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

May 2021

JOHNS HOPKINS
BLOOMBERG SCHOOL of PUBLIC HEALTH
Center for Health Security

## Authors

**Paula J. Olsiewski, PhD**
Contributing Scholar, Johns Hopkins Center for Health Security

**Richard Bruns, PhD**
Senior Scholar, Johns Hopkins Center for Health Security

**Gigi Kwik Gronvall, PhD**
Senior Scholar , Johns Hopkins Center for Health Security

**William P. Bahnfleth, PhD, PE**
Professor of Architectural Engineering, Pennsylvania State University

**Gunnar Mattson**
MPH Student, Johns Hopkins Bloomberg School of Public Health

**Christina Potter, MSPH**
Analyst, Johns Hopkins Center for Health Security

**Rachel A. Vahey, MHS**
Analyst, Johns Hopkins Center for Health Security

## Expert Reviewers

**Destiny Aman, MS**
Founder, JPoint Collaborative

**Claire Barnett, MBA**
Founder and Executive Director, Healthy Schools Network

**Anita Cicero, JD**
Deputy Director, Johns Hopkins Center for Health Security

**Corey Metzger, PE**
Principal, Resource Consulting Engineers, LLC

**Joel Solomon, MA**
Senior Policy Analyst, National Education Association

**Brent Stephens, MSE, PhD**
Department Chair and Professor of Civil, Architectural and Environmental Engineering, Illinois Institute of Technology

**Simon Turner, BSc**
Chief Executive Officer, Building Cognition, LLC

**Crystal Watson, DrPH, MPH**
Senior Scholar, Johns Hopkins Center for Health Security

## Acknowledgments

The authors would like to thank Divya Hosangadi, Andrea Lapp, and Tanna Liggins for their valuable support of the project, and Julia Cizek, Jaclyn Fox, Kathleen Fox, Margaret Miller, and Prarthana Vasudevan for their design, editing, and publication support. This effort was funded by support from the Open Philanthropy Project.

Suggested citation: Olsiewski PJ, Bruns R, Gronvall GK, et al. *School Ventilation: A Vital Tool to Reduce COVID-19 Spread*. Baltimore, MD: Johns Hopkins Center for Health Security; 2021.

© 2021 The Johns Hopkins University. All rights reserved.

# 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]

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.

***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

### 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.

## References

1. US Centers for Disease Control and Prevention. COVID data tracker. Accessed March 19, 2021. https://covid.cdc.gov/covid-data-tracker
2. Levin Z, Choyke K, Georgiou A, Sen S, Karaca-Mandic P. Trends in pediatric hospitalizations for coronavirus disease 2019. *JAMA Pediatr*. 2021;175(4):415-417.
3. Assaker R, Colas AE, Julien-Marsollier F, et al. Presenting symptoms of COVID-19 in children: a meta-analysis of published studies. *Br J Anaesth*. 2020;125(3):e330-e332.
4. Poline J, Gaschignard J, Leblanc C, et al. Systematic SARS-CoV-2 screening at hospital admission in children: a French prospective multicenter study. *Clin Infect Dis*. 2020;ciaa1044.
5. US Centers for Disease Control and Prevention. Information for pediatric healthcare providers. Updated December 30, 2020. Accessed March 19, 2021. https://www.cdc.gov/coronavirus/2019-ncov/hcp/pediatric-hcp.html
6. American Academy of Pediatrics. Children and COVID-19: state-level data report. Accessed March 16, 2021. http://services.aap.org/en/pages/2019-novel-coronavirus-covid-19-infections/children-and-covid-19-state-level-data-report/
7. Bixler D, Miller AD, Mattison CP, et al. SARS-CoV-2–associated deaths among persons aged <21 years—United States, February 12-July 31, 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69(37):1324-1329.
8. Viner RM, Mytton OT, Bonell C, et al. Susceptibility to SARS-CoV-2 infection among children and adolescents compared with adults: a systematic review and meta-analysis. *JAMA Pediatr*. 2021;175(2):143-156.
9. *Education Week* staff. Map: Where are schools required to be open for the 2020-21 school year? *Education Week*. July 28, 2020. Updated May 19, 2021. Accessed May 20, 2021. https://www.edweek.org/leadership/map-where-are-schools-closed/2020/07
10. *Education Week* staff. Coronavirus and learning: what's happening in each state. *Education Week*. April 3, 2020. Updated July 24, 2020. Accessed March 16, 2021. https://www.edweek.org/policy-politics/coronavirus-and-learning-whats-happening-in-each-state/2020/04
11. Taras HL; American Academy of Pediatrics Committee on School Health. School-based mental health services. *Pediatrics*. 2004;113(6):1839-1845.
12. Ralston K, Coleman-Jensen A. USDA's national school lunch program reduces food insecurity. *Amber Waves*. August 7, 2017. Accessed March 16, 2021. https://www.ers.usda.gov/amber-waves/2017/august/usda-s-national-school-lunch-program-reduces-food-insecurity
13. Council on School Health. School-based health centers and pediatric practice. *Pediatrics*. 2012;129(2):387-393.
14. Lloyd M. Domestic violence and education: examining the impact of domestic violence on young children, children, and young people and the potential role of schools. *Front Psychol*. 2018;9:2094.
15. Greenberg M, Costigan T. Can learning social skills in school pay off beyond the classroom? *Culture of Health* blog. Published September 5, 2017. Accessed March 16, 2021. http://www.rwjf.org/en/culture-of-health/2017/08/learning-social-skills-in-school.html
16. Barr H. School closures particularly hard on children with disabilities. *Human Rights Watch*. Published June 15, 2020. Accessed March 16, 2021. https://www.hrw.org/news/2020/06/15/school-closures-particularly-hard-children-disabilities
17. Agostinelli F, Doepke M, Sorrenti G, Zilibotti F. When the great equalizer shuts down: schools, peers, and parents in pandemic times. Cambridge, MA: National Bureau of Economic Research; 2020. Accessed May 14, 2021. https://www.nber.org/system/files/working_papers/w28264/w28264.pdf

18. Gilbert LK, Strine TW, Szucs LE, et al. Racial and ethnic differences in parental attitudes and concerns about school reopening during the COVID-19 pandemic—United States, July 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69(49):1848-1852.

