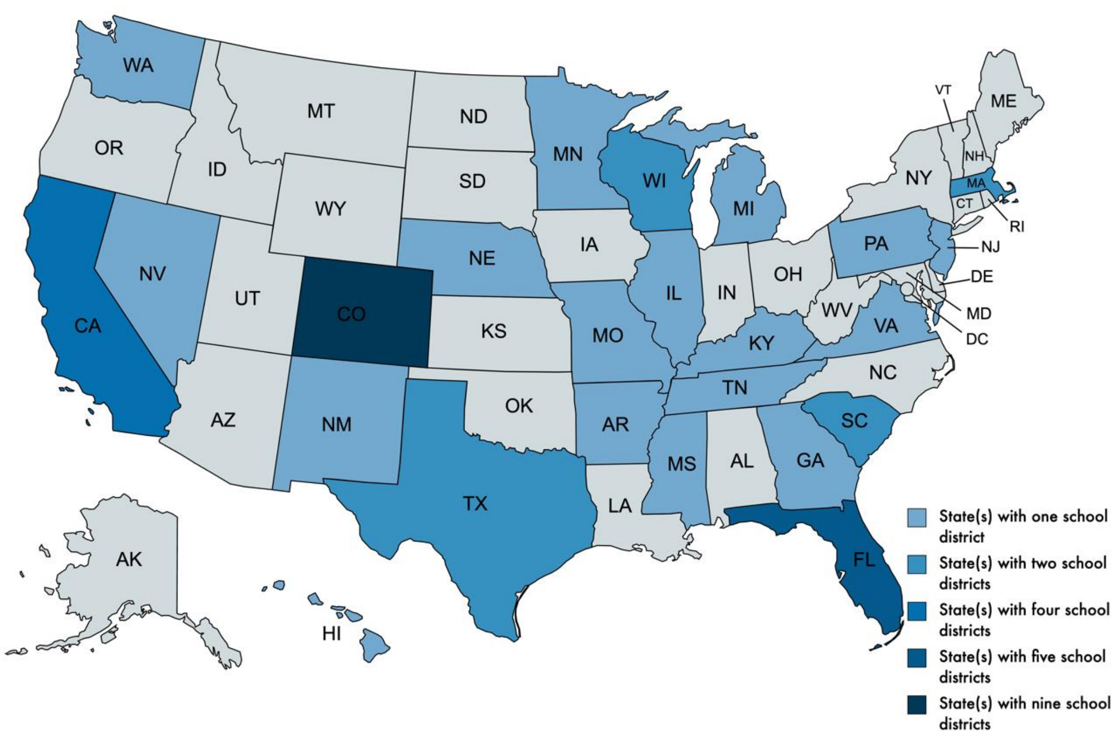
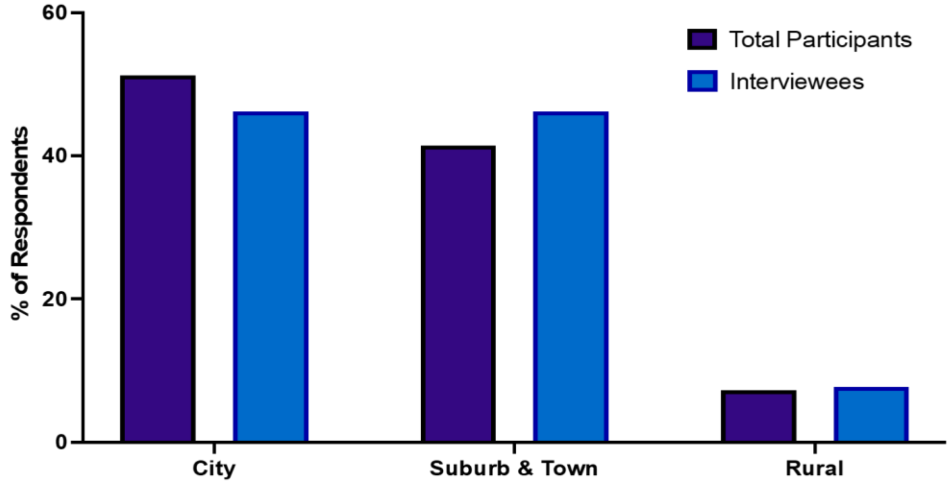


Figure 3. Locale of Survey Respondents (n=41)



Overview of Survey Results

When the coronavirus pandemic was declared in March 2020, 59% of school districts in our cohort switched to virtual learning, and 15% of school districts were not in session (Figure 4). Virtual learning peaked in May, with 87% of schools using online education (in some school districts, teachers and staff had the option to work in person while students remained virtual). In September 2020, the month traditionally marking the new academic year, virtual learning dropped to 38% of school districts. By January 2021, only 19% of school districts were conducting all-virtual learning, while hybrid learning and primarily in-person learning comprised 60% and 19% of school districts, respectively.

We asked the survey respondents how they had prioritized and implemented, during the pandemic, the six IAQ strategies of ventilation and filtration to help reduce coronavirus transmission in schools. We found that how the participants prioritized each IAQ measure correlated with the degree of success with which they employed each strategy in at least some of their schools.

Mechanical ventilation strategies geared towards bringing in fresh, outdoor air were the most commonly prioritized. Approximately 89% of participants highly prioritized increasing outdoor air supply through existing HVAC systems, and 79% of participants highly prioritized implementing a pre/post-occupancy flushing strategy (Figure 5). Accordingly, these mechanical ventilation strategies were the most frequently implemented amongst school districts: 87% increased outdoor air supply through existing HVAC systems in at least some of the schools, and 77% imposed a pre/post-occupancy flushing strategy in at least some of the schools (Figure 6).

Increasing outside air through the use of operable windows was the least prioritized IAQ measure during the pandemic. Approximately 64% of participants considered opening windows a low priority, and 77% rated placing fans in areas to increase exhaust a low priority (Figure 5). These measures were also the least implemented. Approximately 55% of participants did not use opening windows as a mitigation strategy in any of their schools and 64% did not implement running exhaust fans in any of their schools (Figure 6).

Compared to mechanical ventilation, filtration was the next most highly prioritized IAQ measure among school districts. Approximately 66% reported that upgrading to higher grade MERV filters was a high priority. In comparison, 43% highly prioritized installing air cleaners with HEPA filters (Figure 5). These filtration strategies were also second-most frequently implemented: 70% of participants upgraded to higher grade MERV filters, while 60% of participants employed air cleaners with HEPA filters (Figure 6).

Figure 4. School opening status during the pandemic (n=47)

