MANAGING AIR QUALITY DURING THE PANDEMIC:

How K-12 Schools Addressed Air Quality in the Second Year of COVID-19

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EXECUTIVE SUMMARY

The COVID-19 pandemic has impacted daily life for most Americans since it began to spread widely in early 2020. As knowledge of the important airborne transmission mode for SARS-CoV-2 became clearer, many K-12 schools implemented airborne infection control measures to reduce interruption to in-person learning and address community spread. It is well-accepted that measures to reduce airborne infection contribute to slowing community transmission and reducing the societal impact of COVID-19, future pandemics, and seasonal epidemics. Building engineering controls such as ventilation and filtration are effective strategies and are especially important given that widespread masking, immunization, and testing are insufficient to eliminate outbreaks. However, the effective implementation of such controls in schools presents challenges related to heating, ventilation, and air conditioning (HVAC) equipment capabilities, building features, impressions of effectiveness, internal and external opinion, budget, and more. School districts have faced barriers to broad implementation across schools, such as diverse building stock and disparate control systems, climate, and other indoor air quality threats due to wildfires or urban pollution.

This report builds on "Preparation in the Pandemic: How Schools Implemented Air Quality Measures to Protect Occupants from COVID-19," published in April 2021 by the Center for Green Schools with technical support from ASHRAE. This update reflects how the pandemic, and schools' responses to it, have evolved in the intervening months.

As a follow-up to the prior survey conducted in February–March 2021, we conducted a national survey of public school districts in October–December 2021 to assess the implementation of a range of ventilation, filtration, disinfection, and air quality monitoring strategies. We received complete survey responses from 88 districts representing over 4,000 schools and over 2.6 million students, mostly representative of city and suburban districts.

We found that:

- **School districts prioritized** increasing outdoor air intake. Increasing outdoor air through HVAC systems was the most prevalent building engineering control measure taken, followed by opening windows.
- **Similar to the last report,** the top challenge for schools in implementing many of the recommended indoor air quality (IAQ) measures was that buildings' HVAC systems were not designed to implement the recommendations.
- **School district characteristics** such as demographics, locale, and size were not associated with the number of IAQ measures taken, but were associated with the implementation of specific measures, such as increasing outdoor air through HVAC systems and assessing outdoor air delivery.

- **American Rescue Plan** Elementary and Secondary School Emergency Relief (ARP ESSER) funding has been used to support the implementation of IAQ measures more than funding from operating or capital budgets. Just over half of school districts reported that they felt they had access to funding to support additional engineering controls.
- **Non-urban districts** were more likely to lean on state and local guidance, and urban districts were more likely to use federal-level guidance and guidance from national organizations like ASHRAE.
- **Over a quarter of districts** responded that there were no new plans to implement additional ventilation, filtration, or other building changes in schools.

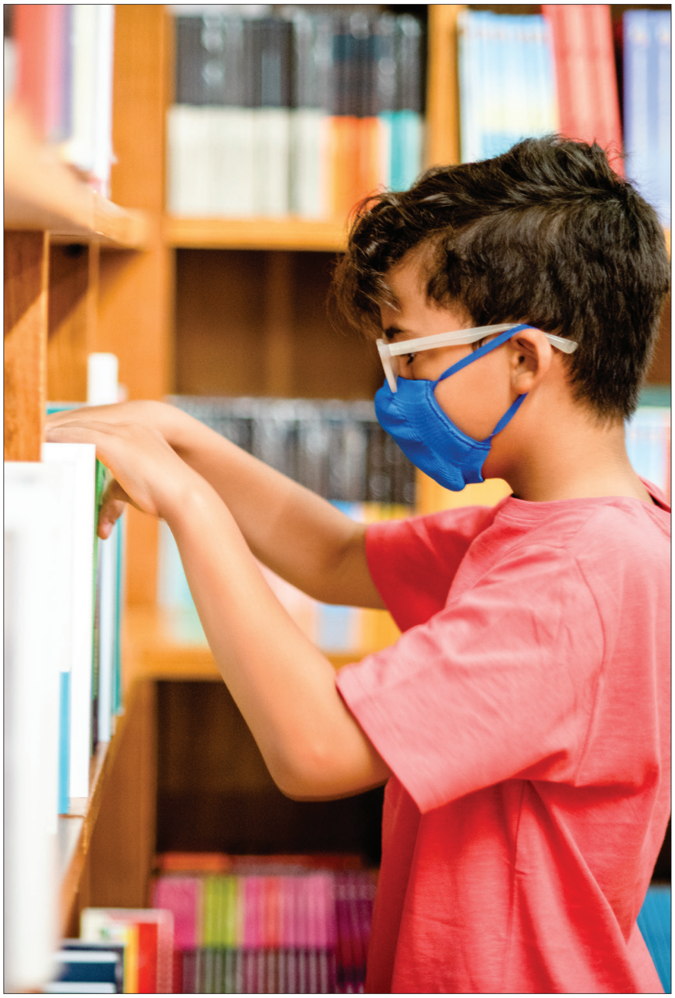
We conducted follow-up focus group sessions with survey respondents that added context and enriched our understanding of district-level implementation, challenges, successes, and future plans. These conversations highlighted on-the-ground stories about the importance of building systems in preventing the spread of COVID-19.

> “*After increasing fresh air ventilation through the pandemic (as well as other mitigation strategies) we found that there was zero spread in our school through the entire previous school year and a half despite very high community spread. During the first two weeks of the new school year in 2021, we had an outbreak at one elementary school with spread throughout the school, which required us to switch to remote learning for a week at that school. All other mitigation protocols remained in place between school years. Upon investigation, we found that the controls had been stuck in a humidity override sequence from the summer, which fully closed classroom dampers in the entire school. This is anecdotal evidence at best, but while an unpopular opinion, it proved to me that ventilation in schools is much more effective at mitigation than masks and distancing.*”
>
> — Survey Respondent

The results highlight the urgent need to better support school districts with implementation of airborne infection control strategies to mitigate the immediate COVID-19 threat, as well as future pandemics, seasonal epidemics, and to improve the overall indoor air quality in the near- and long-term. Additionally, results indicate that school districts in different locales are seeking guidance from different types of sources, with urban school districts more likely to look to federal and national sources and non-urban more likely to seek out local or state sources. Widespread education of school system administrators and staff is needed to ensure that they are aware of both the widely agreed-upon indoor air quality recommendations and the parameters around the use of federal COVID-19 relief funds on indoor air quality measures.

INTRODUCTION

Since it became widespread in the U.S. in early 2020, the COVID-19 pandemic has presented myriad challenges to K-12 school districts throughout the United States and elsewhere. The pandemic presented societies with difficult decisions about how to achieve continuity of high-quality education and illuminated existing inequities within the educational system (Dickinson et al., 2021). School administrators, teachers, staff, students, families, and communities have wrestled with how to balance risks of COVID-19 transmission in schools with the importance of in-person learning for student success. Effectively reducing transmission risk in schools has the dual benefits of supporting educational and societal continuity and reducing overall community spread (Gurdasani et al., 2021, p. 19; Hyde, 2020; Public Health England for the Department of Health, 2014).



The question of how to address COVID-19 in schools has dominated airwaves, social media, and public meetings across the United States. The nature of the COVID-19 pandemic and responses to it have continued to evolve rapidly, sometimes daily. Decision-makers have encountered varied, if not conflicting, guidance on control strategies, including masking. Since the last national survey on IAQ measures in schools, published by the Center for Green Schools in April 2021, widespread administration of vaccines in the United States has changed the public perception of the virus, and the emergence of new variants has meant that guidance from state and federal authorities continues to adapt to changing conditions.

Since 2020, a range of organizations have issued guidance on addressing the COVID-19 pandemic directed towards schools. The advice provided by public health experts and building professionals focused primarily on reducing airborne concentration of infectious aerosols. Strategies for doing so included increasing outdoor air supply mechanically (through the HVAC system) or naturally (by opening windows) and removing contaminants through filtration.

Emergency federal COVID-19 funding provided support for schools to implement infection control measures like acquisition of air cleaners or upgrades to school HVAC systems. Federal funds can be used in a variety of ways to help support the safe operation of schools and to address the impact of the pandemic on students. For the latest round of emergency federal funding, known as the American Rescue Plan Elementary and Secondary School Emergency Relief (ARP ESSER), the U.S. Department of Education provided guidance on strategies to improve ventilation and filtration in schools. These funds can be used to implement facilities improvements that address the risks of COVID-19, but there are many competing priorities as districts spend the funding. Most of the ARP ESSER funds have not yet been spent, and the process varies widely by which districts make decisions about using these funds for indoor air quality improvements.

Though some data exists about whether school districts are planning to use their ESSER funds on HVAC repairs and maintenance, this information is too vague to understand the actual potential impact on air quality. Additionally, the data collection on indoor air quality measures is often lacking in contact tracing and studies of control measure effectiveness. For example, a national study of COVID-19 controls in schools evaluated masking, restricted entry, spacing, student cohorting, desk shields, part time school, no extracurriculars, and outdoor instruction, but did not examine indoor air quality measures (Lessler et al., 2021). Therefore, we believe the data from this survey provide the only national information on the extent to which indoor air quality measures have been implemented in schools.

Here, we build on a national survey of U.S. K-12 schools conducted during 2020 (Hoang & Heming, 2021) through a survey administered in October–December 2021—with follow-up focus group interviews conducted in February–March 2022—that aimed to understand the extent of indoor air quality control measure implementation in public school districts, as well as factors that influenced decision-making, challenges facing implementation, perceived benefits, and plans for future indoor air quality.

The survey we conducted aimed to characterize the experience of school districts on the front lines of the pandemic and the decision-making involved in reducing transmission risk in schools. The goal of this research was to identify opportunities to strategically support school districts in their implementation of indoor air quality and for informing policy. Gathering an on-the-ground perspective of efforts both successful and unsuccessful provides a medium to share knowledge and best practices among professionals and will also contribute findings that can be applied to future advocacy work and research.

METHODOLOGY

We implemented a mixed methods research design composed of a quantitative survey protocol with subsequent qualitative data gathering through focus groups. The survey questionnaire was developed to build upon the one employed in the previous year by Hoang and Heming, which asked about implementation of indoor air quality actions as recommended by the ASHRAE Epidemic Task Force and the Healthy Buildings Program at Harvard T. H. Chan School of Public Health. For this year's survey, school district-level facilities managers (or others involved in the implementation of building control measures for COVID-19), were contacted to respond to a 24-question survey. The survey addressed:

a) **implementation of engineering,** behavioral, and administrative controls, and indoor air quality monitoring in schools across districts,

b) **technical information and funding resources** used and challenges faced regarding indoor air quality implementation,

c) **measured or perceived costs and benefits** of indoor air quality implementation measures, and

d) **plans for promoting healthy indoor environments** beyond the pandemic and perceptions of associated pandemic- and non-pandemic-related benefits.

The survey questions were designed collaboratively by Lawrence Berkeley National Laboratory and the Center for Green Schools at USGBC, with input from ASHRAE. The Center for Green Schools used SurveyMonkey to collect responses during October–December 2021. Survey respondents had the option to only provide the name of their school district and job title or role and remain anonymous. Survey respondents could opt to leave their email address for a follow-up interview. The Center for Green Schools led the survey recruitment effort, including additional outreach through ASHRAE networks, the U.S. Department of Energy's Efficient and Healthy Schools Campaign, the Environmental Protection Agency (EPA) Indoor Air Quality Tools for Schools Program, public health agencies, and other organizations that work with schools.

Following completion of survey response collection, semi-structured focus group interviews were conducted during February-March 2022 among respondents who indicated interest and agreed to participate. The focus group interviews sought to gather more information about how decisions were made and what resources could help in the future. Survey and focus group questions are included in the appendices.

For data analysis, school districts were linked with publicly available sociodemographic information from National Center for Education Statistics (NCES) records. Locales were assigned at the district level. Descriptive statistics for response rates for each survey question were produced. As part of an exploratory analysis, statistical tests (ANOVA, t-tests, and Poisson and logistic regression) were used to evaluate district-level features as potential predictors of district-level IAQ implementation, reported costs, perceived benefits, challenges, funding sources, and plans for future IAQ work.

OVERVIEW OF RESPONDENTS

We received complete survey responses from 94 respondents from 88 districts that could be verified in the NCES database. A single response was selected for inclusion among four districts with multiple responses, leaving one response from each of 88 respondent districts. The median survey completion time was 16 minutes.

The sample of 88 districts represented 4,069 public schools and 2,651,972 K-12 students (not including adult education students). The sample was distributed fairly evenly geographically across the U.S. by state (Figure 1), and mostly reflective of urban and suburban districts, with only 6% and 12% of responses coming from town or rural districts, respectively (Table 1). Despite underrepresenting township and rural districts, the sample was more representative of the national average of students by locale, given higher concentration of students in cities and suburbs compared with towns and rural locales. Overall, the sample of districts had less poverty and a greater White population when compared with the national average. Focus group participants (N=13) had similar characteristics as the overall sample.

Figure 1. Respondents by state (N=88). Tan=no respondents in that state.