19. US Centers for Disease Control and Prevention. Making decisions about children attending in-person school during the COVID-19 pandemic: information for parents, guardians, and caregivers. Updated January 19, 2021. Accessed April 21, 2021. https://www.cdc.gov/coronavirus/2019-ncov/community/schools-childcare/decision-tool.html

20. Nierenberg A, Pasick A. The impact of teacher deaths. *New York Times*. January 29, 2021. Accessed March 16, 2021. https://www.nytimes.com/2021/01/29/us/the-impact-of-teacher-deaths.html

21. COVID-19 school response dashboard. Accessed March 16, 2021. https://statsiq.co1.qualtrics.com/public-dashboard/v0/dashboard/5f78e5d4de521a001036f78e#/dashboard/5f78e5d4de521a001036f78e?pageId=Page_f6071bf7-7db4-4a61-942f-ade4cce464de

22. The COVID Monitor: COVID-19 reporting in K-12 schools. Accessed March 16, 2021. https://experience.arcgis.com/experience/fb52d598982f41faac714b5ebe32e7d1

23. Hess AJ. 27% of teachers are considering quitting because of Covid, survey finds. C*NBC*. December 14, 2020. Accessed March 16, 2021. https://www.cnbc.com/2020/12/14/27percent-of-teachers-are-considering-quitting-because-of-covid-survey.html

24. Dickler J. More teachers plan to quit as Covid stress overwhelms educators. *CNBC*. March 1, 2021. Accessed March 16, 2021. https://www.cnbc.com/2021/03/01/more-teachers-plan-to-quit-as-covid-stress-overwhelms-educators.html

25. Baker P, Green EL, Weiland N. Trump threatens to cut funding if schools do not fully reopen. *New York Times*. July 8, 2020. Updated July 24, 2020. Accessed March 16, 2021. https://www.nytimes.com/2020/07/08/us/politics/trump-schools-reopening.html

26. US Government Accountability Office (GAO). *K-12 Education: School Districts Frequently Identified Multiple Building Systems Needing Updates or Replacement*. Washington, DC: GAO; 2020. Accessed March 16, 2021. https://www.gao.gov/assets/gao-20-494.pdf

27. Department of Defense, Labor, Health and Human Services, and Education Appropriations Act, 2019 and Continuing Appropriations Act, 2019, Pub L No. 115-245, 132 Stat 2981 (2018).

28. US Environmental Protection Agency. Evidence from scientific literature about improved academic performance. Published October 20, 2014. Accessed March 16, 2021. https://www.epa.gov/iaq-schools/evidence-scientific-literature-about-improved-academic-performance

29. Fisk WJ. The ventilation problem in schools: literature review. *Indoor Air*. 2017;27(6):1039-1051.

30. Schneider M. Public school facilities and teaching: Washington, DC and Chicago. Washington, DC: Twenty-First Century School Fund; 2002. Accessed May 14, 2021. https://files.eric.ed.gov/fulltext/ED474242.pdf

31. Bekö G, Wargocki P, Wang N, et al. The Indoor Chemical Human Emissions and Reactivity (ICHEAR) project: overview of experimental methodology and preliminary results. *Indoor Air*. 2020;30(6):1213-1228.

32. Persily A. Challenges in developing ventilation and indoor air quality standards: the story of ASHRAE Standard 62. *Build Environ*. 2015;91:61-69.

33. Wargocki P, Porras-Salazar JA, Contreras-Espinoza S, Bahnfleth W. The relationships between classroom air quality and children's performance in school. *Build Environ*. 2020;173:106749.

34. Chan WR, Li X, Singer BC, et al. Ventilation rates in California classrooms: why many recent HVAC retrofits are not delivering sufficient ventilation. *Build Environ*. 2020;167:106426.

35. US Centers for Disease Control and Prevention. Operational strategy for K-12 schools through phased prevention. Updated May 15, 2021. Accessed May 20, 2021. https://www.cdc.gov/coronavirus/2019-ncov/community/schools-childcare/operation-strategy.html

36. National Academies of Sciences, Engineering, and Medicine. *Reopening K-12 Schools During the COVID-19 Pandemic: Prioritizing Health, Equity, and Communities*. Washington, DC: The National Academies Press; 2020. https://doi.org/10.17226/25858

37. Cicero A, Potter C, Sell TK, Rivers C, Schoch-Spana M. *Filling in the Blanks: National Research Needs to Guide Decisions about Reopening Schools*. Baltimore, MD: Johns Hopkins Center for Health Security; 2020. Accessed March 19, 2021. https://www.centerforhealthsecurity.org/our-work/publications/2020/filling-in-the-blanks-national-research-needs-to-guide-decisions-about-reopening-schools-in-the-united-states

38. ASHRAE. Coronavirus (COVID-19) response resources from ASHRAE and others. Accessed April 23, 2021. https://www.ashrae.org/technical-resources/resources

39. Rivers C, Silcox C, Potter C, et al. *Risk Assessment and Testing Protocols for Reducing SARS-CoV-2 Transmission in K-12 Schools*. Baltimore, MD: Johns Hopkins Center for Health Security; 2020. Accessed March 16, 2021. https://www.centerforhealthsecurity.org/our-work/publications/2020/risk-assessment-and-testing-protocols-for-reducing-sars-cov-2-transmission-in-k-12-schools

40. Falk A, Benda A, Falk P, Steffen S, Wallace Z, Høeg TB. COVID-19 cases and transmission in 17 K–12 schools—Wood County, Wisconsin, August 31-November 29, 2020. *MMWR Morb Mortal Wkly Rep*. 2021;70(4):136-140.

41. Rice KL, Miller GF, Coronado F, Meltzer MI. Estimated resource costs for implementation of CDC's recommended COVID-19 mitigation strategies in pre-kindergarten through grade 12 public schools—United States, 2020-21 school year. *MMWR Morb Mortal Wkly Rep*. 2020;69(50):1917-1921.

42. Morawska L, Milton DK. It is time to address airborne transmission of coronavirus disease 2019 (COVID-19). *Clin Infect Dis*. 2020;71(9):2311-2313.

43. US Centers for Disease Control and Prevention. Science brief: SARS-CoV-2 and surface (fomite) transmission for indoor community environments. Update April 5, 2021. Accessed April 23, 2021. https://www.cdc.gov/coronavirus/2019-ncov/more/science-and-research/surface-transmission.html

44. Park SY, Kim YM, Yi S, et al. Coronavirus disease outbreak in call center, South Korea. *Emerg Infect Dis*. 2020;26(8):1666-1670.

45. European Centre for Disease Prevention and Control (ECDC). Heating, Ventilation and Air-Conditioning Systems in the Context of COVID-19: First Update. Solna, Sweden: ECDC; 2020. Accessed May 14, 2021. https://www.ecdc.europa.eu/en/publications-data/heating-ventilation-air-conditioning-systems-covid-19

46. Allen JG, Ibrahim AM. Indoor air changes and potential implications for SARS-CoV-2 transmission. *JAMA*. April 16, 2021. doi:10.1001/jama.2021.5053

47. Lednicky JA, Lauzardo M, Fan ZH, et al. Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients. *Int J Infect Dis*. 2020;100:476-482.

48. Li Y, Qian H, Hang J, et al. Probable airborne transmission of SARS-CoV-2 in a poorly ventilated restaurant. *Build Environ*. 2021;196:107788.

49. Yan J, Grantham M, Pantelic J, et al. Infectious virus in exhaled breath of symptomatic seasonal influenza cases from a college community. *Proc Natl Acad Sci U S A*. 2018;115(5):1081-1086.

