School Ventilation:
A Vital Tool to Reduce COVID-19 Spread

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Contents

Glossary

Air changes per hour
We refer to 2 types, ventilation and circulation. Ventilation air changes per hour indicates how many times, during 1 hour, the air volume from a space/room is supplied with outdoor air. Circulation air changes per hour, used to measure the performance of air filtration units, indicates how many times, during 1 hour, the air volume from a space is pushed through a filter.*

Air filter unit
A mass-produced self-contained device that pushes air through a filter, usually a high-efficiency particulate absorbing (HEPA) filter, to clean it. Sometimes referred to as a portable or terminal air filter unit.

ASHRAE, formerly the American Society of Heating, Refrigerating and Air-Conditioning Engineers, is a professional association seeking to advance heating, ventilation, air conditioning, and refrigeration systems design and construction. The society and its members focus on building systems, energy efficiency, indoor air quality, refrigeration, and sustainability within the industry. Their activities include research, standards writing, publishing, and continuing education.

HEPA filter
A high-efficiency particulate air filter with removal efficiencies of 99.97% or higher for a mass median particulate size of 0.30 microns.*

HVAC system
The equipment, distribution systems, and terminals that provide, either collectively or individually, the processes of heating, ventilating, or air conditioning (HVAC) to a building or portion of a building.*

Mechanical ventilation
The process of actively supplying air to or removing it from an indoor space by powered equipment, such as motor-driven fans and blowers, often part of a HVAC system.*

Minimum efficiency reporting values
Scaled rating of the effectiveness of air filters. The scale is designed to represent the worst-case performance of a filter when dealing with particles in the range of 0.3 to 1, 1 to 3, and 3 to 10 micrometers. The minimum efficiency reporting values (MERV) rating is from 1 to 16. Higher MERV ratings correspond to a greater percentage of particles in each range captured on each pass. For example, MERV 13, the most common recommendation for upgrades, captures 50%, 85%, and 90% in the 3 ranges.*

Natural ventilation
Movement of air into and out of a space primarily through intentionally provided openings (such as windows and doors), through nonpowered ventilators, or by infiltration.*

Ventilation
The process of supplying air to or removing air from a space for the purpose of controlling air contaminant levels, humidity, or temperature within the space.*

* These definitions and others can be found on the ASHRAE website at https://xp20.ashrae.org/terminology.

Executive Summary

Many kindergarten through 12th grade (K-12) schools in the United States do not have good ventilation. This is a longstanding problem with demonstrably negative effects on student learning. We can and should act to fix this to ensure good indoor air quality for all students, educators, and school staff. During the COVID-19 pandemic, it is even more important that ventilation problems in K-12 schools be addressed now. Along with other mitigation measures, improvements in ventilation in K-12 schools can decrease the risk of SARS-CoV-2 spread.

The US Centers for Disease Control and Prevention (CDC) has provided guidance for safe in-person learning for K-12 schools, recommending a layered approach with multiple public health mitigation measures in place. In addition to testing programs and the potential for vaccination, mitigation measures include use of masks, physical distancing, handwashing and respiratory etiquette, contact tracing, and cleaning and maintaining healthy facilities. This report focuses on an important component of cleaning and maintaining healthy facilities: ventilation. Improvements in ventilation can help reduce risk of transmission of SARS-CoV-2 and other infectious diseases and improve students' overall health and ability to learn. On May 7, 2021, the CDC highlighted the important role of SARS-CoV-2 aerosol transmission in the pandemic, which further underscores the need for improvements to air quality to reduce the spread of COVID-19.

In this report, we consider the impact of the COVID-19 pandemic on children, families, and educators; review the evidence that improvements in ventilation reduces risks of disease transmission; and summarize current ventilation guidelines. While ventilation improvements may often be perceived as a complicated and expensive investment, we demonstrate in a cost-effectiveness analysis comparing ventilation with enhanced ("deep") cleaning that **ventilation improvements are a cost-effective public health measure**. As new, potentially more transmissible variants of SARS-CoV-2 continue to emerge, broad improvements in indoor air quality are important for reducing transmission. Improvements to ventilation are a good use of the COVID-19 relief funds provided to K-12 schools.