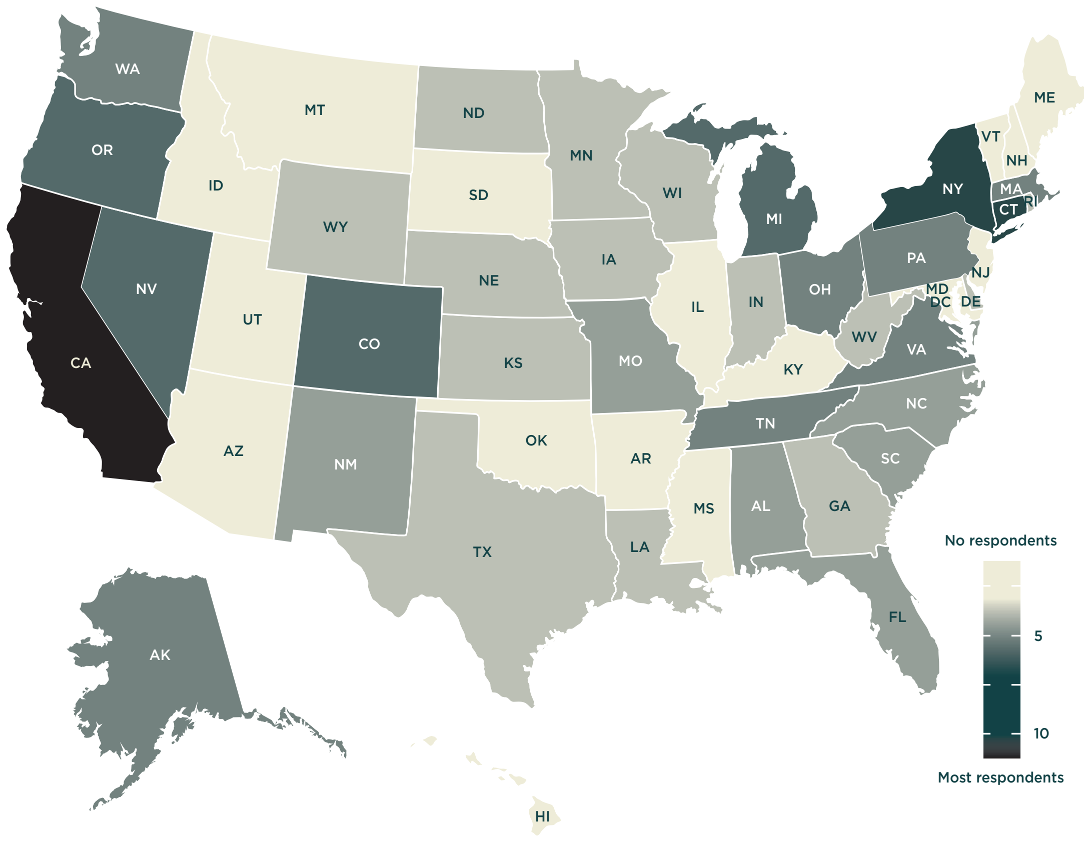


Table 1. Sociodemographic information of respondent districts compared with national averages

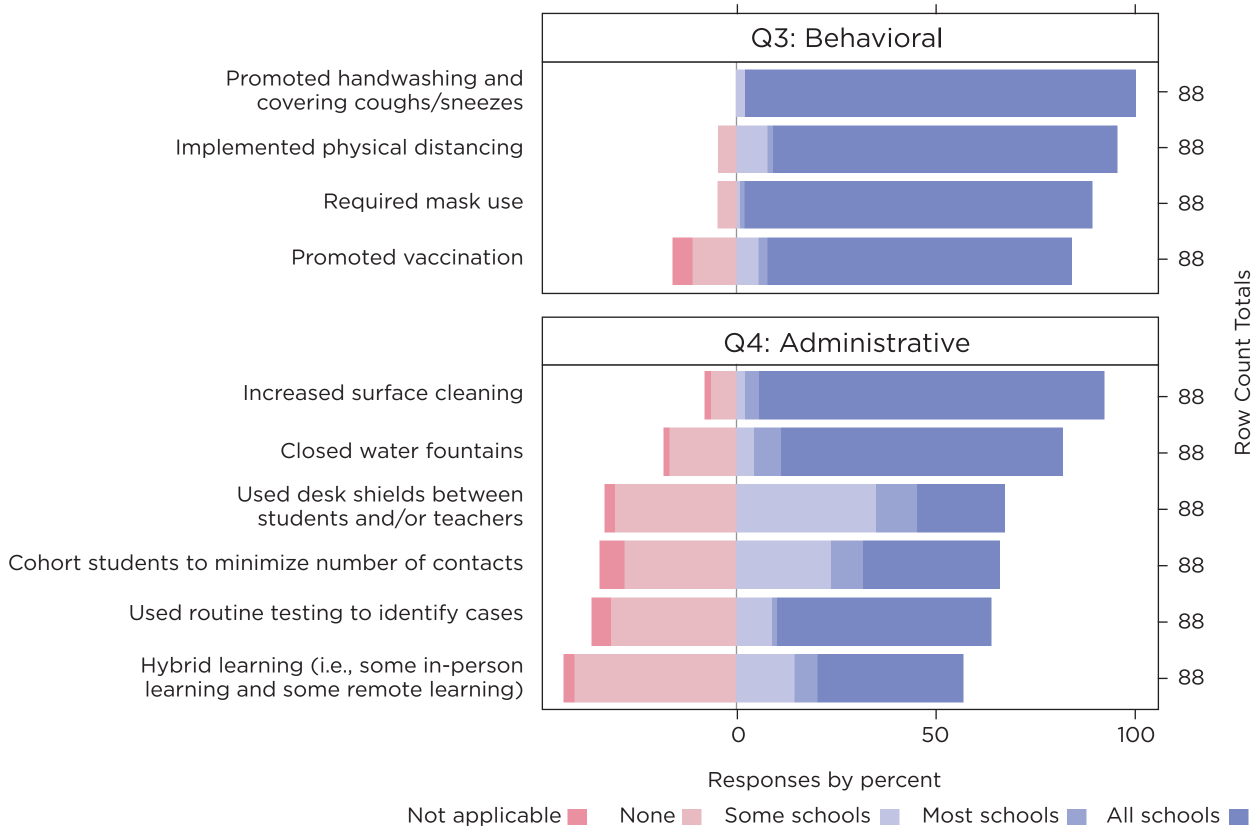
District characteristic	All respondents (N=88)	Focus group respondents (N=13)	National average[2]
	District-level mean (standard deviation appears in parenthesis)		
Student population	30,136 (59,249)	34,573 (28,343)	3,588 (14,535)
N operational schools	46 (75)	58 (47)	7 (22)
Student-teacher ratio	15.8 (3.8)	16.3 (2.5)	14.4 (9.8)
% Below poverty	12.5% (8.4)	13.8% (7.9)	16.3% (0.13)
% White population	53% (25)	44% (20)	70% (28)
	District count (%)		
Locale • City • Suburban • Town • Rural	 35 (40%) 37 (42%) 5 (6%) 11 (12%)	 6 (46%) 4 (31%) 1 (8%) 2 (15%)	 813 (6%) 3,158 (23%) 2,440 (18%) 7,072 (53%)
Region • Northeast • Midwest • South • West	 21 (24%) 16 (18%) 19 (22%) 32 (36%)	 1 (8%) 2 (15%) 3 (23%) 7 (54%)	 2,852 (21%) 4,874 (36%) 3,117 (23%) 2,640 (20%)
FRPL eligibility[1] • High (>75%) • Mid-high (>50-75%) • Mid-low (>25-50%) • Low (≤25%)	 8 (9%) 24 (27%) 35 (40%) 21 (24%)	 2 (15%) 3 (23%) 8 (62%) 0 (0%)	 1,783 (13%) 4,188 (31%) 4,953 (37%) 2,559 (19%)

[1] FRPL=free or reduced price lunch program.
[2] Data taken from 2017-2018 NCES data used in the State of our Schools 2021 report.
Data Sources: Census SAIPE, NCES District database, NCES ELSI, NCES EDGE

District-level face mask use data compiled by the data services firm, Burbio, was used to compare the sample population with a large, national sample. The Burbio national sample of 500 school districts reported masks were required for students and staff in about two-thirds (68%) of districts nationwide on November 5, 2021. Among respondent districts to this survey, a substantially higher percentage (95%) required at least some masking in schools.

The respondent pool for this report provides useful insights but is not strictly representative of the overall national population. Compared with the Burbio national sample, districts were more likely to have implemented masking and potentially other administrative and behavioral controls to reduce COVID-19 transmission (Figure 2). A high number of the surveyed districts implemented handwashing and cough/sneeze hygiene (98%), mask requirements (93%), physical distancing (86%), and vaccine promotion in all their schools (76%). Eleven percent of districts did not promote vaccination.

Figure 2. Infection controls focused on behavioral and administrative measures (N=88).



Administrative infection control efforts received a range of reported use frequency across sample districts. Eighty-six percent of districts increased surface cleaning and 71% of districts closed water fountains in all schools. Routine testing, hybrid learning, cohorting students, and use of desk shields were used in fewer districts and with more variation in frequency across district schools.

Recruitment of respondents through the EPA IAQ Tools for Schools program and Center for Green Schools networks likely contributed to selection bias toward districts that were more engaged with indoor air quality work. If this population of respondents is to be considered more responsive to implementing pandemic control measures, there is still substantial work to be done to support more widespread implementation of effective IAQ-based controls.

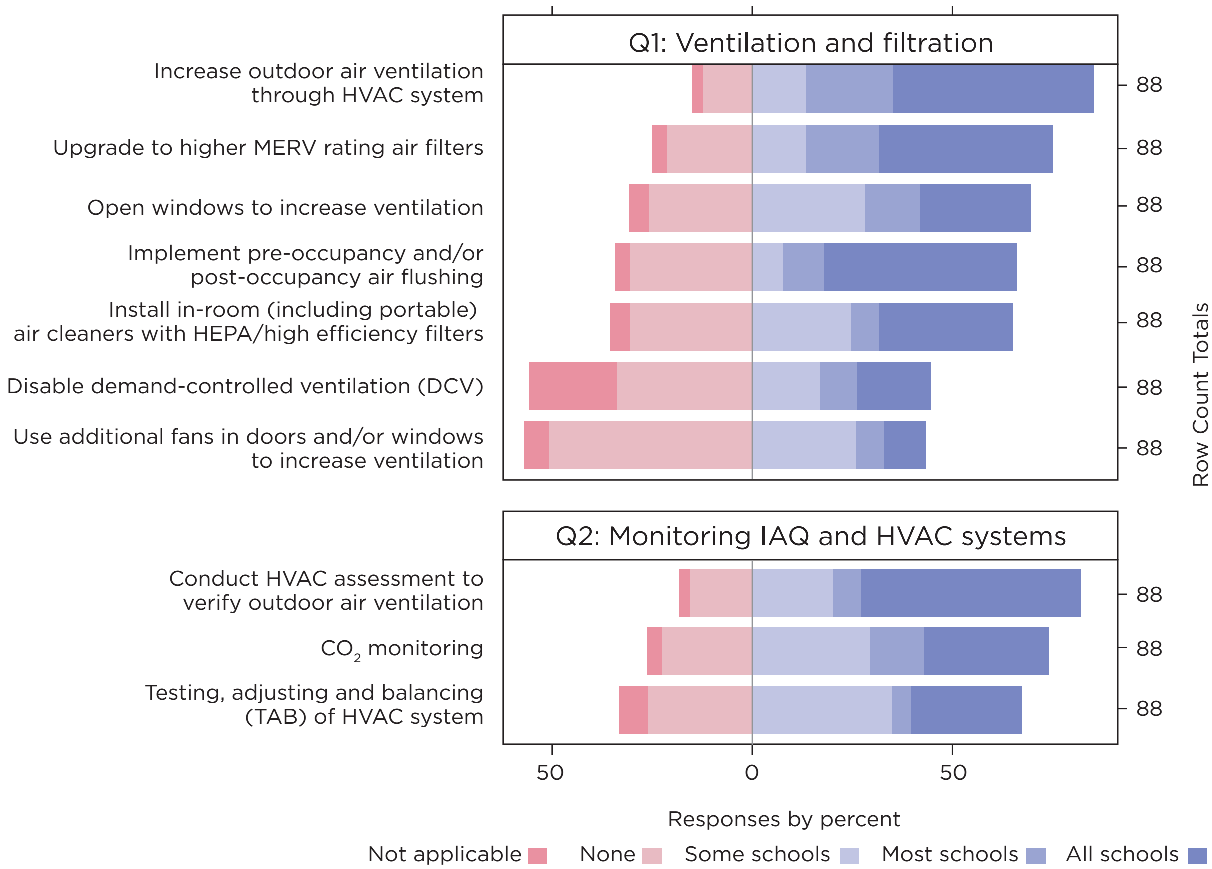
MEASURES EMPLOYED

Increased ventilation through HVAC was the most commonly implemented IAQ building engineering control or monitoring strategy.

Increasing outdoor airflow through the HVAC system was the most widely used IAQ building engineering control or monitoring strategy reported by districts (Figure 3). The survey did not specify the level of increase; respondents were asked about their implementation of any increase in outdoor air. This strategy was implemented to some degree in 85% of districts, and 50% of districts reported that all of their schools implemented increased outdoor air via HVAC. Conducting HVAC assessment to verify outdoor air ventilation rates was also commonly deployed, with 81% of districts reporting use in at least some schools and 55% reporting use in all of their schools. Taken together, these two measures (increasing outdoor airflow and verifying outdoor air ventilation rates) indicate a heavy emphasis on using HVAC systems to introduce outdoor air into classrooms among respondents.