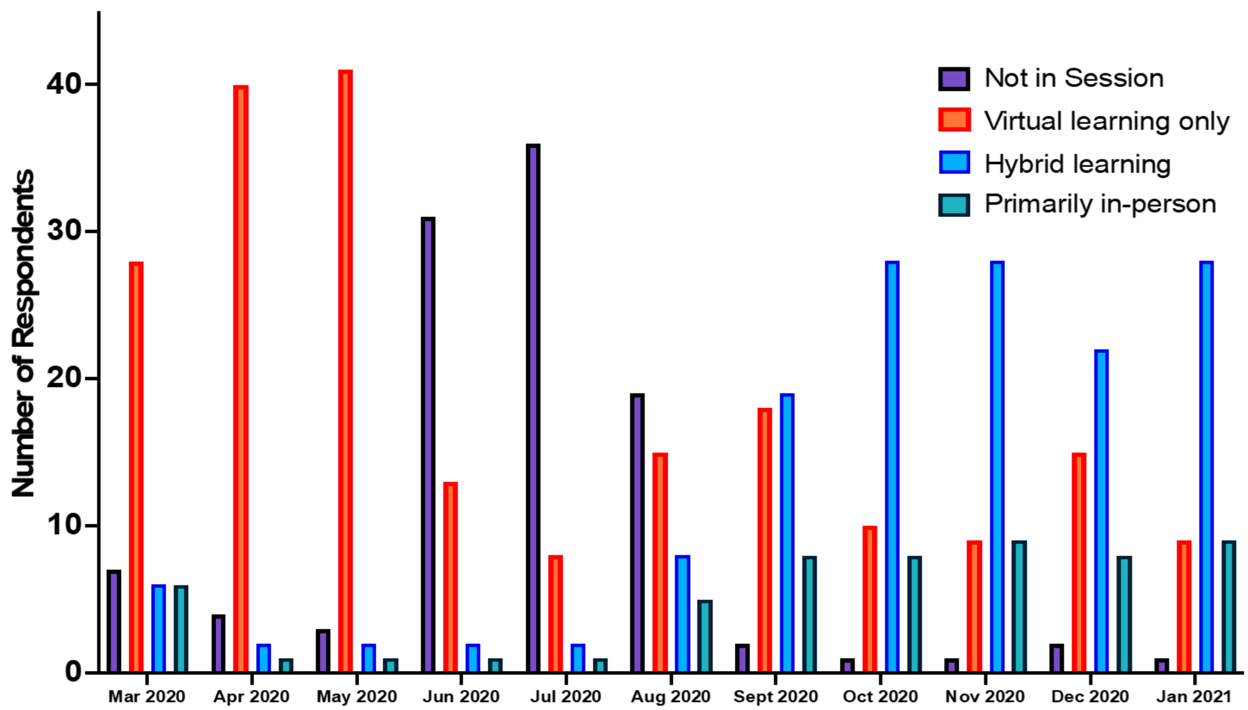


Figure 5. IAQ strategies prioritized in school districts during the pandemic (n=47)

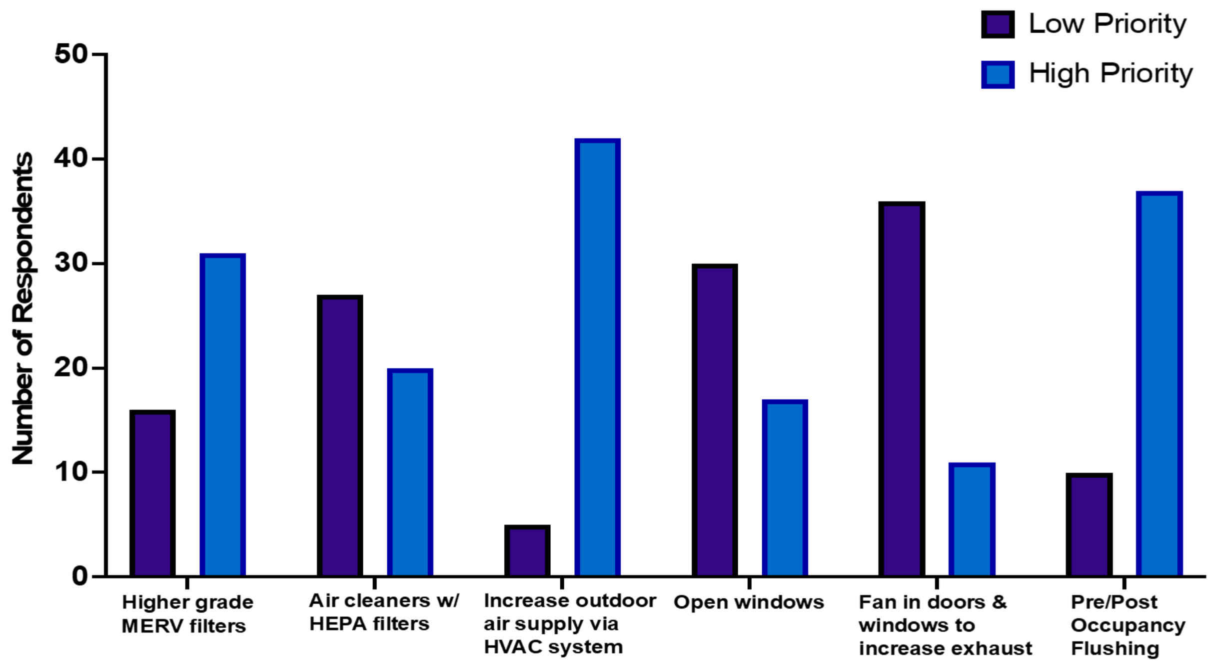


Figure 6. IAQ strategies implemented in school districts during the pandemic (n=47)

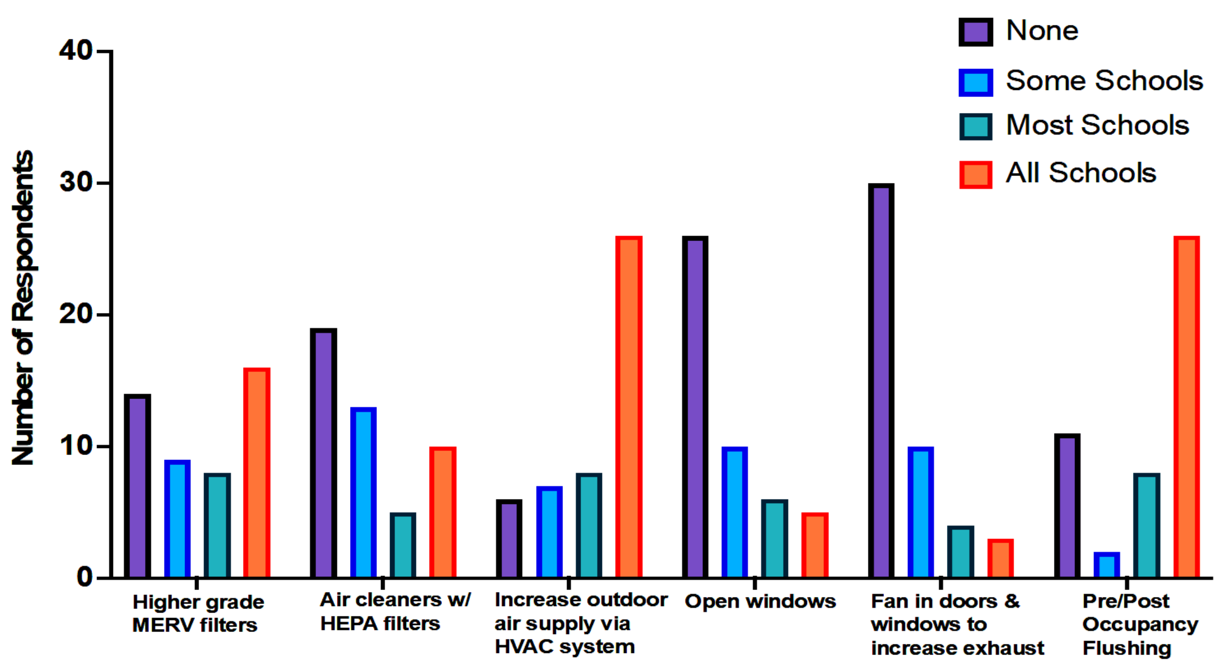


Figure 7 details the top barriers cited by at least 11 out of the 47 school participants (23%) to implementing each IAQ strategy during the pandemic. The one hurdle mentioned for every applicable IAQ measure was that the school building was not designed adequately to support the respective strategy (Figure 7). High cost was the most common barrier to using air cleaners with HEPA filters and the second-most common barrier to upgrading to higher-grade MERV filters (Figure 7). Climate and weather challenges were the most common reasons for not being able to open windows and increase exhaust ventilation using fans (Figure 7).

Figure 7. Common barriers to implementing IAQ strategies in school districts during the pandemic (n=47)

Upgrade to higher grade MERV filters

- Schools not designed to support this strategy
- High cost
- Lack of availability of filters

Air cleaners with HEPA Filters

- High Cost

Increase outdoor air system via HVAC system

- Schools not designed to support this strategy

Open windows

- Climate and weather challenges
- Schools not designed to support this strategy

Use fans in doors and windows to increase exhaust

- Climate and weather challenges
- Not a priority of school district leaders
- School not designed to support this strategy

Pre/post-occupancy flushing

- School not designed to support this strategy

Mechanical ventilation measures to increase fresh air were the most highly prioritized and commonly adopted by schools.