To produce this report and recommendations, we interviewed 32 experts in air quality, engineering, education policy, and communications, as well as teachers at schools that have been open for in-person learning during the pandemic. We examined relevant peer-reviewed scientific literature and engineering best practices for indoor air quality as well as specific guidance for K-12 schools issued by the CDC and expert industry organizations. We also hosted a webinar featuring experts in indoor air quality, engineering, and schools to highlight their expertise and provide recommendations for what can be done now to reduce SARS-CoV-2 transmission through improvements in ventilation and to add to the mitigation measures that schools are already taking.

A broad conclusion of this research is that the benefits to investing in healthy air in schools have the potential to outlast the COVID-19 pandemic. Improved ventilation may give children and school staff healthier indoor air quality for decades in the future, providing a healthier environment for nonpandemic times and potentially reducing risks in future infectious disease outbreaks.

Recommendations

Flexible funds are now available under the American Rescue Plan to invest in K-12 schools to reduce risks related to COVID-19. As administrators consider how they may use these funds to address their schools' needs, we maintain that healthy air should be a priority in schools to (1) increase safety during the COVID-19 pandemic and potential future respiratory disease outbreaks and (2) improve student learning. Investments in healthy indoor air for K-12 schools are crucial for the health of the nation.

Our specific recommendations, in order of near- to long-term priorities, are:

1. School administrators and decision makers should improve school ventilation now by bringing in as much outdoor air as the heating, ventilation, and air conditioning (HVAC) system will safely allow and upgrading filtration.

   In schools with mechanical ventilation, building engineers should maximize outdoor air delivery and increase filtration in the HVAC system by upgrading to the highest efficiency filters the system can handle—MERV (minimum efficiency reporting values) 13, if possible. They can also switch fans from "auto" to "on" so that they operate continuously. For schools with natural ventilation, opening windows may help when combined with child-safe window fans to direct airflow; however, this alone will not guarantee increased ventilation. Windows cannot be opened in many schools, so increasing ventilation cannot be achieved without a portable air filter, which can reasonably and more reliably increase ventilation.

2. School administrators and decision makers should purchase HEPA air filtration units to be placed in classrooms and common occupied spaces.

   Even if ventilation in a school already meets current building standards (many do not), additional air filtration from a portable device can help reduce the potential for SARS-CoV-2 transmission. Portable HEPA air filters are easy to use, HEPA filtration is a proven technology, and the units have the advantage of being always "on." A quiet unit (or combination of smaller units) can increase the number of air changes by at least 3 to 5 times in an 800-square-foot classroom, can be purchased for about $500, and are less taxing on electrical systems than a portable air conditioner. Increasing the number of air changes per hour may substantially reduce aerosol transmission risks.

3. School systems should use only proven technologies for improving indoor air quality: appropriate ventilation, HEPA filtration, or ultraviolet germicidal irradiation. They should not use chemical foggers or any "air cleaner" other than filtration and ultraviolet germicidal irradiation.

   School systems should not use unproven technologies such as ozone generators, ionization, plasma, and air disinfection with chemical foggers and sprays. The effect of these cleaning methods on children has not been tested and may be detrimental to their health. The primary aim for improving air quality should be to remove contaminants and impurities from the air and not to introduce new substances into the air.

4. School administrators and decision makers should stop enhanced cleaning, disinfecting, "deep clean" days, and any other expensive and disruptive cleaning.

   School systems should regularly clean high-touch surfaces and disinfect spaces if a case is identified in the classroom or shared space, in accordance with CDC guidance. Schools should also provide proper hand hygiene resources such as hand sanitizer in classrooms and communal spaces and perform regular cleaning of frequent high-touch areas. However, schools should not implement "deep clean" days as a matter of routine. Fomite (surface) transmission is not a major driver of the spread of SARS-CoV-2. Investments in ventilation will provide more value in risk reduction.

5. School administrators and decision makers should install mechanical ventilation systems where none exist and upgrade those that do not meet current standards.