50. Matthews TG, Thompson CV, Wilson DL, Hawthorne AR, Mage DT. Air velocities inside domestic environments: an important parameter in the study of indoor air quality and climate. *Environ Int*. 1989;15(1):545-550.

51. Bourouiba L. The fluid dynamics of disease transmission. *Annu Rev Fluid Mech*. 2021;53(1):473-508.

52. Kwon KS, Park JI, Park YJ, Jung DM, Ryu KW, Lee JH. Evidence of long-distance droplet transmission of SARS-CoV-2 by direct air flow in a restaurant in Korea. *J Korean Med Sci*. 2020;35(46):e415.

53. Wei J, Li Y. Airborne spread of infectious agents in the indoor environment. *Am J Infect Control*. 2016;44(suppl 9):S102-S108.

54. van Doremalen N, Bushmaker T, Morris DH, et al. Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *N Engl J Med*. 2020;382(16):1564-1567.

55. Morawska L, Tang JW, Bahnfleth W, et al. How can airborne transmission of COVID-19 indoors be minimised? *Environ Int*. 2020;142:105832.

56. Hamner L, Dubbel P, Capron I, et al. High SARS-CoV-2 attack rate following exposure at a choir practice—Skagit County, Washington, March 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69(19):606-610.

57. Zuo YY, Uspal WE, Wei T. Airborne transmission of COVID-19: aerosol dispersion, lung deposition, and virus-receptor interactions. *ACS Nano*. November 25, 2020. doi:10.1021/acsnano.0c08484

58. Silcott D, Kinahan S, Santarpia J, et al. TRANSCOM/AMC commercial aircraft cabin aerosol dispersion tests. Accessed April 23, 2021. https://www.ustranscom.mil/cmd/docs/TRANSCOM%20Report%20Final.pdf

59. Rothamer DA, Sanders S, Reindl D, Bertram TH. Strategies to minimize SARS-CoV-2 transmission in classroom settings: combined impacts of ventilation and mask effective filtration efficiency. Preprint. *medRxiv*. Posted January 4, 2021. Accessed May 20, 2021. doi:10.1101/2020.12.31.20249101

60. van Rijn C, Somsen GA, Hofstra L, et al. Reducing aerosol transmission of SARS-CoV-2 in hospital elevators. *Indoor Air*. 2020;30(6):1065-1066.

61. de Oliveira PM, Mesquita LCC, Gkantonas S, Giusti A, Mastorakos E. Evolution of spray and aerosol from respiratory releases: theoretical estimates for insight on viral transmission. *Proc Math Phys Eng Sci*. 2021;477(2245):20200584.

62. ASHRAE Epidemic Task Force. Core recommendations for reducing airborne infectious aerosol exposure. Accessed April 23, 2021. https://www.ashrae.org/file%20library/technical%20resources/covid-19/core-recommendations-for-reducing-airborne-infectious-aerosol-exposure.pdf

63. Zeng Y, Manwatkar P, Laguerre A, et al. Evaluating a commercially available in-duct bipolar ionization device for pollutant removal and potential byproduct formation. *Build Environ*. 2021;195:107750.

64. Lee CS, Shayegan Z, Haghighat F, Zhong L, Bahloul A, Huard M. Experimental evaluation of in-duct electronic air cleaning technologies for the removal of ketones. *Build Environ*. 2021;196:107782.

65. US Environmental Protection Agency. Ozone generators that are sold as air cleaners: an assessment of effectiveness and health consequences. Accessed April 23, 2021. https://www.epa.gov/indoor-air-quality-iaq/ozone-generators-are-sold-air-cleaners-assessment-effectiveness-and-health

66. US Centers for Disease Control and Prevention. Ventilation in schools and childcare programs. Updated February 26, 2021. Accessed March 16, 2021. https://www.cdc.gov/coronavirus/2019-ncov/community/schools-childcare/ventilation.html

67. ASHRAE Epidemic Task Force. Filtration & disinfection. Updated October 20, 2020. Accessed April 23, 2021. https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-filtration_disinfection-c19-guidance.pdf

68. ASHRAE. In-room air cleaner guidance for reducing COVID19 in air in your space/room. Published January 21, 2021. Accessed April 26, 2021. https://www.ashrae.org/file%20library/technical%20resources/covid-19/in-room-air-cleaner-guidance-for-reducing-covid-19-in-air-in-your-space-or-room.pdf

69. ASHRAE Epidemic Task Force. Schools & universities. Updated May 14, 2021. Accessed May 17, 2021. https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-reopening-schools-and-universities-c19-guidance.pdf

70. Paradise R. *An Investigation to Determine the Level of Knowledge of Facility Maintenance by Public School-Building Level Administrators*. Dissertation. University of Central Florida; 2006. Accessed May 17, 2021. https://stars.library.ucf.edu/etd/945

# Appendix A. Summary of Current Guidance for Healthy Indoor Air

The US Environmental Protection Agency (EPA) has long promoted improving indoor air quality in schools and provides guidance to states, school administrators, and teachers for how to improve the air quality in school settings.[1] During a health crisis, such as the COVID-19 pandemic, stakeholders look to public health leaders for guidance. Accordingly, EPA guidance should be reflected in public health messaging. This section describes guidance from the US Centers for Disease Control and Prevention (CDC), released on February 26, 2021, and from the ASHRAE Epidemic Task Force.

## CDC: Ventilation in Schools and Childcare Programs

The CDC recommendations on ventilation in schools and childcare programs focus on increasing access to outdoor air; maximizing ventilation with heating, ventilation, and air conditioning (HVAC) system settings; and filtering air.[2] The guidance is summarized in this section.

### Use natural and/or mechanical ventilation to increase air replacement and flow

To help bring in outdoor air, opening windows and doors when possible is an effective and natural way to enhance airflow and reduce the concentration of virus particles in schools. To help increase effectiveness, child-safe fans can be secured in windows to direct outdoor air in and circulate contaminated air out another window.

For schools with mechanical ventilation, make sure that HVAC systems meet code requirements and are properly serviced. Set the system to bring in as much outdoor air as it will safely allow, increase the total airflow supply to occupied spaces, and reduce recirculation. To refresh air in occupied spaces, run the HVAC system for 2 hours before the building is occupied. For simple HVAC systems controlled by a thermostat, set the fan control switch from “auto” to “on” to provide continuous air filtration and distribution.

For air filtration, make sure the filters are sized, installed, and replaced according to manufacturers’ instructions. To increase filtration, especially in high-risk areas, portable air filters that use HEPA filters can be added to the space to enhance air cleaning. If ventilation and filtration options are limited, consider the use of ultraviolet germicidal irradiation as a supplemental treatment to inactivate the SARS-CoV-2 virus.[3]

Please consult with a qualified professional to ensure the systems are designed and installed in the space properly. In some spaces, such as kitchens and restrooms, exhaust ventilation systems should be operated at full capacity while the school or childcare program is occupied and for 2 hours after. Opening school transportation vehicle and bus windows is equally important to increase natural ventilation in those closed spaces.