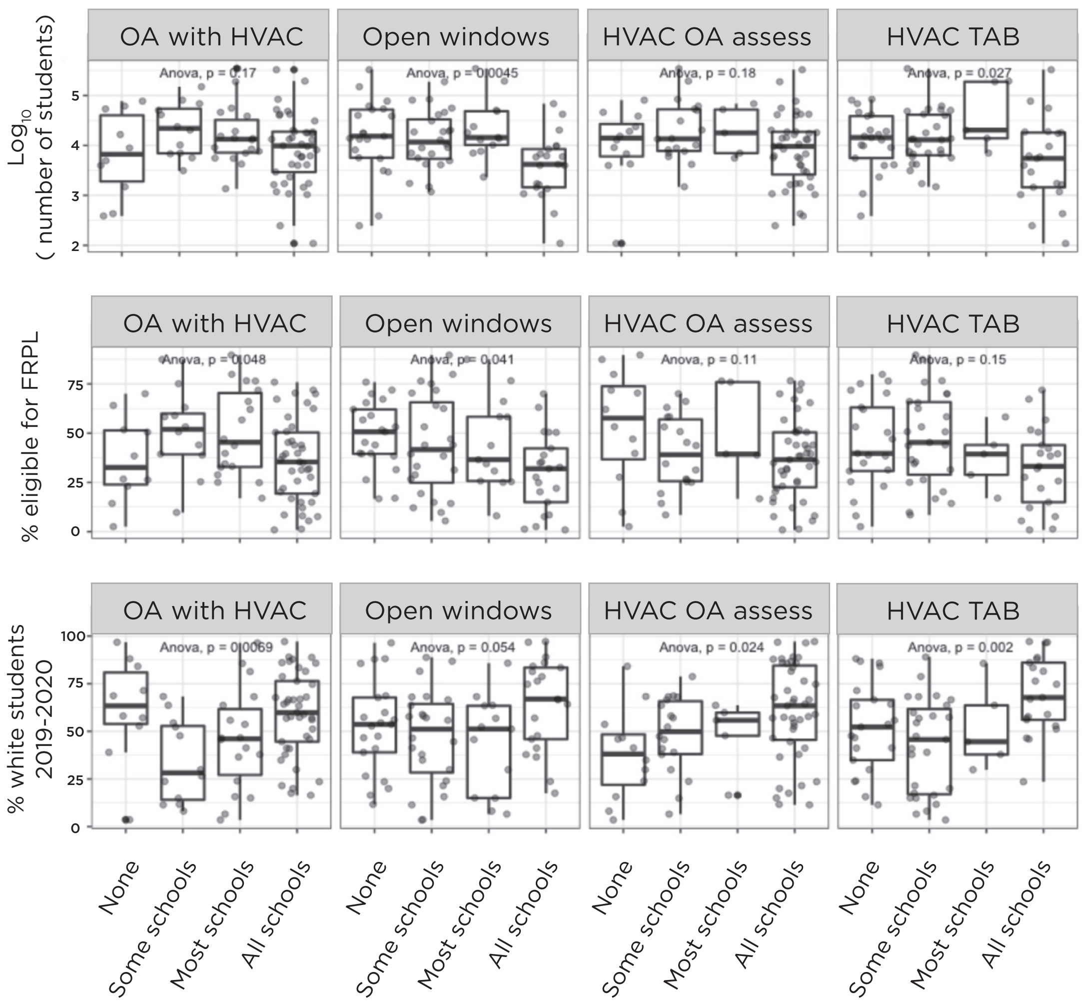
Other measures, including upgrading to higher efficiency filters (generally with higher Minimum Efficiency Reporting Values [MERV] ratings), opening windows, pre-/post-occupancy air flushing (generally during daytime hours), use of in-room filtration-based air cleaners, conducting CO_2 monitoring, and conducting testing, adjusting, and balancing of HVAC systems were all used to some degree in more than half of the surveyed districts. Disabling demand-controlled ventilation and using fans in windows and/or doors (above usual) to increase ventilation were the approaches used with lowest frequency, with less than half reporting any use. Ventilation and filtration strategies were used by a much greater proportion of districts than air disinfection by germicidal ultraviolet light (GUV). Compared with the implementation of behavioral and administrative strategies discussed earlier (Figure 2), building-related strategies like HVAC assessments, CO_2 monitoring, and interventions by ventilation and filtration were implemented in fewer districts and at a lower frequency across schools in districts where they were implemented.

Figure 3. Airborne infection control measures focused on ventilation, filtration, HVAC assessment, and CO_2 monitoring (N=88).



The overall number of indoor air quality measures implemented in at least some schools was not associated with any district-level characteristics tested. However, when looking at the implementation of individual measures, four IAQ measures—increasing outdoor air with HVAC, opening windows, assessing outdoor air delivered by HVAC, and testing, adjusting, and balancing HVAC—show some associations with district characteristics (Figure 4). The implementation of these IAQ measures was found to be associated with student demographics. Districts with a higher percentage of White students were generally more likely to implement these four IAQ measures in all district schools. Larger districts and districts with higher percentage of free and reduced-price lunch (FRPL) eligibility were less likely to implement several of these IAQ measures in all schools. Locale was not found to be associated with the level of IAQ measure implementation across district schools.

Figure 4. Boxplots and ANOVA p-values for the extent of implementation of ventilation, filtration, monitoring, and HVAC assessment by district population characteristics.



Number of students:
Larger districts were less likely to report opening windows and doing TAB work at all schools.

% FRPL eligibility:
Districts with higher percent FRPL eligibility were less likely to report opening windows and increasing outside air with HVAC at all schools.

% White students:
Districts with higher percent White students were more likely to implement all four IAQ measures at all schools.

FOCUS GROUP INSIGHTS

Focus group discussion revealed a common interest in central HVAC air systems, including the maximization of outdoor air when possible and filtered recirculated air when climatic conditions reduced feasibility of bringing in substantial outdoor air. The strategy of using standalone filtration devices, in classrooms for example, was met with some hesitation due to doubts about the long-term sustainability related to maintenance. There was uncertainty about how to think about long-term use of portable air cleaners post-pandemic, and districts did not wish to acquire many new devices that might potentially turn into “junk” later on.

However, those that did use standalone air cleaners reported that teachers appreciated having them because they provided a sense of security that there was some visible airborne infection control measure within indoor spaces. Focus group participants noted that contributions of the HVAC system were less trusted by teachers and staff, perhaps because they were less conspicuous given their integration into the building, and perhaps because the HVAC system actually did have low capacity to deliver outdoor air or recirculated filtered air.

Districts reported using some process to evaluate indoor air quality and flag certain spaces for additional air cleaning, such as increasing outdoor air through HVAC systems and/or adding in-room air cleaners. However, respondents did express some confusion about which tools and strategies to use for assessing indoor air quality, indicating that additional guidance would be helpful.

With respect to making changes to provide COVID-19-safe learning environments, there was a common feeling that changes to HVAC would provide enough protection for COVID-19 control. It was noted that the delivery of additional outdoor air via HVAC systems is limited during extremely hot, cold, dry, or humid outdoor conditions, revealing acknowledgement of some limits to HVAC in creating safe spaces. Concern associated with elevated energy use and costs associated with bringing in and conditioning increased volumes of outdoor air ventilation by HVAC was commonly expressed.

Districts reported a concern for equitable implementation of control measures across schools. Providing an equitable implementation of building engineering control measures for airborne infection control was described as a hindrance to using certain strategies across the entire district. Specifically, for some districts, upgrading to MERV 13 or higher filters was noted as a control strategy that could not be applied to all buildings or systems and was therefore not used at all.

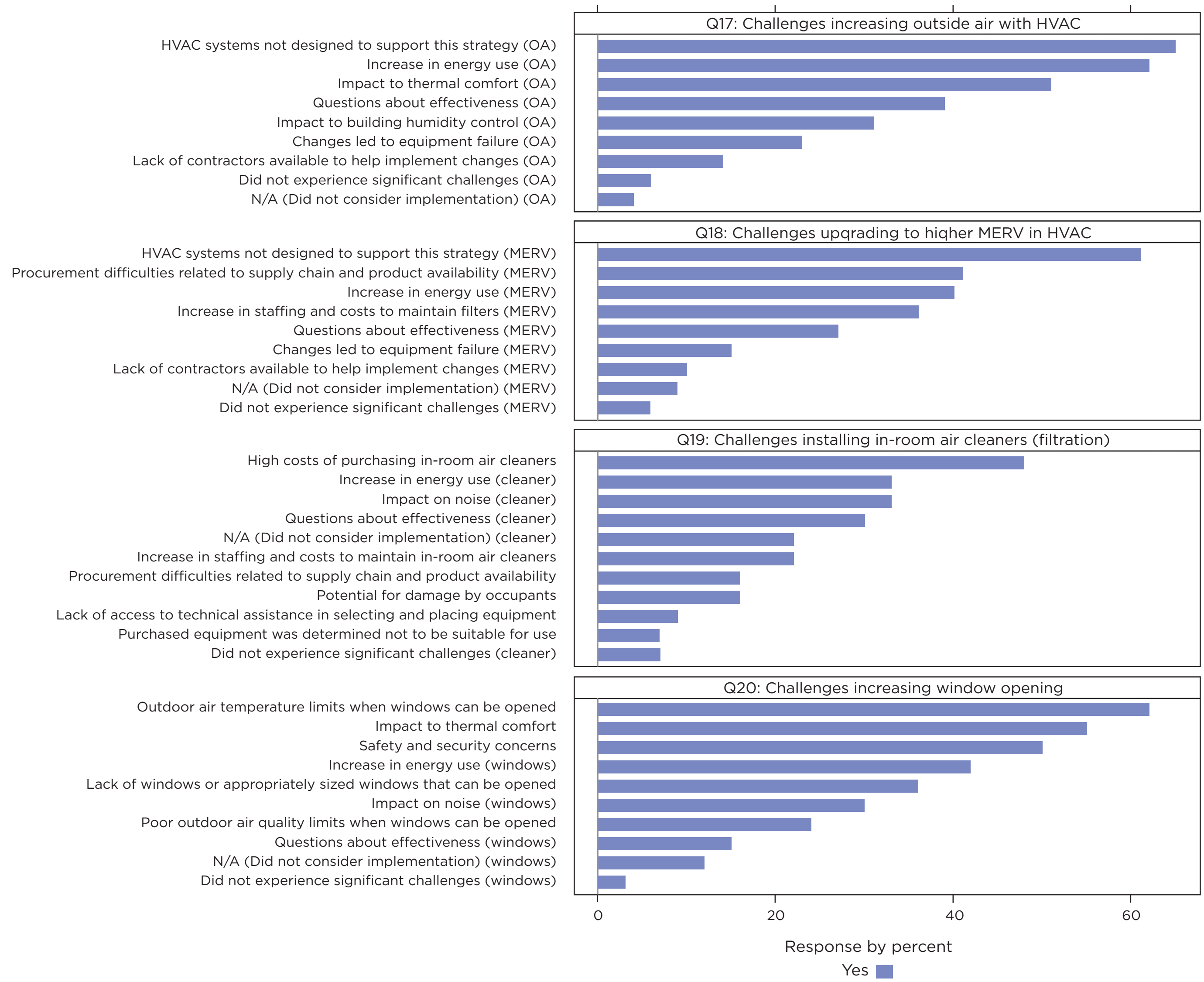
> “*Another thing to try and balance is the equity versus what you can do at your sites. Because at some sites you can do more but then you have to answer the equity question for your whole district as to why you aren’t doing it everywhere else. So we just stopped at [MERV] 11 because not all our sites have equipment that can handle the more efficient filters.*”
>
> — Focus Group Participant

CHALLENGES ENCOUNTERED

Schools struggle with HVAC systems not designed to implement ventilation and filtration improvements.

The most widely cited challenge to increasing outdoor air via HVAC systems was HVAC systems that were not designed to enable greater outdoor air flow (74%, Figure 5). Similarly, regarding upgrading to higher efficiency filters in HVAC systems, the most cited challenge to implementation was that systems were not designed to support higher efficiency filters (69%). The same finding was reported from the previous survey (April 2021). Costs and procurement for MERV filters and air cleaners were challenges for districts with higher non-white and high FRLP eligibility, whereas HVAC challenges related to outdoor air and MERV upgrades affected urban and highly populous districts the most.

Figure 5. Challenges with implementing indoor air quality measures (N=88; districts selected as many responses as applicable per question).

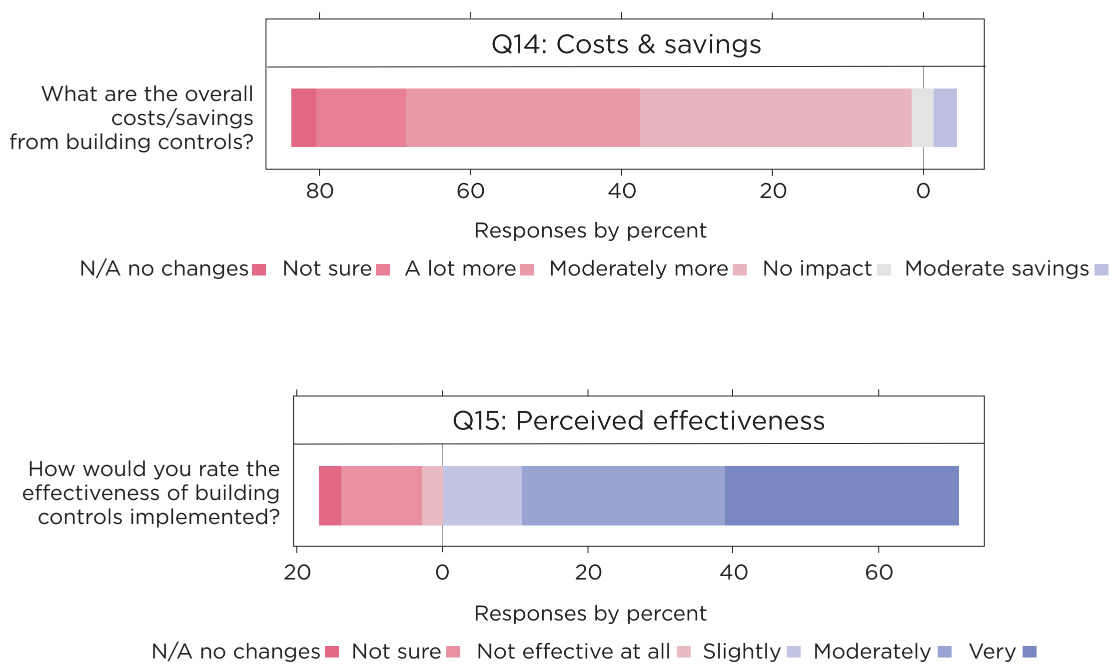


Uncertainty around efficiency and cost caused concerns about increasing outside air through HVAC systems.

Despite the fact that increasing outside air through the HVAC system was implemented most consistently among the ventilation and filtration measures (Figure 3), almost half (45%) of responding schools indicated that they had feelings of uncertainty about its effectiveness, and the majority (71%) indicated concerns about increased energy use from this measure. In comparison, only 17% of districts questioned the effectiveness of opening windows, and 47% noted energy cost increases from opening windows. Respondents that had questions about the effectiveness of using in-room air cleaners and using higher MERV filters in HVAC systems were 34% and 30%, respectively. Thirty eight percent of districts reported challenges around increasing energy use from using in-room air cleaners and 46% reported the same challenge for higher efficiency MERV filters (Figure 5).