   All students, teachers, and staff deserve healthy air, and many are not currently getting it. Proper ventilation will improve health and education. Ventilation systems should meet all applicable codes and standards, be regularly maintained, and be verified that the systems are functioning as designed. If schools only have natural ventilation, HVAC systems should be installed. Upgrades to facilities will take time but will improve ventilation in schools for the long term.

6. The US government should convene a federal task force dedicated to school air quality to develop guidance for long-term, sustainable, cost-effective improvements to indoor air quality in schools. This guidance should include accountability measures to assess improvements.

   The task force should be composed of experts in air quality, industrial hygiene, building science, HVAC systems, epidemiology, engineering, children's environmental health, and education. Together, they should develop guidance for improving, monitoring, and maintaining good indoor air quality. The task force should create standards for school systems to account for different ventilation systems, climates, and conditions around the country. It should also develop a certification for HVAC installers and commissioners and, importantly, should provide recommendations for oversight and accountability so that the nation's K-12 students and teachers have the benefit of healthy air in schools. The well-documented problems of poor indoor air quality in K-12 schools have been allowed to continue for decades. A path forward is needed to fix these problems to give students, teachers, and staff in K-12 schools the healthy air they deserve.

Ventilation

The process of supplying air to or removing air from a space for the purpose of controlling air contaminant levels, humidity, or temperature within the space.[*]

* Definition from ASHRAE, https://xp20.ashrae.org/terminology.

Introduction: The Current State of COVID-19 and Ventilation in US K-12 Schools

The Impact of COVID-19 on Children, Families, and Educators

The COVID-19 pandemic has had a drastic, negative impact on the health and education of children in the United States. Although the physical impact of COVID-19 disease on children is generally less severe, compared to adults, they are often asymptomatic and not prioritized for diagnostic testing. As a result, the lack of testing has contributed to the underreporting of cases in children.[1-5] Still, according to the American Academy of Pediatrics and the Children's Hospital Association, as of April 22, 2021, more than 3.71 million US children had tested positive for SARS-CoV-2, which is equivalent to about 4,931 cases per 100,000 children. Of these cases, 0.1% to 1.9% of pediatric infections resulted in hospitalization and 0.00% to 0.03% resulted in death, according to state-level data.[6] Children of color have not been affected equally by the pandemic. Hispanic, Black, and American Indian/Alaska Native children face disproportionate risk of severe disease or death,[7] with older children having an increased risk of infection and disease compared to younger children.[8]

In addition to direct health risks, when schools moved from in-person to online learning during the pandemic many students were no longer able to access valuable life resources, including mental health services, food assistance, medical resources, safe spaces away from domestic violence, and valuable social interaction with their peers.[9-15] The loss of these services disproportionately affects students with disabilities and students from low-income communities.[16,17] Parents and families of students have also struggled with the choice between continuing with remote learning and sending children back to school in unsafe conditions. Their concerns include the disruption of children's education, inability to secure childcare, and difficulty working productively with remote learning as well as the fear of SARS-CoV-2 being brought into the household, putting vulnerable household members at risk due to in-person learning.[18,19]

Educators also have been negatively affected by the pandemic and modifications or cessations of in-person learning. While there is a lack of comprehensive surveillance on the national level to discern how many teachers and staff members have been infected or died due to COVID-19, state and private efforts have attempted to measure the burden of SARS-CoV-2 transmission in schools.[20-22] On April 8, 2021, the COVID Monitor's aggregate reporting from official state, school district, and school websites estimated at least 742,000 COVID-19 cases associated with kindergarten through 12th grade (K-12) schools: about 466,000 students, 200,000 staff, and the rest unspecified.[22] According to *The New York Times* in late January 2021, the American Federation of Teachers, a major teachers' union, reported that at least 530 US educators have died of COVID-19.[20] However, these figures are likely an underestimate of the true toll of COVID-19 on educators; a lack of testing and failure to consistently conduct epidemiologic investigations because of resource constraints may make true accounting impossible.