Compared to pre-pandemic times, school districts' use of HVAC systems in at least some buildings to increase outdoor air supply during the pandemic rose significantly by 78% ($p<0.001$, Figure 8). The proportion of school districts that implemented this measure differed significantly depending on whether the measure was viewed as low priority or high priority ($p<0.001$, Figure 9). Nearly all (98%) school districts that considered this strategy a high priority were able to carry it out in at least some of the school buildings (Figure 9). Meanwhile, none of the school districts that considered this strategy a low priority implemented it in any school building (Figure 9).

Figure 8. Implementation of increasing outdoor air supply using HVAC systems (n=47)

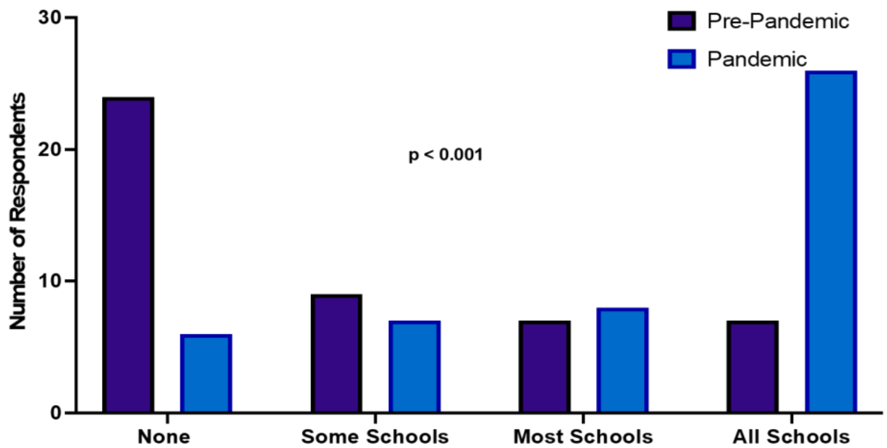
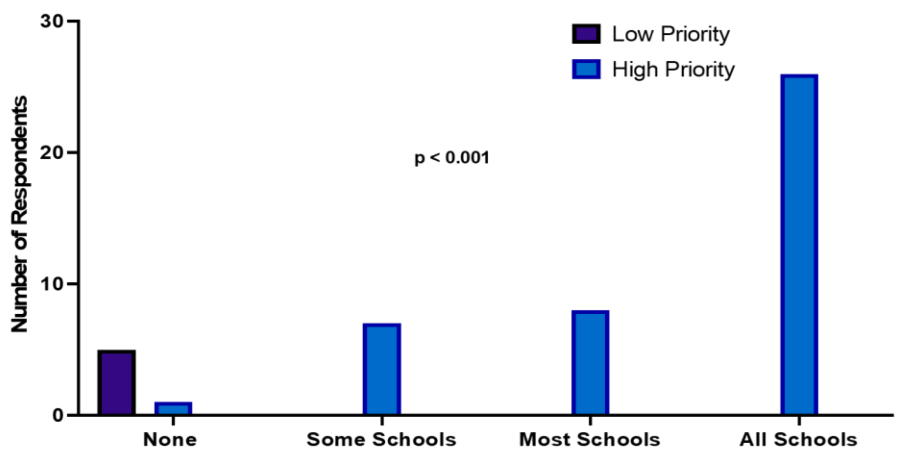


Figure 9. Implementation of increasing outdoor air supply using HVAC systems during the pandemic between respondents who considered it low vs. high priority (n=47)



Flushing rooms with fresh air before and after they are occupied for a pre-specified duration was similarly popular. This strategy saw a significant uptick of 260% in its implementation in at least some school buildings during the pandemic ($p<0.001$, Figure 10). Figure 11 illustrates how this trend was significantly driven by those school districts who had rated this strategy as a high priority ($p<0.001$).

Figure 10. Implementation of pre/post-occupancy flushing strategy (n=47)

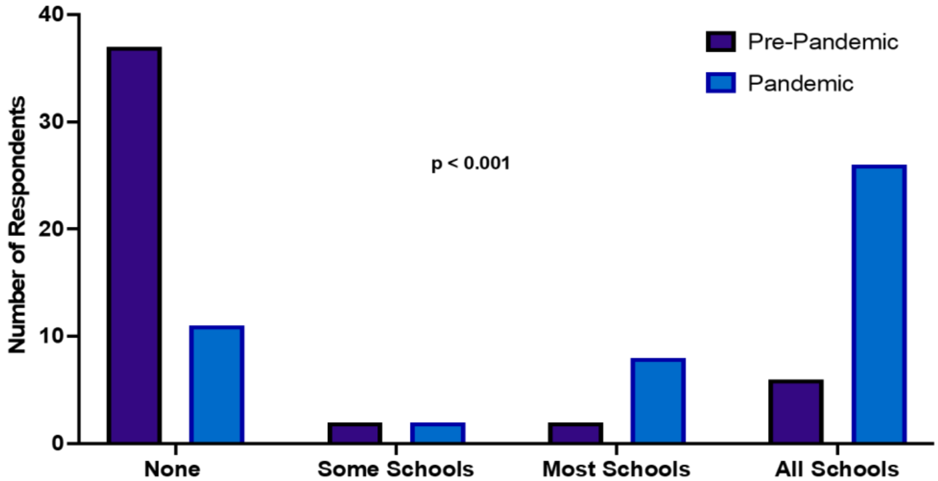
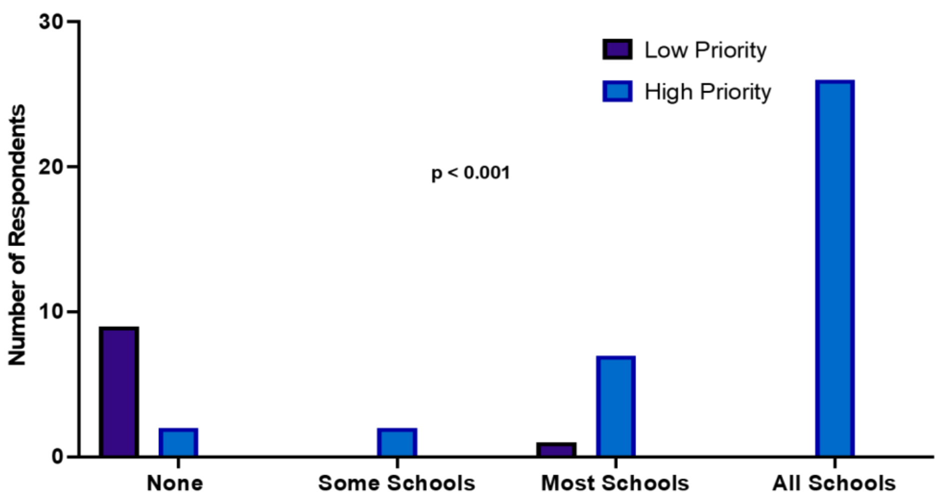


Figure 11. Implementation of flushing strategy during the pandemic between respondents who considered it low vs. high priority (n=47)



Despite the high adoption frequency of the two mechanical ventilation strategies, many respondents noted obstacles in their execution. The number one cited barrier was that at least some of their school buildings were not designed to support this strategy (Figure 7). Some buildings were so dated that there were no controls to automate. As one participant detailed,

> *Winter-time ventilation in schools... heated by radiant hot-water heaters did not have the option for flushing, increasing airflow, or filtration. Identifying custom solutions among a large portfolio of buildings was difficult. Re-programming costs and time allocation for HVAC sequence of operations to achieve ASHRAE recommendations was extensive and time-consuming. Hiring technical support to evaluate systems, strategies, and technologies was an extensive coordination exercise and included added cost for professional services. Field verification of software changes in HVAC systems was not easily performed as thoroughly as desired.*

Others mentioned the lack of staff and personnel bandwidth to keep up with the breadth of IAQ work needed in their school districts. As one participant wrote,

> *Our staff has been fully consumed with managing COVID protocols, e.g., social distancing, barriers, face masks, contact tracing, bussing, cleaning...We do not have the bandwidth and/or expertise to deal with HVAC-related issues.*

Measures related to increasing outside air through operable windows were the least prioritized and least employed.