If your district, school, or childcare program needs more ventilation support, select an HVAC professional with knowledge of ASHRAE standards to inspect and repair HVAC systems in schools. Your state or local jurisdiction may also regulate HVAC system settings and maintenance, so make sure that the HVAC professional you select is aware of those regulations as well.[4]

**Filter the air to capture virus particles and remove them from air flow**
In addition to improving ventilation, filtering virus particles out of the air crucial and can be done relatively simply by using available products and technology. Some school HVAC systems can support additional filtration functionality on their own, while others will need to be retrofitted. To increase filtration, especially in high-risk areas, schools can add standalone or portable air filters that use HEPA filters to enhance air cleaning.

Additional technical suggestions include:

- Make sure the filters are sized, installed, and replaced according to manufacturers' instructions.
- Select filtration levels (minimum efficiency reporting values, or MERV, ratings) that are maximized for equipment capabilities. Use MERV 13 if equipment allows, while assuring the pressure drop is less than the fans' capability; MERV 14 is preferred per filtration and disinfection guidance. Consider HEPA filters in critical areas.
- Target highest achievable air change rate for in-room air cleaner units that will not generate excessive noise or have a negative impact on space air distribution.

For detailed information on selecting portable HEPA air filtration devices, consult the EPA's *Guide to Air Cleaners in the Home*.[5]

**Ensure good maintenance protocols to ensure healthy operation of systems**
Additional technical suggestions in the CDC guidance include:

- All retrofits and modifications must meet or exceed, not contradict, ASHRAE 62.1 guidelines and must continue to meet or exceed applicable codes and standards.
- Perform initial air flush of all spaces prior to people reentering a building by operating mechanical systems for a minimum period of 1 week prior to students returning and minimum of 2 hours prior to people reentering the building.
- Perform monthly checks of air handling units and rooftop units, including checks for particulate accumulation on filters.
- Apply and use outdoor air quality sensors or reliable web-based data for outdoor pollution information as part of the new ventilation operation.

## ASHRAE Epidemic Task Force

Founded in 1894, ASHRAE is a global society advancing human wellbeing through sustainable technology for the built environment. The society and its members focus on building systems, energy efficiency, indoor air quality, refrigeration, and sustainability in the industry. Through research, standards writing, publishing, and continuing education, ASHRAE shapes tomorrow's built environment today.[6]

The ASHRAE Epidemic Task Force was established in March 2020 to help deploy ASHRAE's technical resources to address the challenges of the current pandemic and future epidemics as they relate to the effects of heating, ventilation, and air conditioning systems on disease transmission in healthcare facilities, the workplace, home, and public and recreational environments.[7]

**Core Recommendations for Reducing Airborne Infectious Aerosol Exposure** (January 6, 2021)[8]
The following recommendations are the foundation of detailed guidance issued by the ASHRAE Epidemic Task Force. They are based on the concept that, within limits, ventilation, filtration, and air cleaners can be deployed flexibly to achieve exposure reduction goals subject to constraints that may include comfort, energy use, and costs. This is done by setting targets for equivalent clean air supply rate and expressing the performance of filters, air cleaners, and other removal mechanisms in these terms.

1. Public Health Guidance. Follow all regulatory and statutory requirements and recommendations for social distancing, wearing of masks and other personal protective equipment, administrative measures, circulation of occupants, reduced occupancy, hygiene, and sanitation.
2. Ventilation, Filtration, Air Cleaning
   - 2.1 Provide and maintain at least required minimum outdoor airflow rates for ventilation as specified by applicable codes and standards.
   - 2.2 Use combinations of filters and air cleaners to achieve MERV 13 or better levels of performance for air recirculated by HVAC systems.
   - 2.3 Only use air cleaners for which evidence of effectiveness and safety is clear.
   - 2.4 Select control options, including standalone filters and air cleaners, that provide desired exposure reduction while minimizing associated energy penalties.
3. Air Distribution. Where directional airflow is not specifically required, or not recommended as the result of a risk assessment, promote mixing of space air without causing strong air currents that increase direct transmission from person to person.
4. HVAC System Operation
   - 4.1 Maintain temperature and humidity design set points.
   - 4.2 Maintain equivalent clean air supply required for design occupancy whenever anyone is present in the space served by a system.

4.3 When necessary to flush spaces between occupied periods, operate systems for a time required to achieve 3 air changes of equivalent clean air supply.

4.4 Limit reentry of contaminated air that may reenter the building from energy recovery devices, outdoor air, and other sources to acceptable levels.

5. System Commissioning. Verify that HVAC systems are functioning as designed.

**Guidance for Schools and Universities**

Below is a summary of ASHRAE's guidance for schools and universities as of August 20, 2020. The full guidance can be found on the ASHRAE website (https://www.ashrae.org/technical-resources/reopening-of-schools-and-universities).

- All retrofits and modifications must not contradict ASHRAE 62.1 guidelines and must continue to meet or exceed applicable codes and standards.
- Verify proper separation between outdoor air intakes and exhaust discharge outlets to prevent/limit reentrainment of potentially contaminated exhaust air (generally minimum of 10 foot separation).
- Select filtration levels that are maximized for equipment capabilities, use MERV 13 if equipment allows, while assuring the pressure drop is less than the fans' capability; MERV 14 is preferred per filtration and disinfection guidance. Consider HEPA filters in critical areas.
- Disable demand-controlled ventilation systems using carbon dioxide sensors where feasible.
- Perform initial air flush of all spaces prior to occupants reentering building by operating mechanical systems for minimum period of 1 week prior to students returning and for minimum of 2 hours prior to occupants reentering building.
- Perform monthly checks of air-handling units and rooftop units, including checks for particulate accumulation on filters.
- Apply and utilize outdoor air quality sensors or reliable web-based data for outdoor pollution information as part of the new ventilation operation.
- Introduce terminal or portable all-electric HEPA/UV machines in each classroom
    - Target highest achievable air change rate for units that will not generate excessive noise or have a negative impact on space air distribution.
    - Ensure flow patterns maximize mixing of air in classrooms.
- Run dedicated outdoor air system (DOAS) units 2 hours before and after occupancy.
- Turn on exhaust fans when DOAS is running (for school days only).