In addition to the threat of disease, educators have faced unprecedented stresses and obstacles to providing quality education during the pandemic. Anecdotal reporting, surveys, and interviews have shown that educators have reported pandemic-related feelings of being unsafe while conducting in-person learning as well as increased job dissatisfaction, burnout, and interest in early retirement or leaving the teaching profession altogether.[23,24] Educators have also faced intense pressure from communities and from local and national governments to reopen, despite school funding and occupational security for staff members often not taking precedence.[25]

Ventilation Problems in US K-12 Schools Predate COVID-19

Poor air quality in K-12 schools is a longstanding concern, predating COVID-19. According to a nationwide survey of school districts performed by the Government Accountability Office (GAO) in June 2020, 54% of public school districts needed to update or replace multiple building systems or features in their schools.[26] This study was performed as part of a provision in the Joint Explanatory Statement accompanying the Department of Defense and Labor, Health and Human Services, and Education Appropriations Act, 2019 and Continuing Appropriations Act, 2019[27] to study the conditions of public school facilities. The study did not investigate closures or conditions resulting from COVID-19. GAO visited 55 schools in 6 states, half of which reported HVAC-related problems. An estimated 41% of districts need to update or replace HVAC systems in at least half of their schools, which represents about 36,000 schools across the nation in need of updates to HVAC systems.

Poor air quality has far-reaching effects in K-12 schools. The EPA has compiled extensive evidence supporting the correlation between indoor air quality and student performance, absenteeism, and even teacher retention.[28] In a review of 11 studies evaluating the association between ventilation rates and student performance, improved performance with higher rates of ventilation ranged from 2.2% to more than 15%.[29] For teachers, school facility conditions were noted as an important factor in teaching quality. In a teacher-reported survey of facility conditions in Chicago and Washington, DC, poor indoor air quality was the most frequently cited problem. For DC respondents, two-thirds of teachers indicated that indoor air quality was fair or poor, and more than half of Chicago teachers reported indoor air quality as poor.[30]

People emit carbon dioxide and other bioeffluents, but the impact of human emissions on indoor air quality is poorly understood.[31] Levels of indoor carbon dioxide greater than 1,000 parts per million have been used as a proxy for inadequate ventilation.[32] A 2017 review of ventilation problems in schools found that ventilation rates in classrooms fell far short of minimum ventilation rates outlined in ASHRAE standards for air quality.[29] Poor ventilation has had a negative impact on learning. In 8 of 11 studies reviewed, researchers found an association between inadequate ventilation rates or elevated carbon dioxide concentrations and decreases in at least 1 metric of student performance. The 2017 review also reported that with increased ventilation rates or lower carbon dioxide concentrations, there were statistically significant improvements in student performance, including a decline in absence rates. A 2020 study showed that increasing the ventilation rates in classrooms could bring significant benefits in learning performance and pupil attendance, providing a strong incentive for improving classroom air quality.[33]

Even when school districts invest in upgrading their HVAC systems, serious problems may still remain. A 2020 study[34] showed that in schools retrofitted with new HVAC equipment, problems were found with HVAC equipment, fan control, and/or filter maintenance in 51% of classrooms studied. The problems that were detected highlight the need for better oversight on HVAC system installation and commissioning to ensure adequate classroom ventilation, as well as the need for periodic testing of ventilation systems and ongoing maintenance checks.

Qualified technicians are needed to assess HVAC system function in school facilities in a standardized manner and report the results of these assessments to appropriate stakeholders. However, according to the GAO survey of the 50 states and District of Columbia, most states do not conduct statewide assessments. School districts are usually responsible for such assessments, with funding to address identified facility needs coming from districts that likely have already strained budgets.

Prioritizing Ventilation During COVID-19

Guidance for safe school opening has changed dramatically during the COVID-19 pandemic, causing confusion at K-12 schools. Multiple guidance documents, organizational reports, and peer-reviewed publications, from public and private actors with varying levels of supporting scientific evidence, have been released over the course of the pandemic to encourage a safe return to in-person learning.[35-38] These publications recommend a range of COVID-19 prevention and control strategies (see Appendix A for a summary of current CDC and ASHRAE ventilation guidance).