Compared to the other four IAQ strategies, improving natural ventilation through operable windows with or without exhaust fans gained the least traction among school districts. Compared to pre-pandemic times, school districts' use of open windows in at least some buildings to increase the flow of fresh, outdoor air during the pandemic did rise by 31% ($p<0.001$, Figure 12). The proportion of school districts that implemented this measure differed significantly depending on whether the measure was viewed as low priority or high priority ($p<0.001$, Figure 13). All but two school districts (88%) who rated opening windows as a high priority strategy had implemented it in at least some of the school buildings compared to 20% of school districts who viewed it as low priority (Figure 13).

Figure 12. Implementation of opening windows (n=47)

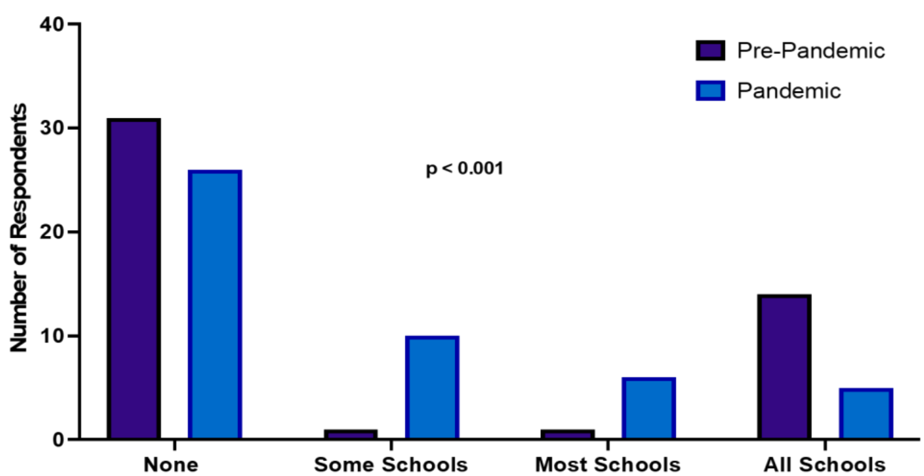
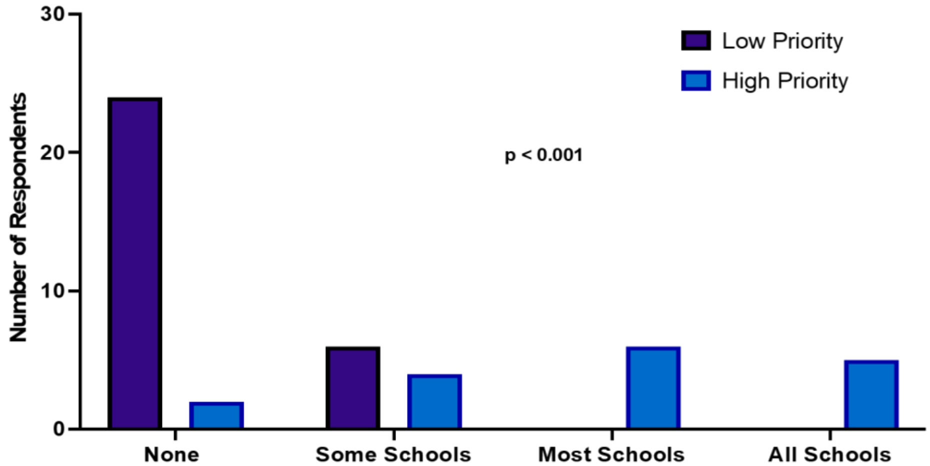


Figure 13. Implementation of opening windows during the pandemic between respondents who considered it low vs. high priority (n=47)



Employing fans in windows and doors to increase exhaust was the least popular strategy implemented in school districts. There was no significant difference between the reported use of this strategy before and during the pandemic ($p<0.08$, Figure 14). However, the proportion of school districts that did implement this measure differed significantly depending on whether the measure was viewed as low priority or high priority ($p<0.001$, Figure 15). All of the school districts (100%) who believed employing exhaust fans was a high priority had implemented it in at least some of school buildings compared to 17% of school districts who viewed it as low priority.

The top obstacle for employing either windows or fans was challenges related to the outside environment (Figure 7). There was also widespread concern about whether box fans could increase the infection risk by spreading the virus particles in the air. As one survey participant expressed,

> *Opening windows poses safety and air quality concerns from buses and car exhaust in addition to temperature control and noise issues...Additional fans utilized in space would potentially increase the spread [of] infectious aerosols through the space.*

Figure 14. Implementation of using fans to increase exhaust (n=47)

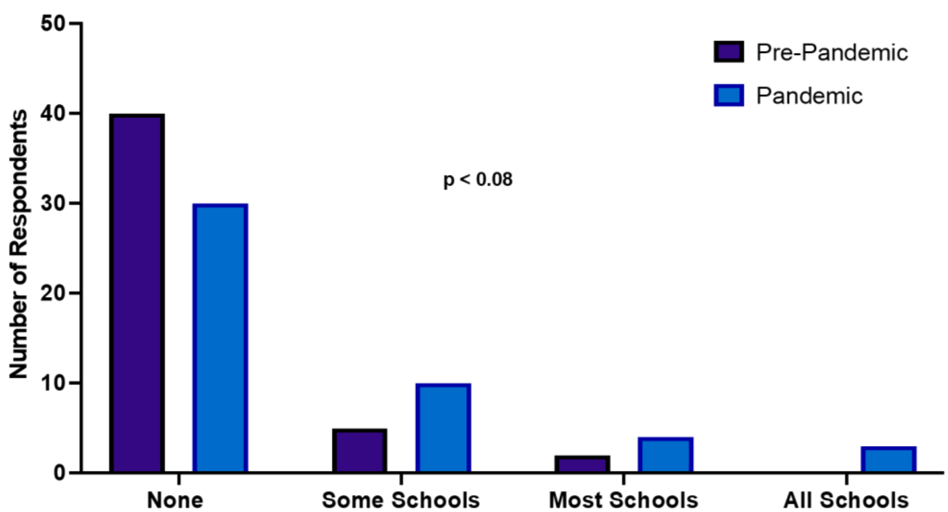
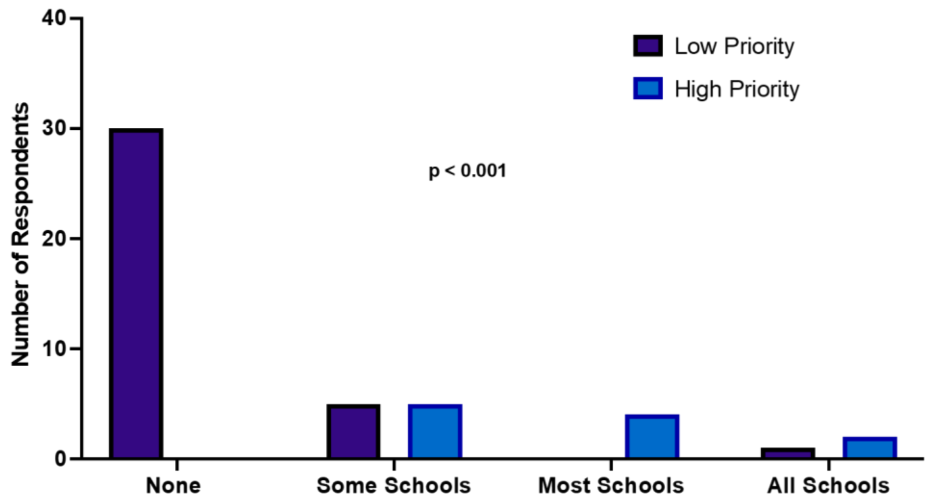


Figure 15. Implementation of using fans to increase exhaust during the pandemic between respondents who considered it low vs. high priority (n=47)



The pandemic ushered in a significant increase in the use of filtration measures.