It is important to note that ASHRAE guidance includes the following statement: **Only use air cleaners for which evidence of effectiveness and safety is clear.**

## References


1. US Environmental Protection Agency. Creating healthy indoor air quality in schools. Accessed April 23, 2021. https://www.epa.gov/iaq-schools
2. US Centers for Disease Control and Prevention. Science brief: SARS-CoV-2 and surface (fomite) transmission for indoor community environments. Update April 5, 2021. Accessed April 23, 2021. https://www.cdc.gov/coronavirus/2019-ncov/more/science-and-research/surface-transmission.html
3. National Institute for Occupational Safety and Health (NIOSH). *Environmental Control for Tuberculosis: Basic Upper-Room Ultraviolet Germicidal Irradiation Guidelines for Healthcare Settings*. Washington, DC: NIOSH; 2007. Accessed May 20, 2021. https://www.cdc.gov/niosh/docs/2009-105/default.html
4. ASHRAE. ANSI/ASHRAE 62.1-2019. Ventilation for acceptable indoor air quality. Peachtree Corners, GA: ASHRAE; 2019. Accessed April 23, 2021. https://webstore.ansi.org/Standards/ASHRAE/ANSIASHRAE622019?source=blog&_ga=2.148687287.1606157056.1613843549-1965444031.1613843549
5. US Environmental Protection Agency (EPA). *Guide to Air Cleaners in the Home*. 2nd ed. Washington, DC: EPA; 2018. Accessed May 17, 2021. https://www.epa.gov/sites/production/files/2018-07/documents/guide_to_air_cleaners_in_the_home_2nd_edition.pdf
6. ASHRAE. About ASHRAE. Accessed April 21, 2021. https://www.ashrae.org/about
7. ASHRAE. ASHRAE Epidemic Task Force established. Published March 31, 2020. Accessed April 23, 2021. https://www.ashrae.org/about/news/2020/ashrae-epidemic-task-force-established
8. ASHRAE Epidemic Task Force. Core recommendations for reducing airborne infectious aerosol exposure. Published January 6, 2021. Accessed April 23, 2021. https://www.ashrae.org/file%20library/technical%20resources/covid-19/core-recommendations-for-reducing-airborne-infectious-aerosol-exposure.pdf

# Appendix B. Purpose, Methods, and Analysis

## Purpose

To assess the related challenges and solutions to indoor air quality in US kindergarten through grade 12 (K-12) schools during and after the COVID-19 pandemic.

## Methods and Analysis

### Review of published literature and previous reports

The Johns Hopkins Center for Health Security surveyed the peer-reviewed and gray literature on air quality in schools, the effect on student learning, and the emerging science of SARS-CoV-2 transmission in indoor environments.

### Interviews

The Center interviewed 32 technical experts (listed in Appendix C) with expertise in K-12 education, environmental health, indoor air quality, aerosol science, building science, risk communication, and engineering that work in related fields in academia, the private sector, and government laboratories. The goal was to collect their expert advice about options for improving indoor air quality in schools both during and after the COVID-19 pandemic.

### A National Conversation on Indoor Air and K-12 Schools During the COVID-19 Pandemic

The Center completed a preliminary analysis that synthesized the results of the literature review and expert interviews. Those findings were used to facilitate discussion during a webinar hosted by the Center that was held on February 23, 2021. More than 450 people participated in the meeting. Participants in the webinar included representatives of US academic institutions, private industry, local school districts, private schools, health departments, and the local, state, and federal government. The latter included the US Centers for Disease Control and Prevention, Environmental Protection Agency, Department of Homeland Security, Defense Threat Reduction Agency, Department of Health and Human Services, and National Institute of Standards and Technology. The meeting agenda and recorded webinar link are provided in Appendix D. The speakers and their biographies are listed in Appendix E.

### Final report

This report presents the Center's scientific and policy assessment for improving indoor air quality in K-12 schools during and after the COVID-19 pandemic, informed by our expert interviews, literature review, and February 23, 2021, webinar discussions. The views expressed in this report do not necessarily reflect specific views of the webinar participants or sponsors.

## Appendix C. Interviewees

**Destiny Aman, MS**
JPoint Collaborative

**William Bahnfleth, PhD, PE**
Pennsylvania State University
Institutes of Energy and the Environment

**Claire Barnett, MBA**
Healthy Schools Network

**Eric Benyo, MA**
Autocase

**Kenneth Bernard, MD, DTM&H**
Former Special Assistant to the US President for Biodefense
Former Assistant Surgeon General

**Eric Bill, MEcon, MBA**
Autocase

**Dominique Brossard, MS, MPS, PhD**
University of Wisconsin–Madison
Life Sciences Communication

**Gail Carpenter, MA**
Olathe School District (Olathe North High School)

**Richard L. Corsi, PhD, PE**
Portland State University

**Peter DeCarlo, PhD**
Johns Hopkins University
Department of Environmental Health and Engineering
Whiting School of Engineering

**Laura Kolb, MPH**
US Environmental Protection Agency
Indoor Environments Division

**Corbett Lunsford, BM**
Home Diagnosis TV Series

**Grace Lunsford, BFA**
Home Diagnosis TV Series

**Colleen Markman, MEd**
Olathe School District (Havencroft Elementary)

**Linsey Marr, PhD**
Virginia Tech University
Civil and Environmental Engineering

**Shelly Miller, MS, PhD**
University of Colorado Boulder
College of Engineering and Applied Science

**Lidia Morawska, MSc, PhD**
Queensland University of Technology (Brisbane, Australia)
International Laboratory for Air Quality and Health

**Beth Maldin Morgenthau, MPH**
New York City Health Department
Office of Emergency Preparedness and Response

**Alisha Morris, MA**
Olathe School District (Olathe West High School)

**Jayne Morrow, MS, PhD**
Montana State University

**William Nazaroff, MEng, PhD**
University of California, Berkeley

**Roger Platt, JD**
US Green Building Council

**Chris Pyke, PhD**
ArcSkoru, Inc.

**Lesliam Quiros-Alcala, MSc, PhD**
Johns Hopkins Bloomberg School of Public Health
Department of Environmental Health and Engineering

**Ana María Rule, PhD**
Johns Hopkins Bloomberg School of Public Health
Department of Environmental Health and Engineering

**Richard Shaughnessy, PhD**
University of Tulsa
Indoor Air Quality Research

**Joel Solomon, MA**
National Education Association

**Jelena Srebric, MSc, PhD**
University of Maryland
Department of Mechanical Engineering

**Brent Stephens, MSE, PhD**
Illinois Institute of Technology
Architectural Engineering

**Simon Turner, BSc**
Building Cognition, LLC

**Kevin Van Den Wymelenberg, PhD, MArch**
University of Oregon
Department of Architecture

**Tricia Wang, PhD**
COVID Straight Talk

# Appendix D. Expert Webinar

**A National Conversation on Indoor Air and K-12 Schools During the COVID-19 Pandemic**

The COVID-19 pandemic has had catastrophic impacts on children's education in the United States. Kindergarten through grade 12 (K-12) schools have had to compensate with ever-changing policies related to in-person schooling. Teachers and staff have struggled with limited guidance and resources for teaching safely. Children and their families have had to cope with disease risk and limited access to typical school functions, including in-person learning, health resources, childcare, and food security. Guidance and resources have since been made available to school administrators for the prevention and mitigation of transmission, but ventilation in schools—an issue even prior to the pandemic—is often neglected in the provision of guidance and resources. This meeting explored next steps and priorities for the current administration to improve indoor air quality in schools during and after the pandemic. More than 450 people participated in the webinar on February 23, 2021.