A similar analysis was performed for the survey question about the overall effectiveness of all ventilation, filtration, and other building controls implemented in schools. Respondents were asked to base their judgment of effectiveness on experience and/or data. About 70% of respondents considered all measures they implemented to be moderately or very effective, based on their own judgement and experience (Figure 6). Twelve percent of respondents were unsure about the overall effectiveness of implemented measures. District-level characteristics like locale and demographics were not correlated with how respondents perceived measures' effectiveness.

Figure 6. Overall costs and perceived effectiveness of implemented indoor air quality measures.



FOCUS GROUP INSIGHTS

Despite desires for the central HVAC system to provide sufficient clean outdoor air, doubts about HVAC effectiveness appeared to stem from lack of systematic and/or real-time data indicating delivery of outdoor or filtered air into school spaces. Building managers know that opening outdoor air dampers on HVAC units will lead to increased outdoor air delivery indoors, assuming the system is working properly; however, it is less clear to what extent changes to damper openings are associated with air exchange rates unless this is being measured. Measurement of clean air delivery arose as an important factor to inform understanding of the level of indoor air quality provided. In addition, there is uncertainty about how much clean air exchange is required to achieve acceptable risk.

> *Another silver lining to the air testing report is that we were able to find issues that we wouldn't otherwise find through general maintenance unless there was a complaint from a teacher or custodian. We were able to get HVAC professionals in there to say like, "we noticed your dampers are closed, we noticed this motor is burned out, this unit hasn't been running for some time.*
>
> — Focus Group Participant

Concerns also exist about how IAQ measures impact the experience of students and teachers in the classroom. Sixty-three percent and 57% of districts indicated concern about the impacts of window opening and increasing outside air via HVAC on thermal comfort, respectively. Seventy-one percent of districts indicated that outdoor air temperature limiting when windows could be opened was a challenge, while 57% indicated that safety and security were challenges with window opening. Noise associated with window opening and in-room air cleaners were indicated as challenges in 35% and 39% of districts, respectively. This report did not examine the relationship between a specific respondent's level of concern and their likelihood of implementing the measure.

About three-quarters of respondents reported a cost increase from changes related to ventilation, filtration, and other building controls (Figure 6). Respondents were asked to consider changes in costs from energy, materials, and staffing, compared with the same period during a typical school year prior to the pandemic. Fourteen percent of respondents were unsure about changes in costs. Based on the analysis conducted, there was not a significant ($p<0.05$) association between district characteristics and cost savings or increases resulting from implementing IAQ measures.

FOCUS GROUP INSIGHTS

Focus group respondents touched on factors related to costs. One district noted that the disinfecting wipes for surfaces is a cost that is adding up. Additional costs arising from students not being in school and needing summer school, new testing dates, etc., were also of concern. Understanding the extent to which airborne infection control measures can reduce some of these costs associated with students being out of the physical school was underscored as important for school board meetings where budgeting decisions about building-related air quality control measures are being discussed. Gaining a better understanding of the economic costs and benefits of implementing various indoor air quality measures would be appreciated by districts.

> *I had a conversation with our administration about the impact to our budget that we are going to have this year and next year because we get paid per student per day in the classroom. If all of a sudden we are short a bunch of students our budget shrinks. So if we have healthier kids because we have better ventilation, I don't know what the numbers are and I don't know that we can say what the numbers are, but we can certainly say they are linked. Ventilation keeps kids in the seats, which keeps the budget happy.*
>
> — Focus Group Participant

RESOURCES AND DECISION-MAKING

Federal, state, and/or local agency and ASHRAE guidance were the most frequently cited resources.

Respondents reported using a combination of sources to inform decision-making about the indoor air quality controls implemented in school buildings. Federal agency guidance such as that from Centers for Disease Control and Prevention (CDC) or U.S. Department of Education were the most frequently cited resources, followed by ASHRAE guidance, public health departments, state departments of education, and consultants (Figure 7). Other school districts were cited as useful resources among 36% of respondents, and academic researchers were cited by 21%. Where used, consultant support mostly consisted of consulting engineers (64%). Interestingly, non-urban districts were more likely to use state or local guidance than federal when compared with urban districts (Figure 7X), a finding that could prove useful for government and non-profits attempting to reach non-urban districts with guidance and assistance.

Figure 7. Guidance resources (N=88) and consultants (N=53) informing indoor air quality decision making. Districts selected as many responses as applicable per question (row).

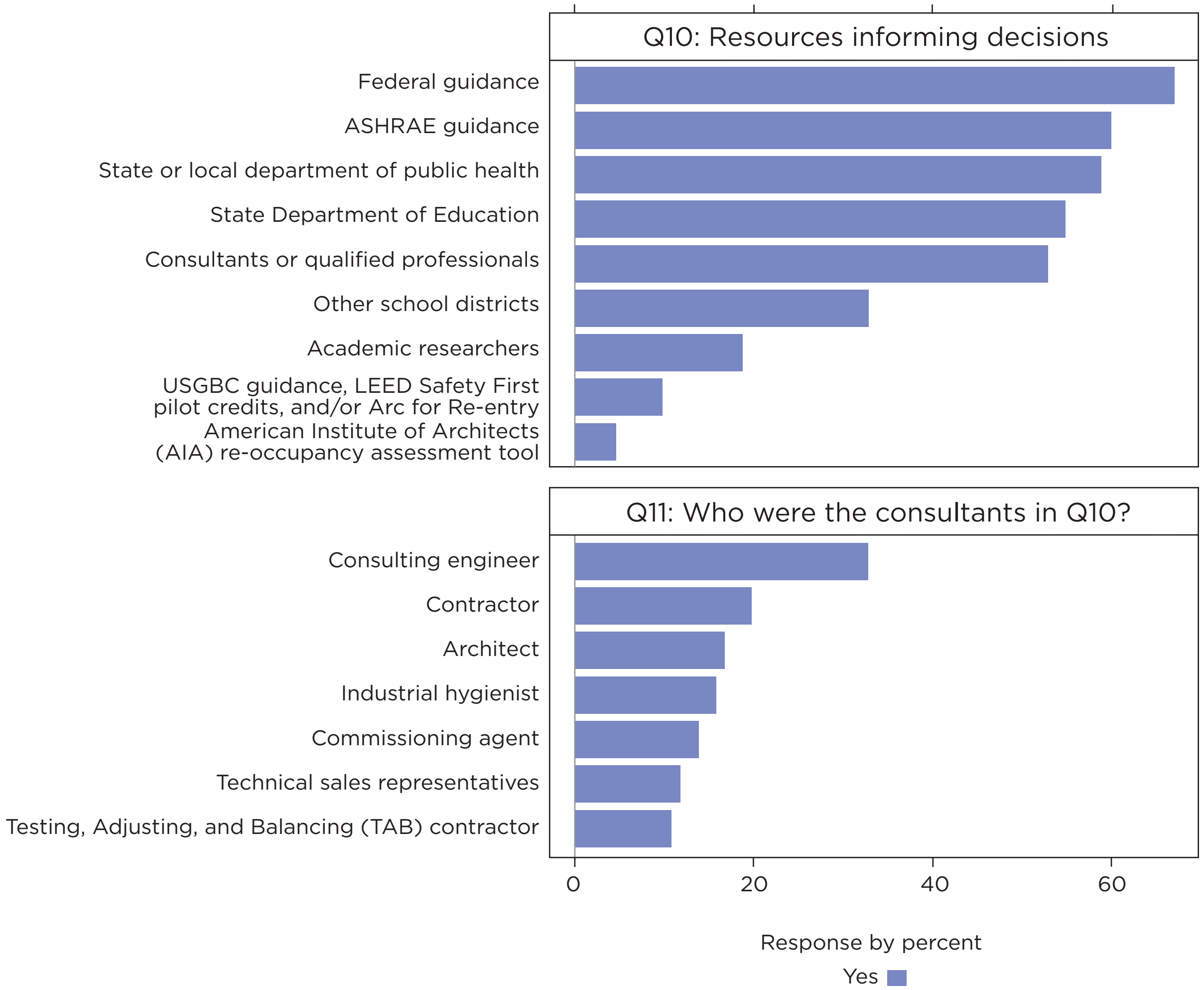
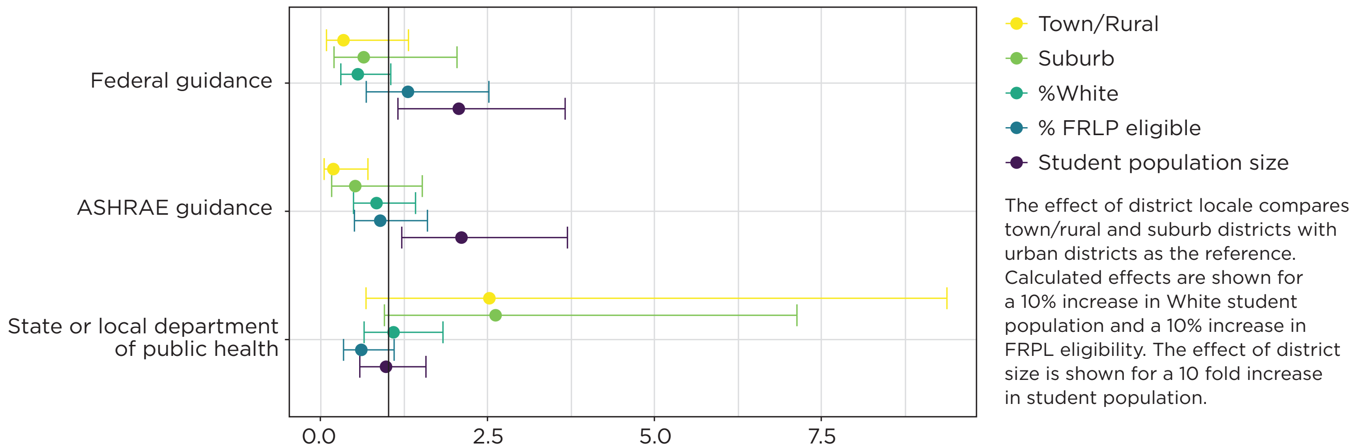


Figure 7X. Odds ratios (points) and 95% confidence intervals (bars) for the three most cited sources of guidance informing decisions about IAQ for COVID-19 control.



Among the responding districts, 75% of town/rural and 76% of suburban districts reported relying on state or local department of public health for guidance, compared to only 54% of urban districts. On the other hand, larger school districts showed increased odds of relying on federal and ASHRAE guidance. In Figure 7X and subsequent plots of odd ratios, the effect of district locale is determined by comparing town/rural and suburb districts with urban districts as the reference. The odd ratio plots also show the calculated effects of district characteristics from a 10% increase in White student population and a 10% increase in FRLP eligibility. The effect of district size is shown for a 10-fold increase in student population size.

FOCUS GROUP INSIGHTS

Focus group respondents indicated challenges with sorting through numerous sources of evolving guidance over the course of the pandemic. A large number of solicitations from vendors of various air cleaning products also posed a challenge.

Regarding particular points of confusion, there was discussion among focus group interviewees about an acceptable CO_2 level to achieve and to check for during monitoring efforts. Providing clearer guidance for CO_2 monitoring within the context of the number of people present, activity levels, and the other air cleaning measures used (e.g., filtration, GUV) could help schools accurately monitor their IAQ and get the most out of their measurements as a tool for infection control.

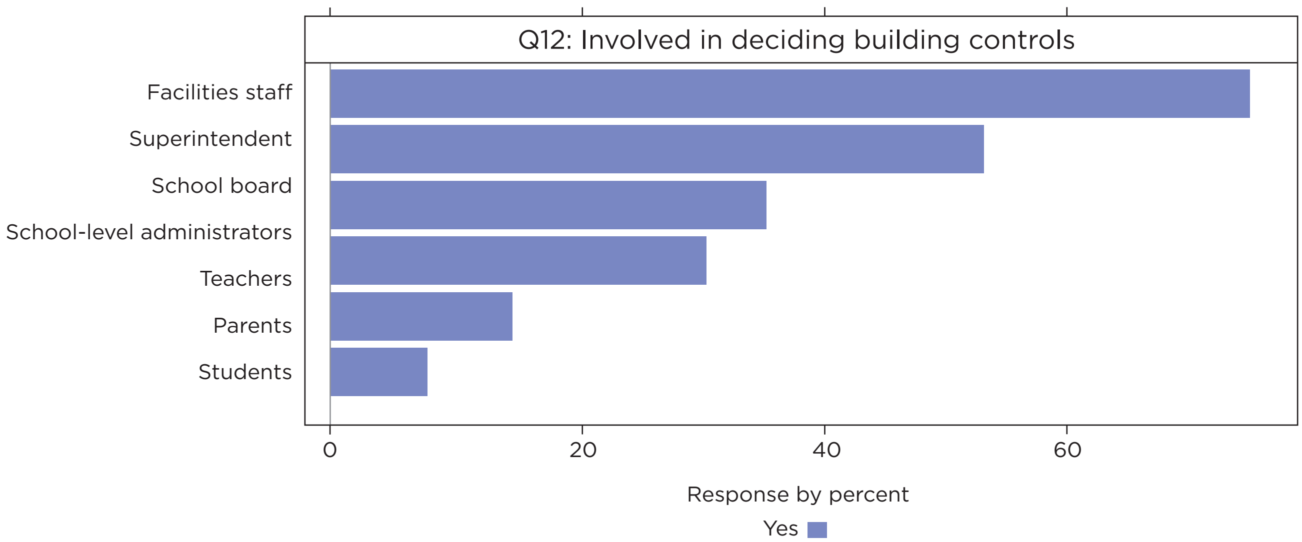
Monitoring of indoor air quality was performed, although methods, data interpretation, and how to use the data to act were all generally unclear and discussed as a source of uncertainty among interviewees.