Strategies have included universal masking of students and staff, physical distancing, enhanced handwashing and hygiene protocols, regular COVID-19 testing of students and/or staff, reduced capacity of students in classrooms, cohorting of students to reduce the number of contacts between students, vaccine prioritization for staff, symptom screening for staff and students, contact tracing efforts in collaboration with the local health department when needed, and improved ventilation in schools.[39,40] However, the relative importance of each of these strategies, as well as how to fund and implement them, has been unclear for schools, educators, other staff members, students, and family members.[41] While a combination of these strategies is recommended as part of a school's overall COVID-19 prevention and mitigation plan, improvements to ventilation and indoor air quality in school buildings, which have not been sufficiently prioritized over the past year, should be used as a key mitigation tool.

For this study, we interviewed 32 experts in ventilation, air quality, and infectious disease transmission (for more information on the study design and methods, see Appendix B). While expert community and epidemiologic investigations have indicated that improvements to ventilation, in conjunction with other mitigation measures, help reduce the risk of airborne transmission of SARS-CoV-2, many experts expressed frustration about how advice to improve ventilation and the importance of ventilation has been communicated to school systems and the public. All too often, information regarding the importance and implementation of ventilation improvements to combat COVID-19 has been underemphasized, lacking sufficient detail, or left out entirely. This neglect has been attributed to either a reluctance to recognize aerosol SARS-CoV-2 transmission or the perception that ventilation improvements are highly technical and expensive, especially in comparison to more simple, straightforward recommendations such as universal masking or physical distancing.[42] It is also possible that in determining options to reduce risk, individuals are drawn to active, visible strategies like surface cleaning, which is perceived to "kill germs," but might discount quieter background strategies like ventilation and filtration—despite the fact that they are more broadly effective. Still, while cleaning practices are important, particularly for high-touch areas and in the event of a documented case, the disruptive and expensive "deep clean" days that have been instituted as a COVID-19 mitigation measure in many schools are not necessary.[43] Schools should stop deep clean days as a matter of routine; investments in ventilation will provide more value in risk reduction.

Evidence Base for Ventilation Effectiveness in Reducing SARS-CoV-2 Transmission

Considerable evidence indicates that the primary means of SARS-CoV-2 virus transmission is through the air, that there is an increased risk of transmission in indoor environments, and that the risk from fomite transmission is low.[43] Proper and consistent physical spacing and mask wearing can mitigate the potential risks of droplet transmission, but increased ventilation can address the risks of airborne transmission.

Risks of SARS-CoV-2 spread in indoor environments

There is extensive evidence that the SARS-CoV-2 virus can be spread through the air in a crowded indoor environment.[44-46] For example, air samples from hospital rooms previously occupied by COVID-19 patients have yielded SARS-CoV-2 virus capable of infection in laboratory samples in low concentrations.[47] A case study looking at a COVID-19 outbreak in a restaurant in Guangzhou, China, showed that secondary cases occurred along the line of airflow generated by indoor air conditioning systems, while individuals not in the line of airflow were not infected. This case supports aerosol transmission of SARS-CoV-2 virus due to poor ventilation.[48]

> ***Improved ventilation is the best way to reduce airborne transmission of COVID-19, but some schools face challenges.***
>
> - Older school buildings historically have poorer air quality
> - Ventilation rates are associated with better education outcomes
> - Pandemic improvements provide an opportunity to address longstanding issues for all students

Actions such as exhaling, talking, and coughing release microdroplets that pose an exposure risk for individuals, even at distances over 1 to 2 meters from the infection source.[49] Given typical indoor air velocities with HVAC systems, 5 micron droplets can evaporate and move over 10 meters when originating at a height of 1.5 meters.[50,51] Experimental studies have shown that aerosolized particles of SARS-CoV-2 are stable and viable for several hours, with a half-life over 1 hour.[52-55] The longer that infected and susceptible individuals share an indoor space, the higher the risk of exposure as demonstrated by outbreak attack rates.[45,56] The airborne transmission pathways that have been proposed are dependent on particle deposition mechanisms in the lung, but the influence of the surrounding environment is also an important factor.[57] There has been debate about the relative importance of droplet sizes that may lead to infection, but when considering indoor environments where students are gathered for long periods of time, an emphasis should be made on reducing the likelihood of airborne transmission, particularly as schools will be following a combination approach (ie, masks, spacing, testing) to reduce risks.