- Watch the February 23 webinar.
- A National Conversation on Indoor Air and K-12 Schools During the COVID-19 Pandemic

## Appendix E. Speakers and Biographies

**Dr. Paula Olsiewski, Contributing Scholar, Johns Hopkins Center for Health Security.** She is a pioneering leader in policy and scientific research programs in the microbiology and chemistry of indoor environments. Her expertise in partnering with academic, governmental, and for-profit stakeholders fostered innovation and built research capacity through the creation of diverse stakeholder networks.

**Dr. William Bahnfleth, Professor of Architectural Engineering, Pennsylvania State University.** His research interests include indoor environmental control topics, protection of building occupants from indoor bioaerosol releases, and ultraviolet germicidal irradiation systems. He is the chair of ASHRAE's Epidemic Task Force.

**Ms. Claire Barnett, Founder and Executive Director, Healthy Schools Network.** She is the nation's premier voice for children's environmental health at school.

**Dr. Richard Corsi, Dean of the Maseeh College of Engineering & Computer Science, Portland State University.** He is an internationally recognized expert in the field of indoor air quality. His research is motivated by the fact that the average American lives to 79 years and spends 70 of those years inside of buildings, and that lifetime exposure to harmful air pollution, even that of outdoor origin, is dominated by the air we breathe indoors.

**Dr. Ana Rule, Assistant Professor of Environmental Health and Engineering, Johns Hopkins Bloomberg School of Public Health.** She is an expert in the development and evaluation of novel sampling and analysis strategies for the assessment of exposure to biological aerosols, e-cigarette aerosols, and particulate matter.

**Dr. Brent Stephens, Department Chair and Professor of Civil, Architectural and Environmental Engineering, Illinois Institute of Technology.** He is an expert in indoor air quality and building science.

**Mr. Simon Turner, Chief Executive Officer, Building Cognition LLC,** a consulting firm specializing in indoor air quality. Mr. Turner has a background in biology, and his interest for the past 30 years has been the impact of buildings and their features on human cognition and health.

**Dr. Delphine Farmer, Associate Professor of Chemistry, Colorado State University.** Her research focuses on outdoor atmospheric and indoor chemistry with an emphasis on understanding the sources and sinks of reactive trace gases and particles and their effects on climate, ecosystems, and human health.

**Dr. Kenneth W. Bernard, Former Special Assistant to the US President for Biodefense and Former Assistant Surgeon General.** He served as a special assistant to the president for security and health during the Clinton and George W. Bush administrations.

**Dr. Chris Pyke, Senior Vice President, Arc Skoru Inc.** He is a principal investigator for the Green Health Partnership, a long-term research initiative. Prior to joining Arc, he was research officer for the US Green Building Council, chief strategy officer for Aclima, and chief operating officer for GRESB, and a physical scientist with the US Environmental Protection Agency.

**Mr. Joel Solomon, Senior Policy Analyst, National Education Association (NEA).** He currently leads NEA's cross-departmental Safety and Health Team, which guides NEA's safety and health response to the COVID-19 pandemic. In this capacity, he steers efforts to review and enhance in-person learning plans for schools and institutions of higher education, develop written guidance, provide strategic and policy advice, and advance members' safety and health interests in the Biden-Harris administration and US government agencies.

**Ms. Destiny Aman, Founder, JPoint Collaborative.** She is a behavioral science and risk communications specialist with experience translating science into practical solutions to increase resilience at individual, community, and national levels. Currently, Ms. Aman splits her time between her own consulting practice, JPoint Collaborative, and supporting the International Association for Bioscience and Environmental Criteria (IBEC), a nonprofit focused on developing and promoting creative adaptations to the ongoing global pandemic.

**Dr. Gigi Kwik Gronvall, Senior Scholar, Johns Hopkins Center for Health Security.** She is an immunologist by training. During the COVID-19 pandemic, she has led the Center's ongoing efforts to track the development and marketing of molecular and antigen tests and serology tests, as well as the development of national strategies for COVID-19 serology (antibody) tests and SARS-CoV-2 serosurveys in the United States. She has also written about the scientific response to the COVID-19 pandemic and implications for national and international security.

# Appendix F. Cost-Effectiveness of Surface Cleaning vs. Ventilation

In this technical appendix, we provide a cost-effectiveness estimate of 2 SARS-CoV-2 infection control measures intended to remove or reduce virus transmission in the school environment. This analysis aims to help schools prioritize actions that will more effectively reduce SARS-CoV-2 transmission with limited resources.

### Limitations and assumptions

We do not have the data to do a cost-effectiveness analysis for all possible mitigation strategies to protect people in schools from COVID-19, particularly as mitigation measures are being used in a combination approach according to US Centers for Disease Control and Prevention (CDC) guidance. Therefore, we focus on 2 widely used or proposed measures that can be most easily compared. In this cost-effectiveness analysis, we compare 2 methods of reducing transmission of SARS-CoV-2: (1) enhanced "deep cleaning" of contact surfaces and (2) ventilation upgrades to increase air quality. The cost-effectiveness analysis approach allows us to ignore many uncertainties because they apply to both interventions. We focus on how effective each intervention is likely to be, given a similar budget.

Doing a full cost-benefit analysis of the policy recommendations in this report would be extremely difficult, because it is impossible to predict how many COVID-19 cases would be prevented by each of the examined interventions. Also, the expected base rate of transmission in the future would need to be estimated, which may be dependent on unknown details about new variants of the SARS-CoV-2 virus, the success of the mass vaccination campaign, and community transmission levels.

At one extreme, if SARS-CoV-2 is completely contained, then there would be no COVID-19-related benefit to any of these interventions. On the other hand, if people decide not to hold school in person, then there would also be no benefit to any money spent on making schools safer. The benefits come only in the in-between situation where there is enough transmission to be risky, but not so much that school buildings will be shut down. We believe that this is the likely outcome, but we do not know its probability or what the baseline risk will be.

## Available budget for mitigation

In the Coronavirus Response and Relief Supplemental Appropriations Act, passed in December 2020,[1] Congress allocated $54 billion in grants for public kindergarten through grade 12 (K-12) schools. The American Rescue Plan Act, passed in March 2021, allocated an additional $126 billion for K-12 schools, preferentially allocated to schools with poor students using the Title 1 formula.[2]

For illustrative purposes, we analyze what public schools nationwide would achieve for roughly $10 billion, or 1/18th of the total budget allocation of $180 billion. Given that there are roughly 50 million public K-12 students, $10 billion is about $200 per student.[3] This is not a statement that it is improper to spend less or that this level of funding for classroom infection reduction is sufficient to make classrooms "safe." Many schools have been safely open for the length of the pandemic. We also assume that other interventions not analyzed here, such as vaccination, testing, adherence to mask use, and contact tracing, are also done as recommended by public health authorities[*] and may be necessary, in combination with our recommendations, for safe operations.