> *The amount of vendors and cold calls, they came out of everywhere. I'm sure the other folks on this call got them too… we are still getting bombarded by all that information. And that's been a challenge, I will tell you that. Just the amount of that information that is coming to you. That's why we had to go and say 'okay [engineering consultant], is this real? Is this not?' Just to help us with some of those decisions.*
>
> — Focus Group Participant

Facilities staff were key decision-makers in building control implementation.

Of those in districts and schools involved with decision-making about control implementation, facilities staff were most commonly cited (85%), followed by the superintendent (61%) (Figure 8). About one-fifth of the respondents indicated that facilities staff were the sole key decision-makers. School boards and school-level administrators were also substantially involved, with teachers and parents being the least likely to be involved. About 10% of the respondents indicated that the key decision-makers were the superintendent and/or the school-level administrators (sometimes with inputs from the school board) with facilities staff not being involved. About one-third of the respondents indicated that facilities staff and the superintendent and/or school board worked together as the key decision-makers. Parent involvement was the most common among school districts that indicated that they involved all parties in their decision-making process.

Figure 8. District personnel involved in decision-making about indoor air quality implementation (N=88). Districts selected as many responses as applicable per question (row).



> *Perception driven issues that were huge the last two years... people got used to that. Our building has never been cleaner! Can we clean it every day? When we started pulling back from wiping everything down day to day to more business- usual, back to what we were doing before... changing gears with people, you know it's not a surface thing. We are okay. We are still cleaning, but that perception and that expectation—people think we got to keep doing that... perception is a lot of it for us.*
>
> — Focus Group Participant

FOCUS GROUP INSIGHTS

Despite teachers and parents being reported as having low involvement in decision-making involving building control measures, these groups seem to wield strong influence over the ultimate decision-makers, including facilities staff and administration leadership at the district or school level. Community support or hesitancy about certain control measures was cited among interviewees as a powerful force affecting translation of guidelines into practice within schools. When asked about considerations involved in the deployment of upper-room GUV in schools, for instance, districts conveyed a sense of trepidation about safety to GUV exposure and similar concerns that they felt were reflected by parents.

Focus group participants consistently noted an inflection point during which it became clearer that airborne transmission was the predominant mode of transmission and the extent of surface cleaning could perhaps be relaxed to some degree. However, it was also reported that support from parents/guardians, faculty, and staff for stringent surface cleaning regimens hindered efforts to reduce focus on those measures. One district reported performing daily, after-school "scrubbing" of surfaces and surface disinfection with sprayers. Despite noting that they would like to spend less effort on surface cleaning and more on air cleaning, and considering the not-insignificant costs of cleaning solutions and cleaning schedules, maintaining good public relations with a community often vocal in support of surface cleaning was prioritized.

Strong teacher support was also reported for deploying in-room air cleaners because they are tools that are visible in the classroom and provide a tangible sign that there is some air cleaning happening in the room. District respondents suggested that they generally believed that the HVAC systems were likely to be providing enough clean air (outdoor air and recirculated filtered air) and stand-alone air cleaners were not necessarily needed, but that promoting teacher satisfaction with air cleaning control measures was an important driver for determining the suite of controls to implement.

Districts also noted that water fountain closures are persisting, despite little risk of transmission from water bottle filling stations. One district lamented the large amount of single-use plastic water bottles that were being discarded at their schools after water bottle filling stations were shut down. Comments related to environmental sustainability in the changing context of pandemic controls arose as a theme throughout focus group interviews.

> "*I don't know if everyone closed their water bottle filling stations or water fountains? CDC says COVID is not transmissible this way. There was a lot of inertia within our schools. We wanted everything back open because if I go down into the warehouse downstairs in our main distribution center [there were] millions of disposable water bottles. Another thing we did was to really push to get those water filling stations back open and distribute reusable water bottles to all of our students.*"
>
> — Focus Group Participant

ESSER funding has been used to support COVID-19-related indoor air quality more than funding from operating or capital budgets.

Federal COVID-19 relief funding in the form of the Coronavirus Aid, Relief, and Economic Security Act (CARES, March 2020), Coronavirus Response and Relief Supplemental Appropriations Act (CRRSA, December 2020), and the American Rescue Plan Act (ARP, March 2021) were key funding sources used by schools to support the implementation of building controls (Figure 9). Within each of these bills was funding for Elementary and Secondary Schools Emergency Relief, commonly referred to as ESSER. Responding schools relied on ESSER funding to support implementation more than their operation or capital budgets. Larger school districts and districts with higher percentage FRPL eligibility were more likely to use ARP ESSER funding for the implementation of IAQ measures (Figure 9X). Other sources of funding, including state funding and private donations, were less prevalent among respondents.

Figure 9. Sources of funding for indoor air quality measures (N=88). Districts selected as many responses as applicable per question (row).

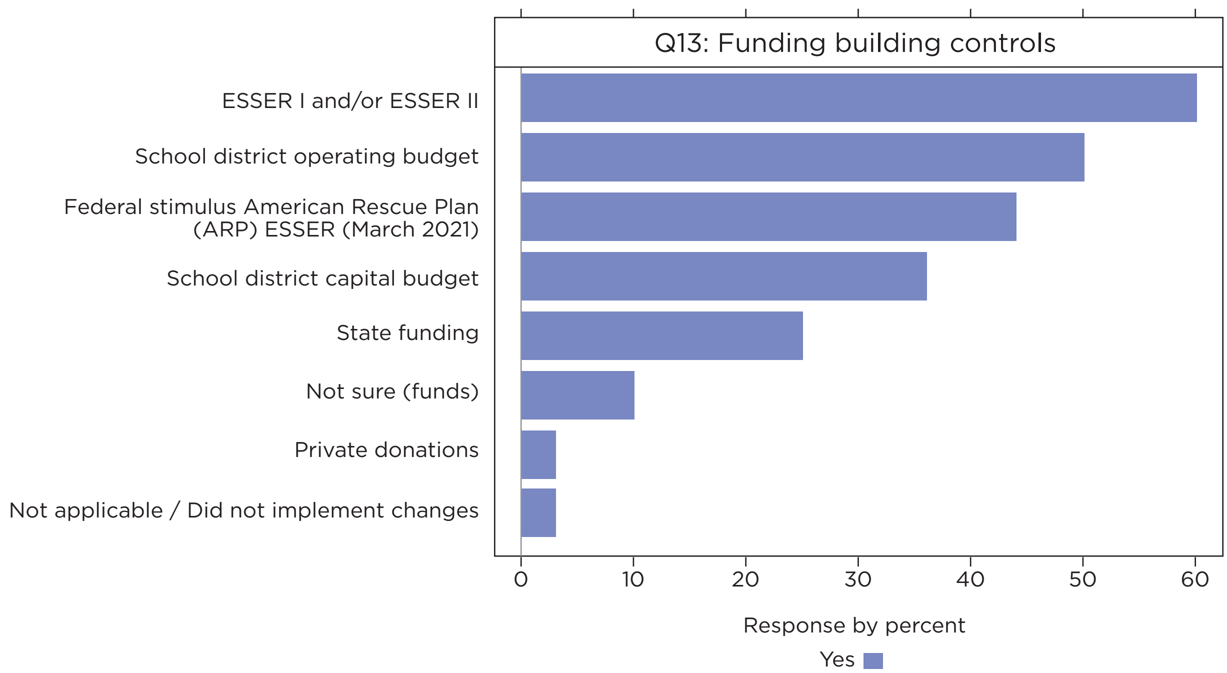
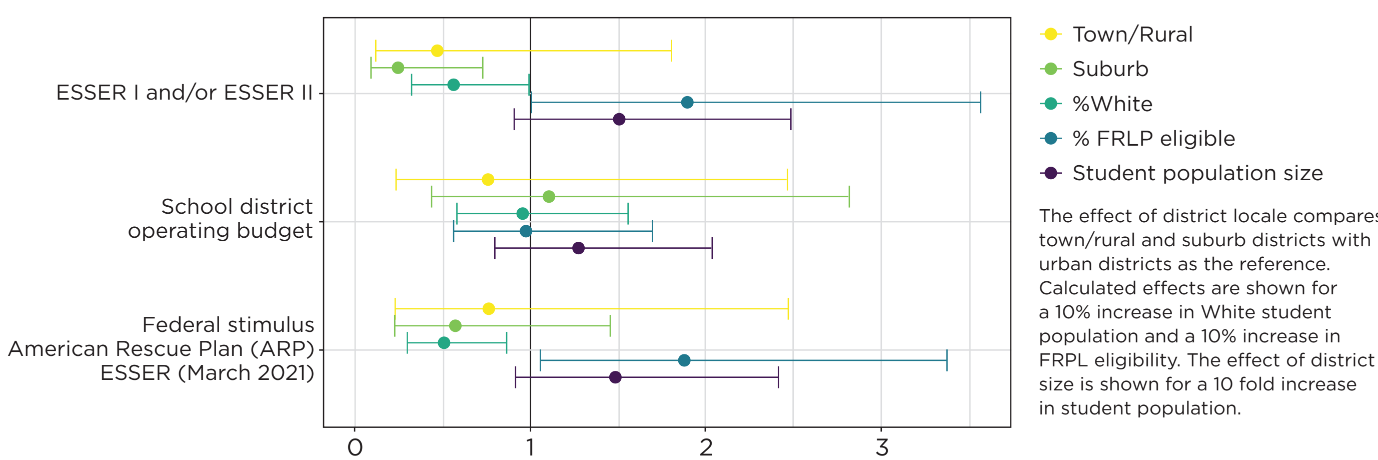


Figure 9X. Odd ratios (points) and 95% confidence intervals (bars) for the three most commonly cited sources of funding used to support the implementation of IAQ measures.



Plans for further ventilation and filtration improvements vary in approach and funding.

Regarding future plans for ventilation- and filtration-based indoor air quality, about half of respondents reported plans to replace HVAC systems to support in-person instruction during the pandemic (Figure 10). Indoor air quality monitoring with CO_2 sensors was also identified for future work in 40% of districts, compared with 26% planning for monitoring of particulate matter (PM) or other air pollutants. Installing in-room air cleaners with high-efficiency filters was planned in 15% of districts. Figure 10X shows that districts with higher percentage of FRPL and larger student population size reported an increase in odds of considering HVAC upgrades, HVAC replacement, and/or CO_2 monitoring in their future plans.

When asked about the benefits of the implemented IAQ measures beyond COVID-19 prevention (Figure 10), the majority of responding schools identified improved indoor air quality (81%) and reduced transmission risk of influenza and other respiratory infections (63%). District characteristics were not found to be associated with perceived benefits of IAQ measures.

Figure 10. Plans and funding for additional indoor air quality and perceived benefits beyond COVID-19 (N=88; districts selected as many responses as applicable per question).