Higher-grade MERV filters and air cleaners with HEPA filters gained substantial popularity amongst respondents. The installation of higher-grade MERV filters in at least some of the schools in the district significantly increased by 120% during the pandemic ($p<0.001$, Figure 16). The proportion of school districts that implemented this measure differed significantly depending on whether the measure was viewed as low priority or high priority ($p<0.001$, Figure 17). Nearly all school districts (94%) that valued higher-grade MERV filters as high priority had them installed in at least some of the schools in the district, compared to only 25% of school districts who viewed them as low priority (Figure 17).

Figure 16. Implementation of higher-grade MERV filters (n=47)

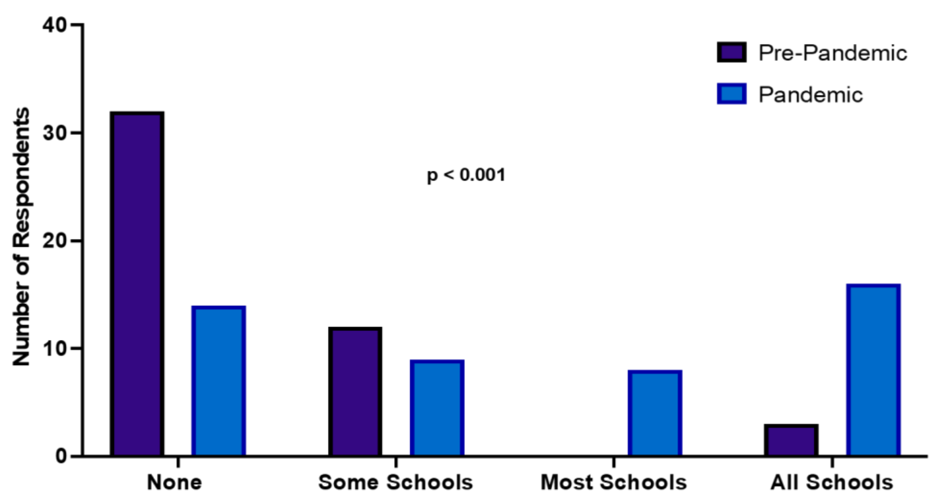
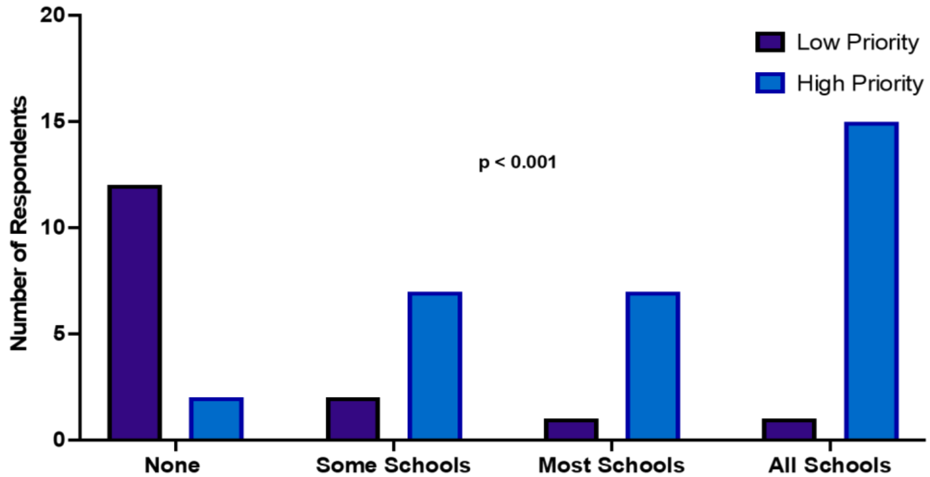


Figure 17. Implementation of higher-grade MERV filters during the pandemic between respondents who considered it low vs. high priority (n=47)



Before the pandemic, only 6% of participants had the recommended MERV 13 filters installed in all of the schools in their district. A minority of participants had filters that were MERV 7 or less (6%) or MERV 11 (15%). The majority of participants had MERV 8 filters (58%) or MERV 8 in combination with either MERV 7 or less (9%), MERV 11 (2%), or all three (4%).

Though most school districts were committed to using MERV filters with higher efficiency ratings, they were less successful at installing the recommended MERV 13 filters. Many school districts believed that their existing mechanical ventilation systems were too old to be compatible with newer filters. Many were concerned that the additional static pressure needed to support the increasing filtration efficiency from either a MERV 8 or 11 to a MERV 13 filter would overwhelm the system. As an interviewee elaborated,

> *There is a lot that goes into that. It's not as simple as swapping out the filters. One, the filters may be different sizes. Two, they're about four or five times the cost.*

Guidelines often provided generic statements that call for applying the highest possible MERV filters, provided there are not substantial negative impacts on HVAC system performance. Nevertheless, many school districts perceived that this emphasis on MERV 13 filters has had an undue influence on the schools' ability to manage expectations with key stakeholders (i.e., parents and staff). As one survey participant explained,

> *The blanket statement sent out [states] it is "recommended to install MERV 13... to provide the best ventilation." Parents and staff feel this is required, yet most of our units are older and cannot support a MERV 13 filter. So when we state we installed a higher rated MERV 11 filter, they feel we have not met the industry standard...People only read MERV 13, and that sticks in their head.*

High cost and lack of availability of filters due to increased demand were also prominent issues. Some schools told stories of being sold MERV filters that were mislabeled and ended up having lower than anticipated ratings. Others mentioned that they had inadequate staffing to handle the many filters that would have to be inspected and maintained.

The implementation of air cleaners with HEPA filters followed a similar trend. The use of air cleaners with HEPA filters in at least some of the school buildings increased significantly during the pandemic. The proportion of school districts that implemented this measure differed significantly depending on whether the measure was viewed as low priority or high priority ($p<0.001$, Figure 19). Nearly all of the respondents

(95%) who elected to not utilize any air cleaners with HEPA filters during the pandemic were those who did not prioritize its use in the first place. Alternatively, respondents (87%) who indicated that they highly prioritized air cleaners with HEPA filters significantly drove the implementation trend in either most or all of the schools.

Unlike MERV filters, high cost was the most common barrier to implementing air cleaners with HEPA filters (Figure 7). Notably, 100% of school districts who considered air cleaners with HEPA filters as low priority cited high cost as a challenge compared to only 48% of school districts who highly prioritized air cleaners with HEPA filters ($p<0.0001$).

This filtration strategy is unique because schools can obtain portable air cleaners with HEPA filters and place them strategically in otherwise poorly ventilated or under-ventilated classrooms, office spaces, and multi-purpose rooms. They can also be placed in higher risk areas such as a nurse's office or areas frequented by people with a higher likelihood of having COVID-19. One school district even noted that they installed HEPA filters in hand dryers used in bathrooms. Due to their visibility, portable air cleaners anecdotally provided appeasing optics by giving occupants a tangible sense of assurance and security. As a result, participants expressed their concern that the indiscriminate use of portable air cleaners in well-ventilated rooms may have unintended consequences in energy waste and misguided expectations. Moreover, running portable air cleaners can make considerable noise that can make classroom learning a challenge.