In this analysis, we focus on the total economic costs of the interventions to society—including schools, caregivers, and students—rather than just the budget cost to schools. Although we provide context by mentioning the appropriations figures, we are describing what can be done for $10 billion in total costs, not $10 billion in appropriations. The economic cost of a policy is more than just the budget cost. It includes all costs that society suffers as a result, even those not written in a budget. One of these costs is opportunity cost, which is the value of the work that one forgoes by choosing one option over another. When teachers are implementing mitigation measures, they are not teaching or preparing to teach, and so the loss of this education must be counted as a cost of asking them to clean classrooms. Any policy analysis must consider the full economic costs, including opportunity costs, to avoid recommending actions that may have a low budget cost but push significant costs to others in society, especially those least able to afford them.

For simplicity and clarity, we analyze all policies as though they were being newly implemented—for example, for schools that have been online only for the 2020-2021 school year. If a school has already purchased ventilation upgrades, this will reduce the additional cost to them of that action in the upcoming school year.

### Surface cleaning[†]

The CDC has estimated that the annual cost of surface cleaning for all public K-12 schools during the COVID-19 pandemic would be between $4 billion and $13 billion ($80 to $260 per student).[4] This wide range comes from uncertainty about how many staff will be required to clean and how long it will take.

Much of this cost is due to hiring new custodial staff. However, several of the teachers we interviewed reported being asked to clean their classrooms (in excess of the cleaning they did prepandemic). About 74% of teachers in a survey report being asked to do COVID-19-related cleaning.[5] While assigning this task to teachers may reduce the immediate budgetary impact, it actually increases the economic cost, because the time

---

* Possibly using some of the other $170 billion allocated to schools, after money is spent on ventilation

† We use "cleaning" here to refer to the entire process of cleaning and disinfection, noting that antimicrobial pesticides do not clean. They must be applied to a clean surface and then sit for the appropriate dwell time in order to be effective.

and effort of teachers is valuable, and spending it on cleaning means that they are not spending it on other activities. Based on studies showing large net benefits of reducing class size, we know that the social value of the time that teachers spend with students is much higher than their salaries, which are in turn generally higher than custodian salaries.[6-8] Therefore, the opportunity cost of teacher time is significantly higher than the cost of custodian time, so having teachers clean will have even higher costs than the CDC estimates.

Over the course of the pandemic, it has become clear that fomites and surfaces are not significant drivers of SARS-CoV-2 transmission; surface cleaning will cause a very small reduction in infection probability.[9,10] On April 5, 2021, the CDC changed its guidance on cleaning because the risk of surface transmission is low.[11,12]

In addition, most cleaning products are a significant source of petrochemicals and volatile organic compounds that may make students sick,[13] which is more likely to happen in schools with bad ventilation. We are unable to quantify the negative health effects of COVID-19-related surface cleaning, but we note that they exist and will reduce or possibly even outweigh the small gains in infection reduction they provide. Children should not handle any school cleaning or disinfecting products, including wipes, because of the potential health harms to them.

### Ventilation*

Students spend most of their time in classrooms, so we focus on classrooms as the unit of analysis. Since school ventilation and filtration also must be improved in common areas, such as cafeterias, we estimate that roughly a quarter of the $10 billion illustrative budget is spent on ventilating these areas, leaving $7.5 billion for classrooms.

Given 50 million students and a national average class size of about 20, there are about 2.5 million public K-12 classrooms.[14] Each classroom would then get about $3,000 ($7.5 billion/2.5 million) to improve the air. This money can be spent on installing or improving heating, ventilation, and air conditioning (HVAC) systems and/or on portable air filtration units.

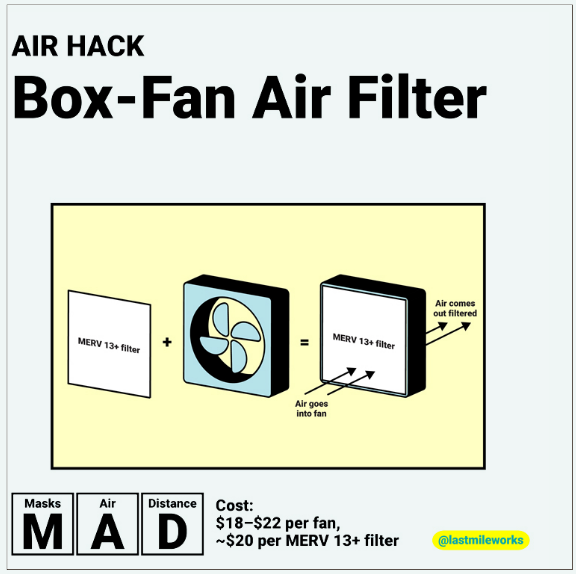
However, $3,000 per classroom is not enough for a newly installed modern HVAC system. Based on our interviews with experts, we estimate that such an installation would cost at least $6,000 per classroom or perhaps less for upgrades to relatively modern systems that are not fully up to code. If installed properly to the correct specifications, such systems will provide both thermal comfort and good ventilation—depending on classroom size, roughly 5 to 7 air changes per hour (ACH) of air in circulation, of which 2 to 3 are ventilation air from outside.

* We use ”ventilation” here to refer to ventilation and air cleaning: processes that push air through filters in order to remove virus particles from it.

As described in the report, there are many reasons to upgrade ventilation, making it a good investment even in the absence of a pandemic. However, given contracting delays due to the demand for HVAC experts to address COVID-19 ventilation concerns in other types of buildings, it is probable that school installations cannot be completed before fall 2021.

By contrast, low-decibel portable filtration units that minimally disrupt the classroom can be quickly purchased and plugged in (or made by hand, see sidebar). We expect that with bulk discounts, a quiet unit (or combination of smaller units) that provides 3 to 5 ACH in an 800-square-foot classroom can be purchased for about $500.[*] When including the cost of electricity at about $100 per year, 5 replacement filters at $20 each, and money to cover teacher time used for operating the device, the total cost will be about $750 per unit for a year of operation.[15†] Some school electrical systems may not be able to support many units and will need to be upgraded. Bids for upgrading the electrical systems in old urban schools to support air conditioners can be as high as $20,000 to $30,000 per classroom, although 4 HEPA filter units require less power than an air conditioning unit.[16] We do not know what percentage of classrooms will require this work or what the cost per classroom would be. If 5% of classrooms require a $10,000 electrical upgrade, this would consume, on average, $500 of the per-classroom budget. This means that each classroom could have 3 air conditioning units designed for a large room (or a larger number of smaller cheaper units), providing about 9 to 15 ACH.[‡]

*Sidebar*




Source: Last Mile, COVIDStraighTalk.org
https://covidstraighttalk.org/boxfanairfilter

* Louder units are cheaper, and some jurisdictions may opt for the cheaper units, especially if the quiet ones are sold out, but the additional noise may disrupt learning, which would generate hard-to-quantify costs.

† For the purposes of the cost analysis, we assume that the pandemic will last only 1 more year, which means that the unit cost cannot be amortized over multiple years. The units may have some additional value to health and comfort after the pandemic—for example, in flu or pollen season. However, in order to provide a conservative cost estimate and avoid potentially overstating their value, we ignore these additional benefits.