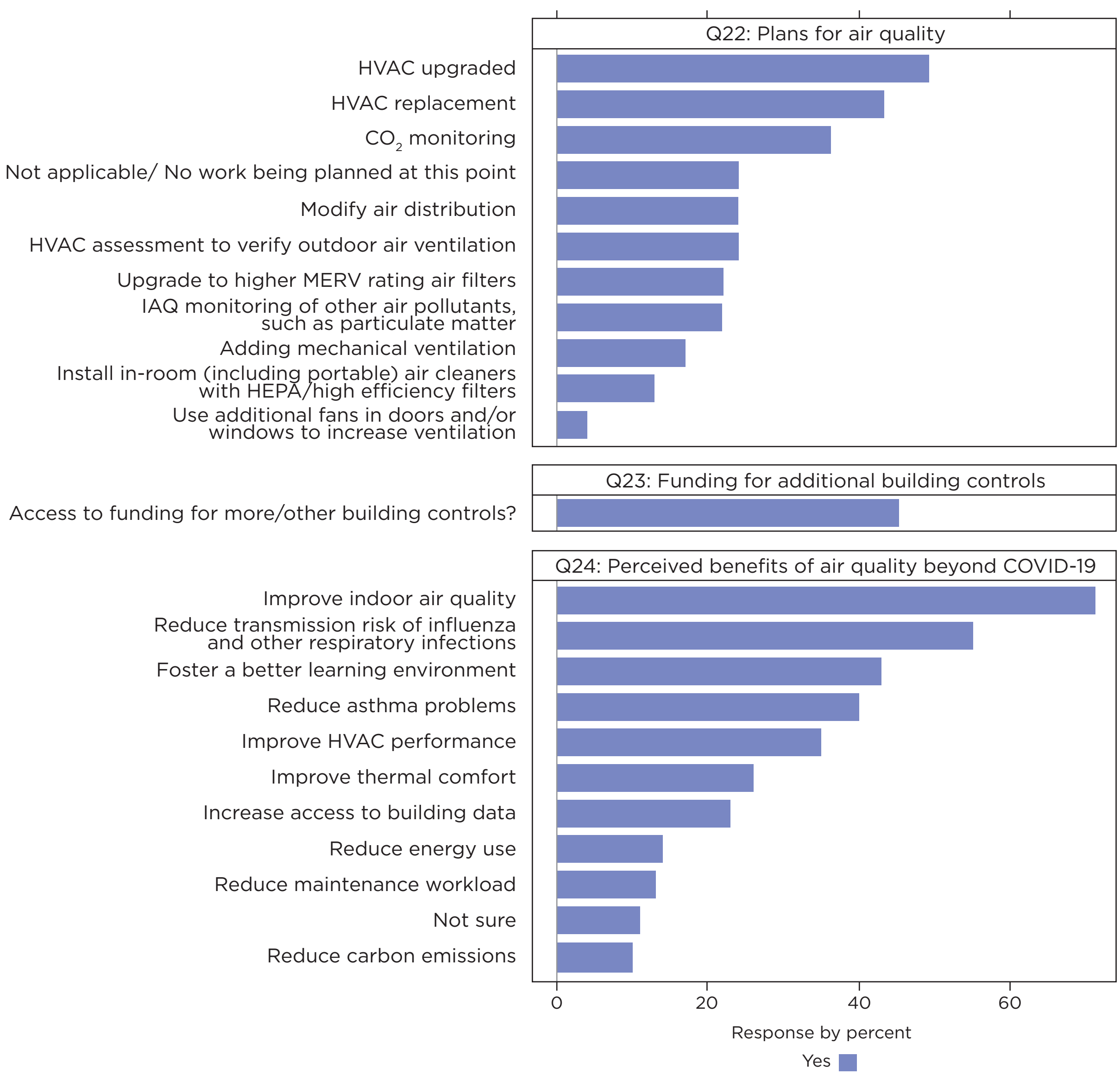
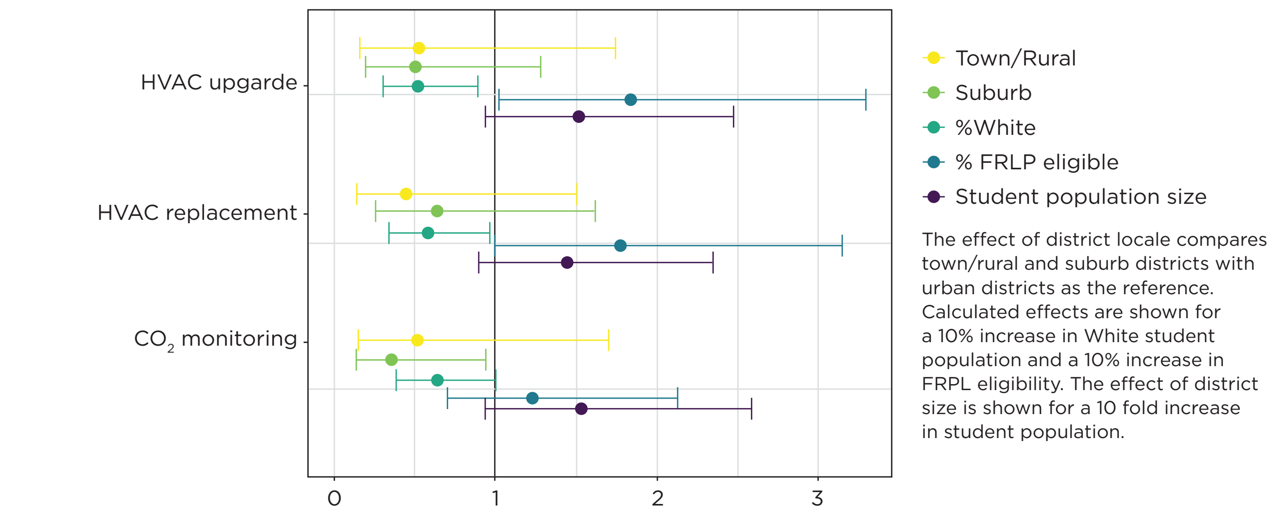
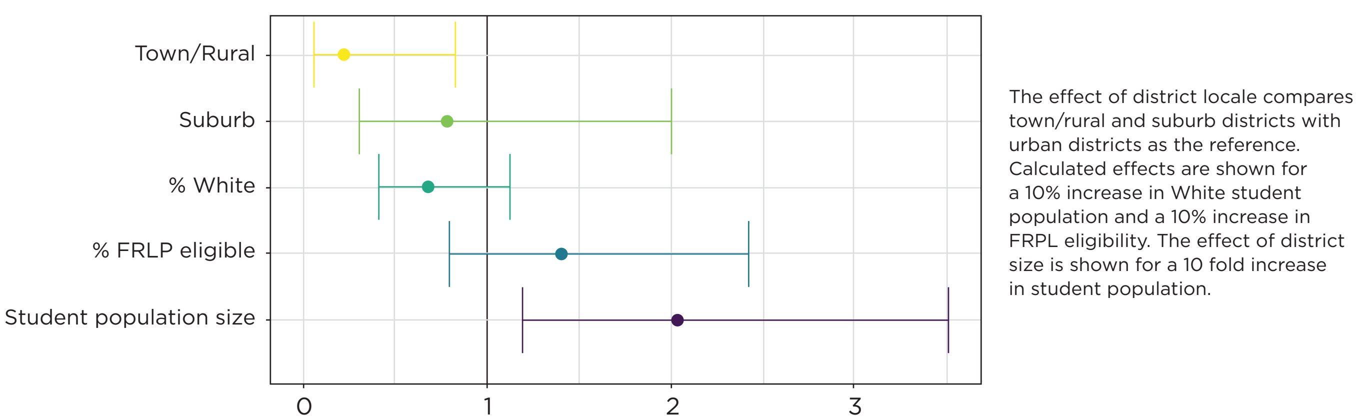


Figure 10X. Odd ratios (points) and 95% confidence intervals (bars) for effects of district characteristics on the three most common IAQ measures that districts are considering in future plans.



Overall, only 54% of districts responded that they have access to funding to implement additional ventilation and filtration strategies or to make other building changes in schools; 23% responded that they do not, and 24% responded that they were unsure. Considering that at least 36,000 of the nation's 100,000 public schools are likely in need of HVAC system updates or replacement (GAO 2020), the lack of capacity to implement additional measures is concerning. Compared with urban districts, town and rural districts combined were less likely to respond that they had access to funding for future work (Figure 10Y). As opposed to smaller districts, larger districts were more likely to respond that they had access to funding to implement additional indoor air quality measures.

Figure 10Y. Odds ratios (points) and 95% confidence intervals (bars) for effects of district characteristics on access to funding for additional IAQ measures.



CONCLUSION

This national survey of public school districts revealed the extent to which indoor air quality upgrades and other infection control measures were implemented, as well as factors related to their use, funding sources, and plans for future indoor air quality improvements. Among district respondents, tremendous efforts were undertaken by schools to assess HVAC performance and implement ventilation and filtration strategies, although to a lesser extent compared with behavioral and administrative approaches. The most common measures within building engineering controls and monitoring were related to increasing outdoor air through mechanical or natural ventilation. Many school districts conducted one-time assessments of system performance. Some districts implemented real-time IAQ measurement capabilities, some of which have publicly available results. Despite these efforts, there is a great deal of opportunity to improve IAQ in schools through more widespread implementation of HVAC ventilation and filtration, operable windows, and germicidal UV (GUV).

Challenges with implementation centered on several main themes that were discussed in focus groups and corresponded with survey responses. HVAC systems not designed to implement ventilation or filtration changes were cited as a common challenge for increasing indoor air quality. Focus group discussions often described concerns with HVAC fans not being able to handle upgrades to filter efficiency, despite industry data indicating that higher efficiency filters do not necessarily correlate with greater pressure drop. Increases in energy demand as a result of increasing outdoor air intake through the building's HVAC system were also widely reported, more often than concerns about energy related to window opening.

The confusion caused by the need to sort through a lot of rapidly changing information related to which COVID-19 controls to prioritize—and a barrage of marketing for air cleaning devices—to make decisions that can be accepted by the broader community was a common theme that emerged in focus groups. Parents were described as having substantial influence on efforts to continue stringent surface cleaning, despite intentions to spend more focus on air cleaning. Community fears about GUV were also cited as a barrier. Identifying acceptable IAQ for respiratory infection control also arose as a challenge, given uncertainty about airborne transmission risks and to what extent risk could be mitigated through different levels of IAQ controls. Similarly, clearer guidance about specific CO_2 levels at which to initiate additional COVID-19 controls was identified as an opportunity for improved technical support.

Federal, state and/or local agency, and ASHRAE guidance were most frequently cited as resources for indoor air quality measures; and ESSER funding was widely used as a funding source for implementing indoor air quality. Acquiring the will and funding to improve indoor air quality—an important shift given evolving recommendations from public health agencies—is really only the first step. Addressing abundant uncertainty about how to properly assess indoor air quality and implement controls that could be considered effective enough to provide some level of acceptable transmission risk within the school community is not a simple process.

The research points to a need for clear guidance and technical support to ensure that districts a) do not rule out the implementation of a particular control measure a priori (e.g., MERV13 upgrade), and b) implement flexible strategies to improve IAQ across districts that have diverse building stock where some control measures are more feasibly implemented than others. Communication to these districts with a variety of building challenges is important to ensure an understanding that multiple strategies can be deployed in different schools to achieve a similar level of air cleaning—there does not need to be a single approach selected.

Where do we go from here?

A 2020 GAO K-12 education report indicated that 36,000 of the nation's 100,000 public schools are likely in need of HVAC system updates or replacement (GAO, 2020). Studies have also shown that schools are important sites of infection transmission for influenza and COVID-19 and can drive community spread (Walsh et al., 2021). While several studies have linked mask/respirator use with decreased risk of infection in public places (Andrejko, 2022) and in K-12 schools across the U.S. (Donovan et al., 2022; Falk et al., 2021; Gettings, 2021; Lessler et al., 2021; Villers et al., 2021), the role of indoor air quality remains an important consideration, given its ability to provide control in situations when individual actions are unpredictable. With both facilities upgrades and COVID-19 control measures in the foreseeable future for many schools, indoor air quality challenges will continue to need solution guidance and will benefit from more nuanced study.

Imperative in continued decision-making on IAQ is the ability, as a nation, to seek to continue emphasis on the long-term health and cognitive benefits of indoor air quality apart from the broader political influence that exists in discussions of COVID-19; only then will we be able to accurately analyze risk and agree to take the most appropriate and effective measures to improve indoor air quality.

Recommendations for further study

The results from this study touch the surface of the IAQ discussion needed for our schools. Additional multi-layered conversations are recommended to support school districts in making informed decisions on appropriate IAQ measure implementation. By looking at the trends in this survey and focus group data, several considerations become apparent as appropriate next steps for research.

- A cost-benefit analysis that breaks down capital and operational expenses and weighs them against the health, healthcare, economic, and learning/cognitive benefits of improved air quality should be done. Guidance from this analysis will especially impact decision-makers in school districts with disparate buildings and equipment who may be uncertain if changes like filter upgrades should be done in part or across the district.

- Assessment studies to evaluate the effectiveness and the combined effects of different building controls are needed. This should include in situ demonstration studies of technologies that districts are less familiar with but are recommended by federal agencies (e.g., CDC), such as upper room GUV.

- A study of climate-specific best practices to better inform IAQ strategies in different parts of the country would be a helpful addition to research on this topic. This study should include considerations such as heat and humidity, as well as susceptibility to factors like wildfires or air pollution.
- As this study found a strong trend in discussions involving the dichotomy of energy consumption versus indoor air quality, this topic would benefit from the development of more informed decision-making strategies. Tradeoffs, efficiencies, control measure effectiveness, sustainability goals, and budgetary concerns all contribute to analyzing these opposing considerations.

Resources

Additional tools to aid in a well-rounded discussion of IAQ measures include education for administrators and educators on efficient tools to improve trust in their success, a more fact-based understanding of a school's overall sustainability measures and their effectiveness, greater sharing across districts and states of successful IAQ strategies that may be worth duplicating, and a more tactical communications plan to earn appropriate buy-in needed for implementation. A detailed analysis of facilities reopening steps and rural, urban, and suburban spending plans by FutureEd focuses especially on indoor air quality and can provide additional resources and best practices recommendations (FutureEd, 2022).

For schools and districts preparing to make decisions on IAQ measures, there are a variety of federal resources available to aid in planning and implementation. COVID-19 relief funding from ESSER includes $176 billion for allocation to K-12 schools—a massive budgetary support for pandemic relief and well-matched to support one-time durable investments in facilities. ARP legislation also supports IAQ efforts through funding for schools and state, local, and tribal government, and the Bipartisan Infrastructure Law earmarks billions of dollars to support community health and safety that are applicable to IAQ strategies and equipment. A practical guide released by the EPA in early 2022 includes principles and best practices for use as part of the White House's Clean Air in Buildings Challenge (EPA, 2022).

Closing

While the COVID-19 pandemic has shone a spotlight on the issues of indoor air quality in schools, the effects of the steps taken to improve the health and safety of our communities through building engineering controls will resound through years and even decades to come. School and district administrators have at their disposal both resources and federal funding aimed at making strategic decisions to improve IAQ and mitigate airborne infection, and this national conversation, as part of ongoing discourse in both sustainability and public health, shall remain at the forefront of facilities management decision-making for the foreseeable future.

ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledge the time and effort spent by school district staff who responded to the national survey, as well as those who spent additional time to participate in focus groups. We appreciate all of the efforts of valued partners who helped to distribute the survey, including the U.S. Environmental Protection Agency's Tools for Schools program leaders. Thank you to Bill Bahnfleth, Chair of ASHRAE's Epidemic Task Force (ETF), and Corey Metzger, Schools Team Lead for the ETF, for their thorough review of both the survey and the final report.