Evidence that ventilation and engineering changes can decrease transmission risks

Because SARS-CoV-2 spreads through the air, indoor ventilation is an important factor in controlling viral transmission in indoor settings. HVAC systems with proper filtration remove exhaled viral particles in indoor air and lower the concentration of virus particles in the room, allowing people to use the room longer at the same infection risk.[55] A US Department of Defense study concluded that there was a lower risk of COVID-19 transmission in airplanes because of advanced ventilation and HEPA filtration systems, as well as use of surgical masks.[58]

Ventilation alone may also be more effective as a mitigation tool than low-quality or poorly fitted masks, and in combination with other mitigation measures (eg, the use of good quality, well-fitted masks; physical distancing), it can greatly decrease the probability of SARS-CoV-2 infection.[59] In addition to mechanical ventilation in HVAC systems, natural ventilation (eg, opening windows) can provide air exchange that lowers infection risk. A study of aerosol transmission of SARS-CoV-2 in elevators found that the time for the number of aerosol particles to decrease 100-fold during normal operation was reduced by a factor of 3 to 9 when elevator doors were open.[60] One modeling study found that an infected person speaking for 1 hour in a poorly ventilated room could lead to infection risk levels of 10% to 20%, but this risk would be reduced by a factor of at least 3 if the ventilation system was increased to 10 air changes per hour.[61]

Guidance on altering ventilation to reduce COVID-19 risks

ASHRAE and the CDC have issued recommendations and guidelines specifically targeted at ventilation in schools to minimize the spread of SARS-CoV-2 in indoor settings. CDC recommendations on ventilation in schools and childcare programs reflect ASHRAE guidance.[62]

CDC and ASHRAE guidance focus on providing and maintaining outdoor airflow, increasing ventilation with HVAC system settings, and filtering the air. HVAC systems are complicated. It is important to consult with a qualified professional to assure that school HVAC systems are designed, upgraded, installed, and operated properly in the space. In addition, ASHRAE and the CDC recommend that building managers verify that HVAC systems are properly operated and maintained.

For schools with natural ventilation, opening windows and doors when possible to bring in outdoor air is an effective way to enhance airflow and reduce the concentration of virus particles. Child-safe fans can be secured in windows to direct outdoor air in and circulate contaminated air out of another window, but airflow patterns should be carefully considered first.

To refresh air in occupied spaces, an HVAC system should be run for 2 hours before the building is occupied. For simple HVAC systems controlled by a thermostat, the fan control should be switched from “auto” to “on” to provide continuous air filtration and distribution. Air filters should be appropriately sized, installed, and replaced according to the manufacturer's instructions. To increase filtration, especially in high-risk areas, air filter units that use HEPA filters can be added to the space to enhance air cleaning. If ventilation and filtration options are limited, CDC guidance recommends that ultraviolet germicidal irradiation be considered as a supplemental treatment to inactivate the virus that causes COVID-19. Consulting with a qualified professional is recommended to ensure that the systems are running as designed and installed properly. There are a number of commercially available technologies that claim to disinfect air using ozone, bipolar ionization, oxidation, plasma, or foggers, but they have not been shown to be safe and effective in the peer-reviewed literature.[63-65] In some spaces, such as school kitchens and restrooms, exhaust ventilation systems should be operated at full capacity while the school or childcare program is occupied and for 2 hours afterward. Additionally, opening school transportation vehicle and bus windows is equally important to increase natural ventilation.[66] CDC guidance notes that all modifications and retrofits must comply with the ASHRAE 62.1 Ventilation for Acceptable Indoor Air Quality guidelines and must continue to meet or exceed applicable codes and standards.[62]

The ASHRAE guidance describes in detail the recommended ventilation rates, temperature, and filtration. In terms of ventilation, the highest achievable air change rate that will not generate excessive noise or have a negative impact on space air distribution should be used, while also ensuring flow patterns maximize appropriate circulation of air in classrooms. In terms of filtration, ASHRAE recommends selecting a filtration level that is maximized for the equipment capabilities, while assuring the pressure drop is less than the fan's capability. Filtration levels are classified as minimum efficiency reporting values, or MERV. A MERV 13 or better should be used if equipment allows, but MERV 14 or better is preferred per filtration and disinfection guidance.[67] ASHRAE also has a 2-page guide for selecting in-room air cleaners for reducing SARS-CoV-2 in the air.[68]