‡ We note an existing estimate that it would cost about $1 billion to put 1 portable air filter in each classroom. Our per-unit cost estimate is roughly double that, to account for electricity and time costs while using a more conservative estimate of unit costs.

Our primary source for the effectiveness of filtration is Rothamer et al.[17] They show that going from baseline to a total of 5 ACH results in a decrease in infection probability by about a factor of 2. Further increasing to 10 ACH results in an additional factor of 1.7 decrease in infection probability, for a total of 3.4—that is, there would be one-third as much infection risk in a classroom with enough filter units to provide 10 ACH.

Other sources show similar or higher protective effects. Curtius et al[18] ran a test of 4 portable air filters, with a total ACH of about 6, and found that this reduced the inhaled dose of virus particles from an infectious person by a factor of 6.

### Summary of the relative effectiveness of ventilation improvements compared to other mitigation measures

We do not know exactly how much risk of SARS-CoV-2 infection will be reduced by surface cleaning or ventilation improvements. However, we have shown that surface cleaning results in much less risk reduction per dollar spent. Therefore, we recommend not spending time or money on routine enhanced classroom cleaning and encourage schools to instead spend their COVID-19 relief funds on improved ventilation.

All schools should have appropriate ventilation,* usually a properly installed and maintained modern building HVAC system with appropriate filters changed regularly. All existing CDC and ASHRAE standards should eventually be followed for the sake of students' overall health and learning. However, in many cases it may not be possible to complete these upgrades during the current pandemic when they may be useful to reduce the spread of SARS-CoV-2, particularly when combined with other mitigation measures. Even in the case of a well-maintained HVAC system running at full capacity (providing 5 to 7 ACH), portable filters in the room bringing the total ACH to 10 or more provide a significant improvement in infection risk reduction. Because such units are not bringing in outside air or changing the temperature (which are important things to do but do not directly help the pandemic response), they are a more cost-effective way of providing virus filtration. In addition, to maximize the health benefits, filters should be changed regularly in an observable and documented way. This type of unit makes it easier for students and caregivers to verify that each classroom has a filter unit and that the filter has been recently changed.

For the reasons that we have described in this section, making sure that there are several portable air filter units in all classrooms and shared areas may be one of the most reliable and cost-effective methods of infection risk reduction. Schools should be strongly encouraged to spend some of their stimulus money in this way.

* Ventilation rates required by building codes that are based on standards that do not explicitly address infection control are not sufficient in the current COVID-19 pandemic situation. The definition of acceptable indoor air quality is ASHRAE 62.1, which applies to schools and is based on control of building-generated emissions and odor control to achieve subjective satisfaction.

## References


1. Coronavirus Response and Relief Supplemental Appropriations Act, Pub L No. 116-260 (2020).
2. Jordan P. What congressional Covid funding means for K-12 schools. FutureEd. Published April 30, 2021. Accessed May 17, 2021. https://www.future-ed.org/what-congressional-covid-funding-means-for-k-12-schools/
3. Riser-Kositsky M. Education statistics: facts about American schools. *Educ Week*. January 3, 2019. Updated February 22, 2021. Accessed March 16, 2021. https://www.edweek.org/leadership/education-statistics-facts-about-american-schools/2019/01
4. Rice KL, Miller GF, Coronado F, Meltzer MI. Estimated resource costs for implementation of CDC's recommended COVID-19 mitigation strategies in pre-kindergarten through grade 12 public schools—United States, 2020-21 school year. *MMWR Morb Mortal Wkly Rep*. 2020;69(50):1917-1921.
5. Gibbons A. Three-quarters of teachers expected to clean classrooms. Tes. Published June 12, 2020. Accessed March 19, 2021. https://www.tes.com/news/coronavirus-exclusive-34-teachers-expected-clean-classrooms
6. Muennig P, Woolf SH. Health and economic benefits of reducing the number of students per classroom in US primary schools. *Am J Public Health*. 2007;97(11):2020-2027.
7. US Bureau of Labor Statistics. Occupational Outlook Handbook: kindergarten and elementary school teachers. Last modified April 9, 2021. Accessed May 17, 2021. https://www.bls.gov/ooh/education-training-and-library/kindergarten-and-elementary-school-teachers.htm
9. US Bureau of Labor Statistics. Occupational Outlook Handbook: janitors and building cleaners. Last modified April 9, 2021. Accessed May 17, 2021. https://www.bls.gov/ooh/building-and-grounds-cleaning/janitors-and-building-cleaners.htm
10. Lewis D. COVID-19 rarely spreads through surfaces. So why are we still deep cleaning? *Nature*. 2021;590(7844):26-28.
11. Goldman E. Exaggerated risk of transmission of COVID-19 by fomites. *Lancet Infect Dis*. 2020;20(8):892-893.
12. US Centers for Disease Control and Prevention. Science brief: SARS-CoV-2 and surface (fomite) transmission for indoor community environments. Update April 5, 2021. Accessed April 23, 2021. https://www.cdc.gov/coronavirus/2019-ncov/more/science-and-research/surface-transmission.html
13. Anthes E. Has the era of overzealous cleaning finally come to an end? *New York Times*. April 8, 2021. Accessed April 23, 2021. https://www.nytimes.com/2021/04/08/health/coronavirus-hygiene-cleaning-surfaces.html
14. McDonald BC, de Gouw JA, Gilman JB, et al. Volatile chemical products emerging as largest petrochemical source of urban organic emissions. *Science*. 2018;359(6377):760-764.
15. National Center for Education Statistics. Schools and staffing survey (SASS). Accessed March 16, 2021. https://nces.ed.gov/surveys/sass/tables/sass1112_2013314_t1s_007.asp
16. airfuji.com. How much does it cost to run an air purifier? Updated May 2, 2020. Accessed March 16, 2021. https://airfuji.com/how-much-does-it-cost-to-run-an-air-purifier/
17. Baltimore City Public Schools. Baltimore City Public Schools' air conditioning plan: update. Published January 2019. Accessed April 23, 2021. https://www.baltimorecityschools.org/sites/default/files/2019-01/HeatingCooling-UpdatedACPlan-January2019_0.pdf
18. Rothamer DA, Sanders S, Reindl D, Bertram TH. Strategies to minimize SARS-CoV-2 transmission in classroom settings: combined impacts of ventilation and mask effective filtration efficiency. Preprint. *medRxiv*. Posted January 4, 2021. doi:10.1101/2020.12.31.20249101
19. Curtius J, Granzin M, Schrod J. Testing mobile air purifiers in a school classroom: reducing the airborne transmission risk for SARS-CoV-2. *Aerosol Sci Technol*. 2021;55(5):586-599.

**Johns Hopkins**
**Center for Health Security**

621 E. Pratt Street, Suite 210
Baltimore, MD 21202

Tel: 443-573-3304
Fax: 443-573-3305

centerhealthsecurity@jhu.edu
centerforhealthsecurity.org

Johns Hopkins Bloomberg School of Public Health | Center for Health Security