APPENDICES

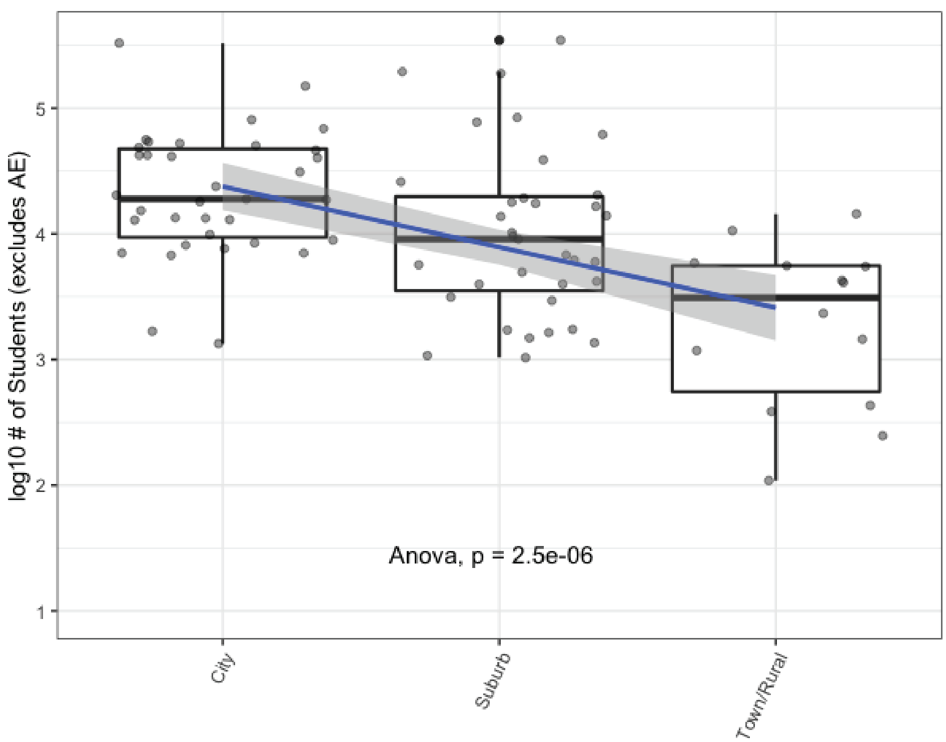
APPENDIX A: DISTRICT DEMOGRAPHICS

Table S1. Districts, schools, and students by locale, compared with national averages

	Number (%) of districts [1]		Percent of schools [2]		Percent of students [2]	
Locale type	Sample	Nat. avg.	Sample	Nat. avg.	Sample	Nat. avg.
City	35 (39.8%)	764 (5.7%)	52.9%	26.7%	51.6%	30.2%
Suburban	37 (42.0%)	3,085 (22.9%)	43.2%	31.9%	46.2%	39.7%
Town	5 (5.7%)	2,486 (18.4%)	1.3%	13.0%	1.0%	11.3%
Rural	11 (12.5%)	7,156 (53.0%)	2.6%	28.4%	1.3%	18.7%

N=88 respondent districts
[1] National data for public school districts (NCES 2013-2014; https://nces.ed.gov/surveys/ruraled/tables/A.1.a.-1_2.asp?refer=; accessed March 2, 2022).
[2] National data for percent of schools and percent of students (NCES 2015-2016; https://nces.ed.gov/pubs2018/2018052/tables.asp ; accessed Feb 4, 2022)

Figure S1. District-level student population over locale types, with collapsed township and rural locale types into town/rural.



APPENDIX B: SURVEY QUESTIONS AND RESPONSES

1. To what extent has your school district implemented the following ventilation and filtration strategies to support in-person instruction in response to the pandemic?

	Not applicable	None	Some schools	Most schools	All schools
Increase outdoor air ventilation through HVAC system (N=88)	2 (2.3%)	11 (12.5%)	12 (13.6%)	19 (21.6%)	44 (50.0%)
Implement pre-occupancy and/or post-occupancy air flushing (N=88)	3 (3.4%)	27 (30.7%)	7 (8.0%)	9 (10.2%)	42 (47.7%)
Upgrade to higher MERV rating air filters (N=88)	3 (3.4%)	19 (21.6%)	12 (13.6%)	16 (18.2%)	38 (43.2%)
Install in-room (including portable) air cleaners with HEPA/high efficiency filters (N=88)	4 (4.5%)	27 (30.7%)	22 (25.0%)	6 (6.8%)	29 (33.0%)
Open windows to increase ventilation (N=88)	4 (4.5%)	23 (26.1%)	25 (28.4%)	12 (13.6%)	24 (27.3%)
Disable demand-controlled ventilation (DCV) (N=88)	19 (21.6%)	30 (34.1%)	15 (17.0%)	8 (9.1%)	16 (18.2%)
Use additional fans in doors and/or windows to increase ventilation (N=88)	5 (5.7%)	45 (51.1%)	23 (26.1%)	6 (6.8%)	9 (10.2%)

2: To what extent has your school district implemented the following monitoring and assessment activities to support in-person instruction in response to the pandemic?

	Not applicable	None	Some schools	Most schools	All schools
Conduct HVAC assessment to verify outdoor air ventilation (N=88)	2 (2.3%)	14 (15.9%)	18 (20.5%)	6 (6.8%)	48 (54.5%)
CO_2 monitoring (N=88)	3 (3.4%)	20 (22.7%)	26 (29.5%)	12 (13.6%)	27 (30.7%)
Testing, adjusting and balancing (TAB) of HVAC system (N=88)	6 (6.8%)	23 (26.1%)	31 (35.2%)	4 (4.5%)	24 (27.3%)

3. During the current school year, have schools in your district implemented other behavioral strategies to support in-person instruction during the pandemic?

	Not applicable	None	Some schools	Most schools	All schools
Promoted handwashing and covering coughs/sneezes (N=88)	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (2.3%)	86 (97.7%)
Required mask use (N=88)	0 (0.0%)	4 (4.5%)	1 (1.1%)	1 (1.1%)	82 (93.2%)
Implemented physical distancing (N=88)	0 (0.0%)	4 (4.5%)	7 (8.0%)	1 (1.1%)	76 (86.4%)
Promoted vaccination (N=88)	4 (4.5%)	10 (11.4%)	5 (5.7%)	2 (2.3%)	67 (76.1%)

4. During the current school year, have schools in your district implemented other administrative strategies to support in-person instruction during the pandemic?

	Not applicable	None	Some schools	Most schools	All schools
Increased surface cleaning (N=88)	1 (1.1%)	6 (6.8%)	2 (2.3%)	3 (3.4%)	76 (86.4%)
Closed water fountains (N=88)	1 (1.1%)	15 (17.0%)	4 (4.5%)	6 (6.8%)	62 (70.5%)
Used routine testing to identify cases (N=88)	4 (4.5%)	28 (31.8%)	8 (9.1%)	1 (1.1%)	47 (53.4%)
Hybrid learning (i.e., some in-person learning and some remote learning) (N=88)	2 (2.3%)	36 (40.9%)	13 (14.8%)	5 (5.7%)	32 (36.4%)
Cohort students to minimize number of contacts (N=88)	5 (5.7%)	25 (28.4%)	21 (23.9%)	7 (8.0%)	30 (34.1%)
Used desk shields between students and/or teachers (N=88)	2 (2.3%)	27 (30.7%)	31 (35.2%)	9 (10.2%)	19 (21.6%)

5. Are your schools using upper-room ultraviolet germicidal irradiation (UVGI; also referred to as germicidal UV or GUV)?

	N-Miss	Other	Not sure	No	Yes, pandemic response	Yes, pre-pandemic
Overall (N=88)	3	0 (0.0%)	3 (3.5%)	78 (91.8%)	4 (4.7%)	0 (0.0%)

6. Are your schools using in-duct ultraviolet germicidal irradiation (UVGI; also referred to as germicidal UV or GUV)?

	N-Miss	Other	Not sure	No	Yes, pandemic response	Yes, pre-pandemic
Overall (N=88)	3	0 (0.0%)	3 (3.5%)	78 (91.8%)	2 (2.4%)	2 (2.4%)

7. Are your schools using bipolar ionization or other ionizers?

	N-Miss	Other	Not sure	No	Yes, pandemic response	Yes, pre-pandemic
Overall (N=88)	7	0 (0.0%)	5 (6.2%)	58 (71.6%)	8 (9.9%)	10 (12.3%)

8. Are your schools using other air cleaning technologies not described above?

	N-Miss	Yes. Please describe:	No	Not sure
Overall (N=88)	18	0 (0.0%)	64 (91.4%)	6 (8.6%)

9. If you answered "yes" to any of the above questions, please provide information on the technology implemented in your schools, such as a description of the devices used and the number and type(s) of spaces (e.g., classroom, cafeteria) where the technology is installed. (free response)

10. What resources or guidance have you used to inform your decisions about which ventilation, filtration, and other building controls to implement in your buildings? Check all that apply.

	Responded yes
Federal guidance (N=88)	67 (76.1%)
ASHRAE guidance (N=88)	60 (68.2%)
State or local department of public health (N=88)	59 (67.0%)
State Department of Education (N=88)	55 (62.5%)
Consultants or qualified professionals (N=88)	53 (60.2%)
Other school districts (N=88)	33 (37.5%)
Academic researchers (N=88)	19 (21.6%)
USGBC guidance, LEED Safety First pilot credits, and/or Arc for Re-entry (N=88)	10 (11.4%)
American Institute of Architects (AIA) re-occupancy assessment tool (N=88)	5 (5.7%)

11. If you selected "consultants or qualified professionals" in the response above, what group(s) have you engaged with to inform your decisions about ventilation, filtration, and other building controls? Check all that apply.

	Responded yes
Consulting engineer (N=53)	33 (62.3%)
Contractor (N=53)	20 (37.7%)
Architect (N=53)	17 (32.1%)
Industrial hygienist (N=53)	16 (30.2%)
Commissioning agent (N=53)	14 (26.4%)
Technical sales representatives (N=53)	12 (22.6%)
Testing, Adjusting, and Balancing (TAB) contractor (N=53)	11 (20.8%)

12. Who among your school community were involved in deciding which ventilation, filtration, and other building controls to implement in your buildings? Check all that apply.

	Responded yes
Facilities staff (N=88)	76 (86.4%)
Superintendent (N=88)	54 (61.4%)
School board (N=88)	36 (40.9%)
School-level administrators (N=88)	31 (35.2%)
Teachers (N=88)	15 (17.0%)
Parents (N=88)	8 (9.1%)
Students (N=88)	0 (0.0%)

13. How has your district funded or how does it plan to fund changes related to ventilation, filtration, and other building controls in your schools? Check all that apply.

	Responded yes
ESSER I and/or ESSER II (N=88)	60 (68.2%)
School district operating budget (N=88)	50 (56.8%)
Federal stimulus American Rescue Plan (ARP) ESSER (March 2021) (N=88)	44 (50.0%)
School district capital budget (N=88)	36 (40.9%)
State funding (N=88)	25 (28.4%)
Not sure (funds) (N=88)	10 (11.4%)
Not applicable / Did not implement changes (N=88)	3 (3.4%)
Private donations (N=88)	3 (3.4%)

14. What are the overall costs/savings from changes related to ventilation, filtration, and other building controls on the costs of operating your buildings, compared with the same period during a typical school year prior to the pandemic? Costs/savings may include energy, materials, and staffing.

	NA/ no changes	Not sure	Moderate savings	No impact on overall costs	Cost moderately more	Cost a lot more
Overall (N=88)	3 (3.4%)	12 (13.6%)	3 (3.4%)	3 (3.4%)	36 (40.9%)	31 (35.2%)

15. How would you rate the overall effectiveness of ventilation, filtration, and other building controls implemented in your schools in controlling infection and supporting in-person instruction during the pandemic? We are interested in your judgment of effectiveness based on experience and/or data.

	Not applicable / Did not implement changes	Not sure	Not effective at all	Slightly effective	Moderately effective	Very effective
Overall (N=88)	3 (3.4%)	11 (12.5%)	3 (3.4%)	11 (12.5%)	28 (31.8%)	32 (36.4%)

16. What observations and/or data do you draw from in determining how effective the ventilation, filtration, and/or other building measures have been in infection control? (free response)

17. What challenges have schools in your district encountered when implementing, or considering implementing strategies to increase outside air ventilation involving HVAC systems during the pandemic? Check all that apply.

	Responded yes
HVAC systems not designed to support this strategy (OA) (N=88)	65 (73.9%)
Increase in energy use (OA) (N=88)	62 (70.5%)
Impact to thermal comfort (OA) (N=88)	51 (58.0%)
Questions about effectiveness (OA) (N=88)	39 (44.3%)
Impact to building humidity control (OA) (N=88)	31 (35.2%)
Changes led to equipment failure (OA) (N=88)	23 (26.1%)
Lack of contractors available to help implement changes (OA) (N=88)	14 (15.9%)
Did not experience significant challenges (OA) (N=88)	6 (6.8%)
N/A (Did not consider implementation) (OA) (N=88)	4 (4.5%)

18. What challenges have schools in your district encountered when upgrading, or considering upgrading, to higher MERV air filters in your HVAC systems during the pandemic? Check all that apply.

	Responded yes
HVAC systems not designed to support this strategy (MERV) (N=88)	61 (69.3%)
Procurement difficulties related to supply chain and product availability (MERV) (N=88)	41 (46.6%)
Increase in energy use (MERV) (N=88)	40 (45.5%)
Increase in staffing and costs to maintain filters (MERV) (N=88)	36 (40.9%)
Questions about effectiveness (MERV) (N=88)	27 (30.7%)
Changes led to equipment failure (MERV) (N=88)	15 (17.0%)
Lack of contractors available to help implement changes (MERV) (N=88)	10 (11.4%)
N/A (Did not consider implementation) (MERV) (N=88)	9 (10.2%)
Did not experience significant challenges (MERV) (N=88)	6 (6.8%)

19. What challenges have schools in your district encountered when installing, or considering installing in-room (including portable) air cleaners with HEPA/high efficiency filters during the pandemic? Check all that apply.

	Responded yes
High costs of purchasing in-room air cleaners (N=88)	48 (54.5%)
Impact on noise (cleaner) (N=88)	33 (37.5%)
Increase in energy use (cleaner) (N=88)	33 (37.5%)
Questions about effectiveness (cleaner) (N=88)	30 (34.1%)
Increase in staffing and costs to maintain in-room air cleaners (N=88)	22 (25.0%)
N/A (Did not consider implementation) (cleaner) (N=88)	22 (25.0%)
Potential for damage by occupants (N=88)	16 (18.2%)
Procurement difficulties related to supply chain and product availability (N=88)	16 (18.2%)
Lack of access to technical assistance in selecting and placing equipment (N=88)	9 (10.2%)
Did not experience significant challenges (cleaner) (N=88)	7 (8.0%)
Purchased equipment was determined not to be suitable for use (N=88)	7 (8.0%)

20. What challenges have schools in your district encountered when increasing, or considering increasing window opening during the pandemic? Check all that apply.