Brief Summary of ASHRAE's Recommended Actions for Schools

1. Schools should use the best filters that the HVAC system can handle, selecting MERV 13 or higher if equipment allows.
2. Schools should place terminal/fixed or portable HEPA filtration devices in each classroom, targeting the highest achievable air change rate that will not generate excessive noise.
3. Schools should maximize outdoor airflow by delivering design ventilation to all occupied spaces, rather than using demand-controlled ventilation systems using carbon dioxide sensors.
4. Schools should apply and use outdoor air quality sensors or reliable web-based data for outdoor pollution information as part of the new ventilation operation. If outdoor air is not healthy, more filtration will be needed.
5. Schools should perform monthly checks of air-handling units and rooftop units, especially checking for particulate accumulation on filters, in order to verify that

HVAC systems are functioning as designed.[69] Additional information on guidance from the US Environmental Protection Agency, CDC, and ASHRAE can be found in Appendix A.

All of these recommendations are valuable. However, in this report we highlight the recommendations that are the simplest, rely the least on technical expertise, can be implemented immediately, are easy to monitor, and are likely to perform well and be cost-effective.

Prioritizing Recommendations

When recommending specific actions, it must be anticipated how effective those actions will be if they are misinterpreted or implemented hastily and how likely the recommendation is to be followed. Any analysis or policy recommendation on cost-effectiveness must be based on likely costs and effectiveness under variable real-world conditions, not laboratory conditions. More complicated recommendations may be ignored, and recommendations that require knowledge or expertise to implement properly have a higher probability of failure than those requiring less knowledge. Two principles are important: (1) incentives matter and (2) what gets measured gets done. It is a general principle of management that recommendations are far more likely to be effective if they are being monitored and enforced in real time by someone who cares about the outcome and has full knowledge of what should be done. Our interviews with people who have experience implementing various standards and programs in school systems confirmed that this general principle applies in this case.

HVAC units in buildings rely on complicated technical specifications to install, and their filters cannot be easily observed by teachers, students, or caregivers. Stakeholders must trust that the specifications were made properly for the unit(s) and the building in which they are installed and that the maintenance schedule was followed. Our interviews with teachers provided several examples of failure to properly install or maintain filters. Researchers have shown that school administrators are often unaware of technical issues related to building maintenance.[70] The failure to continuously monitor HVAC maintenance increases the probability that performance will be at the lower end of the laboratory-measured range.

In contrast, it is much easier for nontechnical school staff and teachers to verify that the portable filter units are turned on and that filters were changed than to troubleshoot an HVAC system. As the maintenance requirements are much easier to communicate than the more technical messaging required for HVAC upgrades, and because air filtration units are mass-produced and delivered ready-to-use (ie, unbox and plug in), there is less chance of significant failure or underperformance with portable filter units, so there is a high probability that they will work in a classroom about as well as they do in the lab.

School Air Quality Task Force

Properly implementing ventilation recommendations can be difficult. Many school systems do not have access to technical experts to adapt and implement these recommendations in a cost-effective way. The federal government can help by issuing guidance and standards. Many people in agencies across government have complementary knowledge and skills to contribute to improving school air quality, and they can and should be gathered to form a working group to share this knowledge.

An interagency effort, including the Department of Education, the Environmental Protection Agency, and health and law enforcement agencies, is required to engage people from multiple government agencies as well as outside experts. A longer-term solution to the problem of poor air quality in schools is needed, as well as the establishment of a set of minimum standards for states and local governments to adopt for K-12 schools, which should include maintenance.

Recommendations

Given the information we have presented in this report, our recommendations are:

1. School administrators and decision makers should improve school ventilation now by bringing in as much outdoor air as the HVAC system will safely allow and upgrading filtration.