Figure 18. Implementation of air cleaners with HEPA filters (n=47)

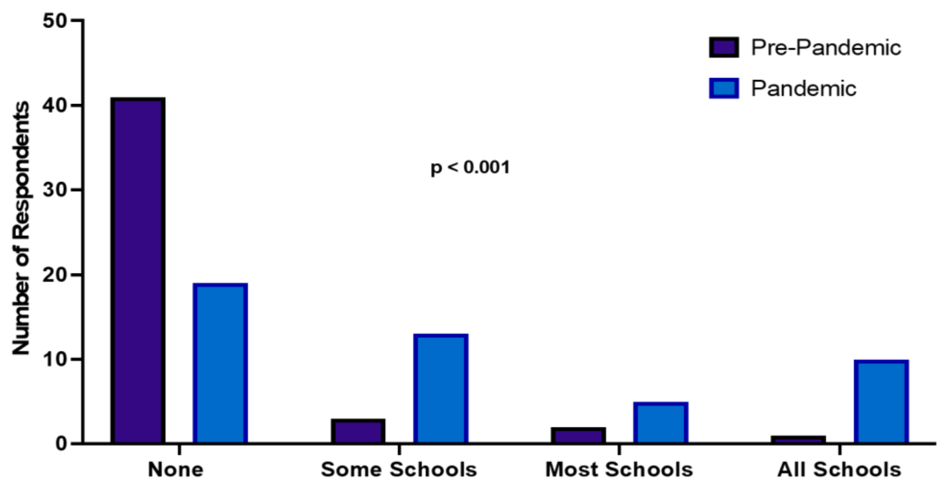
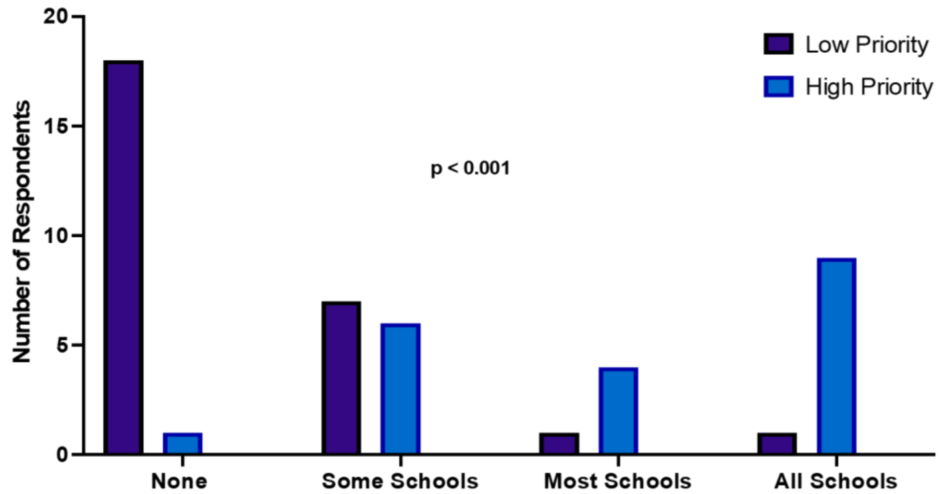


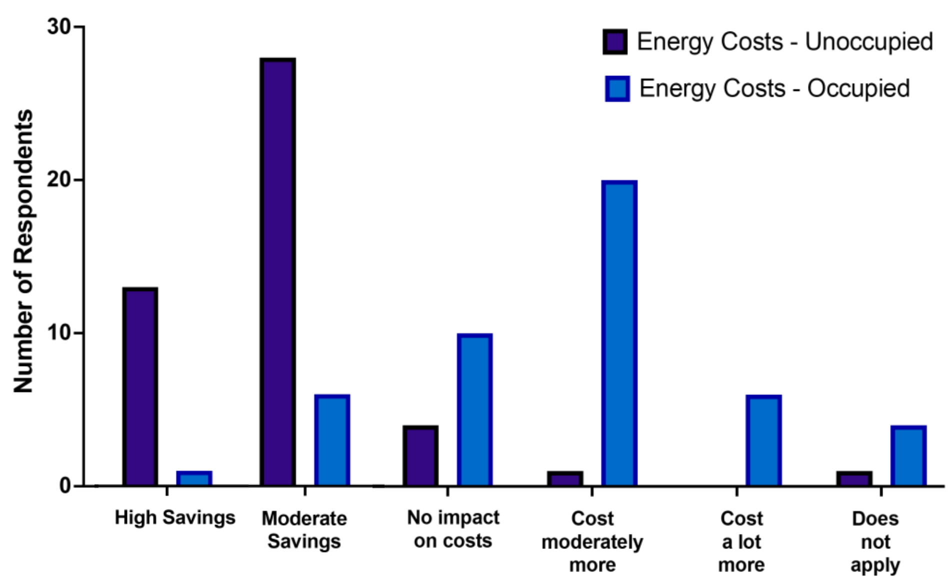
Figure 19. Implementation of air cleaners with HEPA filters during the pandemic between respondents who considered it low vs. high priority (n=47)



HVAC adjustments made during the pandemic significantly impacted energy costs, both positively and negatively.

Respondents were asked what impacts on energy costs they observed over the course of the pandemic, and responses varied based on when schools were occupied. The majority of participants noted either moderate savings (60%) or high savings in energy costs (28%) when their schools were not occupied because of the pandemic, compared with the same period the previous year (Figure 20). However, this trend reversed when respondents answered the same question about impacts on energy costs when their schools were occupied. Over half of participants estimated that their energy costs were either moderately more (43%) or a lot more (13%). Notably, 21% of participants estimated that their IAQ efforts had no impact on costs.

Figure 20. Impact on energy costs during the pandemic when schools were unoccupied vs occupied (n=47)



Pre-existing wealth, decisive leadership, and past infrastructure investments were key facilitators.

Overwhelmingly, comments from survey participants and interview respondents credited any success of their indoor air quality efforts and readiness of their overall coronavirus response to prompt leadership, a cache of pre-existing wealth (for well-funded districts), and/or past investments in infrastructure.

One interviewee recounted how the district had already upgraded all of their filters to MERV 13 at least one year before the pandemic after participating in an influential sustainability conference. Given that schools have a critical public relations role with diverse stakeholders, including parents and staff, the interviewee emphasized that the district's foresight and preparedness "was an element of reassurance for people that the district was on top of things in general, and about COVID." The interviewee further pointed out how crucial it was that the district leadership was "swift and unified in making decisions and implementing measures." Overall, the interviewee considered the school district's response a success, underscoring how the schools "have been operating in hybrid mode since September with no in-school transmission of COVID-19 documented" at the time of the interview.

The funding of K-12 school education and infrastructure is fundamentally inequitable, given its reliance on local wealth. The pandemic has only served to further entrench those inequities along racial and socioeconomic lines. School districts in our cohort that enjoyed a higher-than-average revenue stream remarked at how fortunate they were to have the resources to adapt and pivot as they needed to do during this unprecedented crisis. As one interviewee bluntly bemoaned about the harsh realities,

> *It's really sad for me to go to some of these schools and see...their COVID measure is a piece of plexiglass, and... it's like I wouldn't send my kids or...that they'd be remote learning until this is figured out.*

Large school districts with hundreds of school buildings faced unique barriers as they had to contend with the heterogeneity of building conditions and the public repercussions of their decisions. These hurdles were compounded by the lack of clear guidance and direction, as previously mentioned. As one participant described,

> *[The] major issue is the fact we have [hundreds of] schools and limited time and resources to make improvements at all schools. As such, priorities had to be set, and it wasn't well communicated what those priorities were (which schools, which measures, etc.) with fear that the community will have issues with the schools seen as low priority...*

Insights from the field: Inspection of HVAC systems, IAQ monitoring, and ventilation targets

Inspection and maintenance of current HVAC systems to ensure that they are functioning correctly are critical to any IAQ protocol. Nearly two-thirds of respondents (64%) indicated that their ventilation systems had been recently verified at the time of completing the survey, but the remaining districts had either not verified their systems or were not sure. As one interviewee detailed their experience about their school district's approach,

> *Pretty much the summer was the heavy lift, trying to figure out what we're dealing with in terms of... what sites have the ability to make ASHRAE recommendation measures ... And so that revolved around a series of site verifications that we didn't have a good handle on some of the*

> *sites ... working with the district's building automation contractor to figure out... can we log in and look at all the sites? Can we look at it at every air handler? Do all the air handlers have dampers that are working? Are some of the values that we're seeing online matching the values in the field?*

Two-thirds (66%) of respondents were regularly monitoring IAQ. However, school districts differed widely in how they were measuring IAQ and how often. Some districts relied on "intermittent" checks with handheld devices measuring carbon dioxide. Schools commonly relied on their building automation systems to measure temperature, relative humidity, and/or carbon dioxide levels. Some districts had purchased independent sensors that additionally measured volatile organic compounds (VOCs) and particulate matter (PM). The frequency of monitoring ranged widely, with some participants endorsing inspection every 1-3 years.