	Responded yes
Outdoor air temperature limits when windows can be opened (N=88)	62 (70.5%)
Impact to thermal comfort (N=88)	55 (62.5%)
Safety and security concerns (N=88)	50 (56.8%)
Increase in energy use (windows) (N=88)	42 (47.7%)
Lack of windows or appropriately sized windows that can be opened (N=88)	36 (40.9%)
Impact on noise (windows) (N=88)	30 (34.1%)
Poor outdoor air quality limits when windows can be opened (N=88)	24 (27.3%)
Questions about effectiveness (windows) (N=88)	15 (17.0%)
N/A (Did not consider implementation) (windows) (N=88)	12 (13.6%)
Did not experience significant challenges (windows) (N=88)	3 (3.4%)

21. What other challenges did schools in your district face when implementing or considering implementing ventilation, filtration, and other building controls during the pandemic? (free response)

22. Looking ahead, is your school district planning to implement additional ventilation and filtration strategies, or make other building changes, to support in-person instruction during the pandemic? Check all that apply.

	Responded yes
HVAC upgrade (plan) (N=88)	49 (55.7%)
HVAC replacement (plan) (N=88)	43 (48.9%)
CO_2 monitoring (plan) (N=88)	36 (40.9%)
HVAC assessment to verify outdoor air ventilation (plan) (N=88)	24 (27.3%)
Modify air distribution (plan) (N=88)	24 (27.3%)
Not applicable / No work being planned at this point (plan) (N=88)	24 (27.3%)
IAQ monitoring of other air pollutants, such as particulate matter (plan) (N=88)	22 (25.0%)
Upgrade to higher MERV rating air filters (plan) (N=88)	22 (25.0%)
Adding mechanical ventilation (plan) (N=88)	17 (19.3%)
Install in-room (including portable) air cleaners with HEPA/high efficiency filters (plan) (N=88)	13 (14.8%)
Use additional fans in doors and/or windows to increase ventilation (plan) (N=88)	4 (4.5%)

23. Does your district have access to funding to implement additional ventilation and filtration strategies, or make other building changes, in your schools?

	Yes	No	Not sure
Overall (N=88)	45 (51.1%)	23 (26.1%)	20 (22.7%)

24. What benefits, beyond reducing COVID-19 risk, do you see from the ventilation, filtration, and/or other building controls that were implemented in response to the pandemic? (check all that apply)

	Responded yes
Improve indoor air quality (N=88)	71 (80.7%)
Reduce transmission risk of influenza and other respiratory infections (N=88)	55 (62.5%)
Foster a better learning environment (N=88)	43 (48.9%)
Reduce asthma problems (N=88)	40 (45.5%)
Improve HVAC performance (N=88)	35 (39.8%)
Improve thermal comfort (N=88)	26 (29.5%)
Increase access to building data (N=88)	23 (26.1%)
Reduce energy use (N=88)	14 (15.9%)
Reduce maintenance workload (N=88)	13 (14.8%)
Not sure (benefits beyond COVID) (N=88)	11 (12.5%)
Reduce carbon emissions (N=88)	10 (11.4%)

APPENDIX C: FOCUS GROUP QUESTIONS

1. What strategies did you employ to make in-person school safer during COVID? What were the main reasons for selecting these strategies?
    a. Did your district get the information about the importance of airborne transmission for SARS-CoV-2 and ways to mitigate it? What sources of information helped?
    b. Who did you collaborate with to decide on and implement these strategies?
    c. What set you up for success (or difficulty)? Were there existing relationships that allowed you to respond effectively (within schools/district and/or with external parties such as health departments)?
2. What's going well? What needs to be celebrated?
    a. As facilities staff, what would you wish people in your school community (school board, teachers, union, students, parents, etc.) knew or better understood about the facilities improvements (e.g., HVAC, ventilation, filtration, air cleaning) that your schools have made to support in-person learning?
    b. Can you give any examples of where you saw the impact on COVID control?
3. What are the hardest challenges with implementing airborne COVID controls?
    a. Could be things like (could prompt as the conversation goes).
        i. What to do?
            1. Figuring out the ideal set of controls measures
            2. Prioritizing control measures
        ii. Implementing it?
            1. How to pay?
            2. How to do it?
    b. What can be done about these challenges?
4. How has your response to COVID advanced your longer term thinking about promoting healthy indoor spaces?
    a. How are you thinking about promoting energy efficiency alongside healthy indoor environments?
    b. What type of information, guidance, and/or funding would help you achieve your goals for healthy and energy efficient indoor environments?
5. Years from now, what would be the lessons learned about school facilities from your experience with the pandemic?

APPENDIX D: SUMMARY OF FOCUS GROUP RESPONSES

General

- The interviewees were enthusiastic about their work and described comprehensive implementation of indoor air quality measures. Although we did not conduct a formal analysis of the focus group participants compared to the overall study population (survey respondents), we expect that districts self-selecting to participate in the focus group session are among the most active in pushing the evolution of indoor air quality in schools.

Decision-making about managing COVID-19 in schools

- Participants reiterated that indoor air quality was not a priority at the outset of the pandemic, but that this changed over time as the science clarified the airborne transmission of COVID-19. This evolution was reflected in regularly updated guidance issued by the CDC, local departments of public health, and other channels. Participants referenced a wide range of authoritative bodies providing guidance throughout the course of the pandemic.

- Participants noted that communities were supportive of early efforts to improve hand hygiene and surface cleaning and that they supported keeping these measures in place even after the CDC guidance emphasized a dominant role of airborne transmission for SARS-CoV-2. Some of the surface cleaning measures were intensive, including use of electrostatic sprayers with disinfectants, whole-room GUV, and scrubbing after school was out of session. One respondent described intensive surface hygiene measures that aimed to also help with allergies and their ongoing work to test for surface hygiene using ATP testing. These efforts were well-received and led to reported increases in enrollment in the schools as opposed to nearby public schools.

- Participants discussed fostering community buy-in as an important feature of pandemic response efforts. Administrators were responsive to input from various stakeholder groups, with parents and staff as the primary influencers. For example, the intensity of surface hygiene practices exceeded the public health guidance but was continued due to perceptions and demands of community members in many schools.

- Districts hoped to reduce surface cleaning (noting that the continuous provision of cleaning wipes was a substantial cost) but had not yet decreased these efforts due to community support for them. One district noted that they were likely to get pushback from constituents if they decided to reduce pre- and post-occupancy flushing times, even though doing so wouldn't increase transmission for students. This suggests that community education about indoor air quality represents an important component of broader indoor air quality implementation efforts.

- Respondents described a haphazard process of sorting through the numerous sources of information about how to effectively tackle COVID-19. It was often left to them to make critical decisions based on their own synthesis of various sources that were changing over time. If sources of information generally agreed, then that added confidence. The layered approach, described as a "lasagna approach"[1] by one district respondent, helped build confidence in risk reduction approaches that were able to deploy some, if not all, of the recommended strategies. The hierarchy of controls for COVID-19 may be even more useful if presented with evidence-based criteria for effectiveness according to cost-benefit analyses.

1 Akin to Ian Mackay's "swiss cheese" approach to controlling COVID-19 through a layering of different strategies. Source: Ian M. Mackay, virologydownunder.com and James T. Reason. https://www.nytimes.com/2020/12/05/health/coronavirus-swiss-cheese-infection-mackay.html

Outdoor air and CO_2

- Participants shared questions about guideline values for CO_2 when monitoring in schools. Various ppm levels of CO_2 were cited as being used as thresholds by participants, and there was general confusion about how to effectively use CO_2 measurement for decision-making.
- Participants described various methods and technologies for CO_2 monitoring and evaluation of ventilation rates. Strategies centered around increasing fresh air by increasing ventilation rates and/or extending pre/post occupancy flushing periods up to two hours.
- The challenges with feasibility of conditioning air (temperature and humidity) at the extremes while also bringing in enough outdoor air was discussed. Respondents discussed how factors like building and HVAC system age and capacity, and temperature and humidity were key factors in the capacity to provide outdoor air. One district representative noted that an increase in outdoor air during the winter led to the drying out of bricks and mortar leading to structural problems, while another noted problems with high humidity during the summer months. One participant indicated that increasing energy use with greater ventilation presents cost and climate concerns.
- Districts appeared to focus on bringing in outdoor air and then supplementing with filtration or other technologies when it was challenging to bring in so much due to temperature and humidity. One district described the addition of ionization as a means of reducing the amount of outdoor air ventilation needed. Figuring out how to weigh different factors when making decisions day-to-day was a noted challenge for districts.
- One respondent described an IAQ approach that focused heavily on outdoor air ventilation through HVAC and windows; however, they noted the limitations of this approach in the extreme cold, hot, and humid weather conditions. Their assessment of the ventilation they were able to achieve after opening dampers was that the air quality was acceptable for infection control and other methods were not needed. They also noted that the one outbreak that may have occurred in a school was in a building that upon further inspection had dampers closed and was running on recirculation mode. Another respondent noted a similar approach of increasing ventilation and testing to see if additional layers of protection would be needed; they noted that hundreds of portable air cleaners were distributed to classrooms and gymnasiums and other spaces where ventilation was not deemed high enough.
- Respondents in this focus group described abundant air quality monitoring including testing for CO_2, PM, VOC, temperature, humidity, light, and sound level. Some districts outfitted facilities with sensors and/or have had contractors come to validate a sample of indoor spaces. Dashboards displaying indoor air quality in real time were provided for the community and received positive responses from the community. In some cases, the transparency with IAQ data and indoor environmental quality measures seemed to spur enrollment and in-person learning.

Filtration

- Participants described difficult decisions around equity in upgrading filtration. In some cases, administrators favored keeping all schools at a lower filtration (e.g., MERV 11) rather than upgrading to MERV 13 only in schools where the upgrade was possible.
- Multiple respondents raised challenges with increasing the efficiency of filters to MERV 13, citing concerns with HVAC systems that had limited capacity to handle potential increase in pressure drop. Evidence suggests that pressure drop varies widely among filters, with some MERV 13 filters having a lower pressure drop than others at a lower efficiency rating. More market education is needed on this point.

- Participants worried that standalone filtration units were potentially wasteful "junk" and without long-term benefit. District respondents felt that they could achieve enough infection control through HVAC. Most put their energy into making their HVAC systems better and didn't feel the need to duplicate efforts with standalone filtration.
- Participants had questions about what to do with air cleaners that were placed in classrooms and other spaces when the pandemic ends. Maintenance costs cited by districts suggested that there would need to be funding support to make this a sustainable solution. One respondent noted the need for 1 FTE just to change air filters. There were questions about the benefits that air cleaners would have on student health and performance beyond COVID-19. If there is a good health/performance/cost-benefit rationale, districts felt that it may make sense to keep these units going into the long-term.

Germicidal UV

- Participants communicated concerns within their school communities about Germicidal UV (GUV, sometimes referred to as UVGI). One respondent recounted a story of a system that was not commissioned properly in another state and was shared widely online. This one negative anecdote has caused seemingly disproportionate alarm, as the public is not well-informed on the risks and benefits of this technology.
- The barrage of marketing from vendors selling various control measures was challenging to sort through and helped lead to several districts' decisions to hire independent engineering consultants to study and test various approaches.
- GUV was noted as a potentially helpful control measure for surface disinfection but did not seem to be selected, or in some cases was not considered at all, for air disinfection. One respondent noted that facilities staff decided not to use GUV for air disinfection because of concerns and perceptions about cost, logistics in terms of implementation, and concerns with efficacy.

Cost, benefits, and funding

- Districts emphasized that better information about cost savings from IAQ are needed to move districts to act. The costs of children missing school was an important consideration, and districts are now grappling with some of those costs from the pandemic (e.g., summer schools, additional testing needs, etc.). Better measures of cost aversion or savings due to IAQ could help spur investment.
- The need for additional guidance from ASHRAE and other authoritative bodies about acceptable indoor air quality, how to achieve it, and how to balance costs, energy, and various methods was called for to make financial decision-making easier.
- Elementary and Secondary School Emergency Relief (ESSER) funding was used for standalone filtration units in some districts. It was described by one district as not needed for infrastructure improvements because they felt they already had sufficiently acceptable indoor air quality delivered by existing infrastructure; they instead used the money to cover more immediate, soft costs.

Sustainability

- There were concerns about the continuous need for filters for standalone units and in HVAC, especially during wildfire seasons as indicated by one respondent. They described needing space to store filters, including backup filters, and planning for disruptions in the supply chain. Funds allocated for filters during the pandemic will not be there forever, but plans that rely on filtration for infection control will need a supply of filters for years to come.

- One respondent reported that there was a massive surge in use of plastic water bottles because the district shut down water bottle filling stations due to SARS-CoV-2 transmission concerns. Dealing with this plastic waste from bottles was a concern. Dealing with filter waste may also be an important concern for sustainability moving forward.
- Several respondents noted energy cost increases of roughly 10% over their average due to the level of outdoor air intake and the use of supplementary stand-alone filtration units.

IAQ beyond COVID-19

- Districts performed extensive assessment of HVAC systems and noticed plenty of problems that they may not have realized as soon if they had not done a dedicated effort to evaluate systems due to the pandemic.
- Respondents described a great appreciation for the effect that indoor environmental quality can have on student learning and development. Increases in ventilation in response to the pandemic were described as positive for improving environmental quality to support cognitive performance (potentially evaluated through test scores) beyond the pandemic. There was interest in indoor environmental quality for the benefit of health and cognitive function as a longer-term goal. The simultaneous desire for energy cost reduction was mentioned and discussed in more depth in the first focus group.
- Continual education of both facilities staff as well as community members about the risks of SARS-CoV-2 transmission and effectiveness of control measures seems to be an important area to address into the future.
- Looking towards the longer-term sustainability of indoor air quality, respondents felt that focusing on HVAC and central air approaches would provide the greatest benefit, perhaps in part because it would be a straightforward way to ensure that the building was providing a baseline level of indoor air quality appropriate for learning and supportive of infection transmission mitigation. Districts noted that the addition of GUV, air cleaners, or behavioral approaches such as masking could always be added on top of this baseline level of air cleaning to deal with increases in transmission risk during season epidemics (e.g., influenza) and other outbreaks/emerging infectious disease threats.

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