   In schools with mechanical ventilation, building engineers should maximize outdoor air delivery and increase filtration in the HVAC system by upgrading to the highest efficiency filters the system can handle (MERV 13, if possible). They can also switch fans from "auto" to "on" so that they operate continuously. For schools with natural ventilation, opening windows may help when combined with child-safe window fans to direct airflow; however, this alone will not guarantee increased ventilation. Windows cannot be opened in many schools, so increasing ventilation cannot be achieved without a portable air filter, which can reasonably and more reliably increase ventilation.

2. School administrators and decision makers should purchase HEPA air filtration units to be placed in classrooms and common occupied spaces.

   Even if ventilation in a school already meets current building standards (many do not), additional air filtration from a portable device can help reduce the potential for SARS-CoV-2 transmission. Portable HEPA air filters are easy to use, HEPA filtration is a proven technology, and the units have the advantage of being always "on." A quiet unit (or combination of smaller units) can increase the number of air changes by at least 3 to 5 times in an 800-square-foot classroom, can be purchased for about $500, and are less taxing on electrical systems than a portable air conditioner. Increasing the number of air changes per hour may substantially reduce aerosol transmission risks.

3. School systems should use only proven technologies for improving indoor air quality: appropriate ventilation, HEPA filtration, or ultraviolet germicidal irradiation. They should not use chemical foggers or any "air cleaner" other than filtration and ultraviolet germicidal irradiation.

   School systems should not use unproven technologies such as ozone generators, ionization, plasma, and air disinfection with chemical foggers and sprays. The effect of these cleaning methods on children has not been tested and may be detrimental to their health. The primary aim for improving air quality should be to remove contaminants and impurities from the air and not to introduce new substances into the air.

4. School administrators and decision makers should stop enhanced cleaning, disinfecting, “deep clean” days, and any other expensive and disruptive cleaning.

   School systems should regularly clean high-touch surfaces and disinfect spaces if a case is identified in the classroom or shared space, in accordance with CDC guidance. Schools should also provide proper hand hygiene resources such as hand sanitizer in classrooms and communal spaces and perform regular cleaning of frequent high-touch areas. However, schools should not implement ”deep clean” days as a matter of routine. Fomite (surface) transmission is not a major driver of the spread of SARS-CoV-2. Investments in ventilation will provide more value in risk reduction.

5. School administrators and decision makers should install mechanical ventilation systems where none exist and upgrade those that do not meet current standards.

   All students, teachers, and staff deserve healthy air, and many are not currently getting it. Proper ventilation will improve health and education. Ventilation systems should meet all applicable codes and standards, be regularly maintained, and be verified that the systems are functioning as designed. If schools only have natural ventilation, HVAC systems should be installed. Upgrades to facilities will take time but will improve ventilation in schools for the long term.

6. The US government should convene a federal task force dedicated to school air quality to develop guidance for long-term, sustainable, cost-effective improvements to indoor air quality in schools. This guidance should include accountability measures to assess improvements.

   The task force should be composed of experts in air quality, industrial hygiene, building science, HVAC systems, epidemiology, engineering, children’s environmental health, and education. Together, they should develop guidance for improving, monitoring, and maintaining good indoor air quality. The task force should create standards for school systems to account for different ventilation systems, climates, and conditions around the country. It should also develop a certification for HVAC installers and commissioners and, importantly, should provide recommendations for oversight and accountability so that the nation’s K-12 students and teachers have the benefit of healthy air in schools. The well-documented problems of poor indoor air quality in K-12 schools have been allowed to continue for decades. A path forward is needed to fix these problems to give students, teachers, and staff in K-12 schools the healthy air they deserve.

Conclusion

Airborne transmission of SARS-CoV-2 virus, the virus responsible for the COVID-19 pandemic, can be reduced by improving ventilation. Federal funds are now available to enable schools to make the needed changes. These changes will make our schools healthier during the current pandemic. If improved ventilation is properly installed, operated, and maintained, students and educators will benefit for years to come.

The evidence-based recommendations described in this report can help schools and school districts to address COVID-19-related and longstanding ventilation problems. The report can provide a foundation for infrastructure investments that reliably use proven technology to raise the air quality in schools, which will improve student learning and the health of everyone in school buildings for decades to come.