Targets for ventilation rates varied among school districts, as did the type of standard or target used. School districts cited everything from no explicit standards to air exchange rates expressed as air changes per hour (ACH) to volumetric flow rates described as either cubic feet per minute (CFM) per person or liters per second per person.

Some school districts used IAQ monitoring and ventilation rates as a proactive, data-based approach to inform decision-making about ventilation and filtration. As one participant detailed,

> *We monitor air quality through testing of CO, CO2, temp, dust, sometimes VOCs when buildings are occupied. In September and October, we tested all 5 measurements in every "occupiable" space in 135+ buildings, but the spaces were unoccupied at the time. As we have brought back high-need students, we have reconducted that IAQ testing and made a note of the spaces occupancy levels as well as the presence of ventilation strategies. We also conducted ACH testing at 7 buildings in November and now are doing all buildings through the beginning of March. Lastly, we [are installing] IAQ monitors (5,000) for every classroom in the district. The monitors will measure IAQ measurements live and record the data to a cloud-based software system so we can manage remotely and live and transparently report data through reports and dashboards.*

Other school districts elected a more reactive approach, justifying that their systems have been tested to be maximally optimized for safe occupancy. Therefore, unless there was an outright system failure, data monitoring of indicators such as carbon dioxide would not change decision-making because, as one interviewee explained, "any site that is open right now is going to have the best air quality that it can, given the system type."

However, many survey participants remarked on how the lack of data monitoring has led to challenges in adapting to changing weather conditions. As one survey participant wrote,

> *We...changed all outside air damper minimums to increase ventilation without a good way to know how much more fresh air is actually being brought in. During the very cold weather, this caused us to bring in even more cold air, increasing the risk of bursting pipes and increased energy use.*

Insights from the field: Challenges in finding trusted resources on IAQ technologies, setting priorities, and interpreting conflicting information

The majority (85%) of survey participants referred to ASHRAE's guidance documents to inform their decisions about air quality measures. Other popular resources used were those from the CDC (72%) and the state/local departments of public health or education (57%). Other resources mentioned included materials that came from the EPA's Indoor Air Quality Tools for Schools, WHO, IAQ experts trending on social media, the AIA Re-occupancy Assessment Tool, the Center for Green Schools at USGBC, and the HSPH Healthy Buildings Program. Qualitatively, there seems to be greater deference among participants towards the information coming from professional societies. Some school districts benefited from a longstanding relationship with HVAC and engineering experts and relied heavily on this technical assistance.

The array of different guidance and sometimes conflicting messages served as a common source of frustration for participants. There was a consistent wish for a more centralized message from ideally a consortium of well-respected institutions. As one respondent reflected,

> *One of the things that I would hope would come out of this is a layman's guide to the ventilation code and minimum requirements, because it's being interpreted so differently, that if [bodies like the CDC, Department of Education, ASHRAE, USGBC, etc.] came together and said, hey, this is what you should be doing in each [of these climate zones] ...Right now..., there's 20 different approaches, and... 20 different depths of efficacy... So just more guidance would be nice if it came from like one group of bodies rather than ... 10 different things to look at. It's sad, because nobody knows what to trust.*

Another respondent similarly expanded on the importance of a clear path of information that is customizable depending on the school districts' unique circumstances and climate zone,

> *The key thing is...we need to make sure that there's a flow of information and someone who kind of weeds through the noise to help the school districts ...to make sure that people understand what they can do and should do that [will have] the highest impact...*

When recommending IAQ solutions, it is essential to acknowledge and consider the diversity of infrastructure in school districts. Yet, the independent and siloed approaches taken due to lack of centralized state and national leadership contributed to tension verbalized by some school districts as a "keeping up with the Joneses" phenomenon. As one interviewee recounted,

> *If one of our neighboring jurisdictions is doing something, parents, employees who have kids in those districts or live or talk or follow Facebook or whatever [will say] "well, why, why aren't you doing that?"... And there's a lot of parents that speak to our parents. [It has been] an issue trying to keep up with other school districts and what they're doing because we're all independent. And we may put our money towards, you know, just different technologies or different resources.*

Another participant similarly expressed a feeling of frustration from the lack of leadership,

> *Everybody was left to fend for themselves...there was no extra funding or guidance or help. ... There's been very little to no guidance from any...county health departments... We're kind of just asking around other schools..."what are you guys doing," what is necessary versus not, and kind of going and picking and choosing what we can do.*

At the beginning of the pandemic, some school districts found it difficult to know how to set priorities since the national public health emphasis was initially on cleanliness, personal protective equipment, and physical distancing rather than mitigating airborne transmission. As one interviewee reflected,

> *Because air quality is intangible, not touchable, [the public] can't see how that could change. Unfortunately, that's probably why maybe it wasn't top on our list. But a lot of our decisions were made with the more tangible things of the six feet spacing... changing our classroom setups, changing our cafeteria setups, getting all the disinfectants, and changing our cleaning routines ... They were the more tangible... things you could see and put into practice. [At the beginning] what [we] were hearing was all the sanitation and six-foot distancing and buy the masks.*

School districts were bombarded with persistent salespersons peddling the latest air and cleaning technologies, including those with minimal evidence to-date supporting safety and efficacy. As one participant articulated these unique challenges,

> *[There were] many, and I mean many, vendors selling snake oil. [Our] community members/staff [were] not versed in building science or virus transmission [and wanted] us to implement an all-of-the-above approach without the funding.*

Our investigation focused only on school districts' application of the six most evidence-based ventilation and filtration strategies. Therefore, we cannot make any significant conclusions on the use of other advanced technologies. However, the in-depth interviews suggest that there was considerable use of adjuncts such as bipolar ionization, the application of which seemed to be more frequent in areas where traditional ventilation and filtration strategies were not possible.

Looking toward the post-pandemic world: Investment in school infrastructure is needed to address indoor air quality

Overall, high maintenance costs and outdated infrastructure in the face of changing climate conditions were the most cited challenges to continue to maintain healthy indoor air quality in a post-pandemic world. Recognizing the overall health and learning benefits, approximately 70% of respondents signaled that their schools planned to continue some to all ventilation and filtration measures implemented in response to the pandemic. This crisis has shed light on the benefits of assuring a high level of indoor air quality for infection control and overall wellness for school districts. As one interviewee remarked on the benefits of controlling the level of carbon dioxide,

> *In the future, without the pandemic, we might have considered, well, do we really need CO2 [monitors] in every single classroom?... I feel like with... everything [that] has happened, it's shown that it's so valuable because you can have one classroom, that's completely fine, and have one right next to it with super elevated CO2 levels. Definitely not an optimal learning and working environment.*

It has been documented that schools often fall short of minimum ventilation standards.[2,18-20] At the same time, a consistent and steady stream of research demonstrates that ventilation and healthy IAQ in schools are beneficial for overall health and productivity in addition to infection control. Improved IAQ increases students' schoolwork and test performance, reduces missed school days, and relieves respiratory symptoms.[18,21-23] Additionally, implementing a preventive maintenance program to address IAQ saves money in the long term.[24]

The pandemic has increased awareness of IAQ concerns, and survey and interview respondents were generally hopeful that the awareness might lead to increased support for healthy indoor environments in the longer term. As one respondent articulated,

> *In the cities, [IAQ has] been a concern because of asthma. A lot of inner-city kids suffer from asthma. So air quality is absolutely necessary. Now, because the pandemic is affecting everybody, not just folks who suffer from asthma...ventilation is now the sexy word that's on people's minds. But before, there has always been an issue with ventilation. We just dealt with it. Now, we have to deal with it.*

However, it is essential to recognize that school districts will face difficult ongoing decisions in dealing with the financial costs that have been incurred during this public health crisis. As one interviewee stated,

> *"We deferred money from a lot of projects. There's going to be a lot of deferred maintenance, and there's going to be things that just don't happen, projects that schools want and need that isn't going to happen for a few years until we can recover because of what we had to spend on these measures...But we reprioritized, and it was important to do that.*

Conclusion

This report is the first known national effort to collect school district-level data on the experiences and challenges in implementing IAQ measures in response to the COVID-19 pandemic. Our study fills a critical gap in informing how policymakers and non-profits can better serve schools' needs as they continue to face uncertainty during the COVID-19 pandemic and will continue to face in future ones. The results suggest that school districts still have unmet needs in addressing indoor air quality, in particular, when faced with cost constraints and outdated building infrastructure in the face of changing conditions. The science has been evident on the longstanding public health and economic benefits to enhancing indoor air quality. With additional investment in school infrastructure, school districts will be better prepared to manage air quality risks in the future.

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Appendix A

Locale Classifications Adapted from NCES

Large City: Territory inside an urbanized area and inside a principal city with a population of 250,000 or more

Midsize City: Territory inside an urbanized area and inside a principal city with a population of less than 250,000 and greater than or equal to 100,000

Small City: Territory inside an urbanized area and inside a principal city with a population of less than 100,000

Suburban: Territory outside a principal city and inside an urbanized center

Town: Territory inside an urban cluster but outside an urbanized area

Rural: Census-defined rural territory

Appendix B

Survey Questions and Answer Options

1. What is the name of your school district? Publicly-available district data will be used for analysis. Please be assured that individual responses from this survey will be kept confidential and results will only be shared in aggregate.

2. Given the anticipated need to support safe in-person instruction during the COVID-19 pandemic, for your school district, please indicate how much of a priority implementing or optimizing each listed air quality strategy has been to reduce viral transmission. In other words, what has your district placed the highest value on accomplishing in its schools? (Options: high priority, low priority)

   A. Installing filters with higher MERV ratings (MERV 13 or higher is recommended)

   B. Installing air cleaners with HEPA filters

   C. Increasing ventilation/outdoor air supply through HVAC system

   D. Opening windows

   E. Using additional fans in doors and/or windows to increase ventilation and exhaust

   F. Pre-occupancy and post-occupancy flushing strategy

3. Before the COVID-19 pandemic, had your school district already implemented any of the following strategies in your schools' classrooms? (Options: None of the schools, some of the schools, most of the schools, all of the schools)

A. Installing filters with higher MERV ratings (MERV 13 or higher is recommended)

i. If you did not use MERV 13+ filters in all of your schools, which MERV filters did you use in the majority of your schools before the pandemic? Check all that apply (Options: MERV <7, MERV8, MERV 11)

B. Installing air cleaners with HEPA filters

C. Increasing ventilation/outdoor air supply through HVAC system

D. Opening windows

E. Using additional fans in doors and/or windows to increase ventilation and exhaust

F. Pre-occupancy and post-occupancy flushing strategy

4. During the months of the COVID-19 pandemic, has your school district implemented any of the following strategies in your schools' classrooms? ((Options: None of the schools, some of the schools, most of the schools, all of the schools)

A. Installing filters with higher MERV ratings (MERV 13 or higher is recommended)

B. Installing air cleaners with HEPA filters

C. Increasing ventilation/outdoor air supply through HVAC system

D. Opening windows

E. Using additional fans in doors and/or windows to increase ventilation and exhaust

F. Pre-occupancy and post-occupancy flushing strategy

5. How have your district's choices been informed by the age of students in each school? (text answer box)

6. Which measures do you plan to continue after the pandemic subsides? (text answer box)

7. How are you monitoring air quality in most or all of your schools, and what are you monitoring? (text answer box)

8. Is your district using "safer/greener" options from EPA's N List to clean and disinfect most or all of your schools during the pandemic? (Options: Yes, No, Unsure)

9. How has your school district funded or plan to fund these new indoor air quality measures? Check all that apply. (Options: Federal funding from the Education Stability Fund within the CARES Act (Coronavirus relief funding), State funding sources, School district operation budget, School district capital budget, Other funding choices not listed)

10. Please tell us more detail about how these measures have been funded. (text answer box)

11. We know this has been a rapidly changing school year, month to month. Please select the option that most accurately reflects the operating status of the majority of the schools in your district for each month. (For each month from March 2020 to January 2021, options given: School not in session, Virtual learning only, Primarily in-person learning, Only select populations in-person and every else virtual, Hybrid learning (in-person and virtual))

12. During times when your schools were NOT occupied because of the pandemic, which HVAC and lighting shutdown procedures did you use in the schools, if any? (Options: No shutdown, Schools in unoccupied mode during the day, Schools turned back to night or weekend mode during the day)

13. During times when your schools were NOT occupied because of the pandemic, what impact on energy costs did you see, compared with the same period the previous year? (Options: High savings, Moderate savings, No impact on overall costs, Cost moderately more, Cost a lot more, Does not apply)

14. During times when your schools were occupied, if you have implemented air quality improvement strategies to protect building occupants, what impact on energy costs have you seen, compared with the same period the previous year? (Options: High savings, Moderate savings, No impact on overall costs, Cost moderately more, Cost a lot more, Does not apply/Did not implement air quality improvement measures)

15. Please indicate the status/capabilities of the HVAC system in the majority of your schools. Check all that applies. (Options: Primarily systems with ventilation verified by control components or recent measurement and verification, Primarily systems with ventilation NOT verified by control components or recent measurement and verification, Unsure)

16. What resources, guidance, and/or certifications have you used to inform your decisions about which air quality measures to implement? Please check all that applies. (Options: ASHRAE Building Readiness Guidance, ASHRAE Schools and Universities Guidance, CDC, State-level department (e.g. public health, education), AIA Re-Occupancy Assessment Tool, Other not listed)

17. Please provide more details about the resources you used as well as other resources not listed above. (text answer box)

18. Whether or not you implemented the recommended air quality measures, what barriers and challenges did you see in considering them? (check all that apply)

A. Installing filters with higher MERV ratings (MERV 13 or higher is recommended) (Options: Not a priority of school district leaders, School community did not support action, High cost, Lack of availability of filters, Schools not designed to support this strategy, Lack of access to technical assistance or trusted advice)

B. Installing air cleaners with HEPA filters (Options: Not a priority of school district leaders, School community did not support action, High cost, Lack of availability of purifiers and/or filters, Lack of access to technical assistance or trusted advice)

C. Increasing ventilation/outdoor air supply through HVAC system (Options: Not a priority of school district leaders, School community did not support action, Schools not designed to support this strategy, Lack of access to technical assistance or trusted advice)

D. Opening windows (Options: Not a priority of school district leaders, School community did not support action, Schools not designed to support this strategy, Lack of access to technical assistance or trusted advice, Climate/weather challenges)

E. Using additional fans in doors and/or windows to increase ventilation and exhaust (Options: Not a priority of school district leaders, School community did not support action, High cost, Schools not designed to support this strategy, Lack of access to technical assistance or trusted advice, Climate/weather challenges)

F. Pre-occupancy and post-occupancy flushing strategy (Options: Not a priority of school district leaders, School community did not support action, Schools not designed to support this strategy, Lack of access to technical assistance or trusted advice)

19. Other challenges you and your team have confronted while attempting to implement air quality measures during the COVID-19 pandemic? (text answer box)

20. We are looking for participants for in-depth 30-minute interviews about air quality measures in school districts. If you are able to participate, please write in your email, and we will contact you shortly. These interviews are critical for us to better understand how school districts are adapting on the ground and how non-profits and government entities can better support you in your indoor air quality endeavors during the pandemic.

Appendix C

Perspectives from Higher Education

While our investigation focused on the responses from K-12 school districts, we were able to interview and survey two universities. Given the small sample size, we are unable to make definitive conclusions about the unique experiences in higher education during the pandemic. However, our results suggest that the findings made in this paper may apply to colleges and universities.

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