School Ventilation for COVID-19

Improve Student Health and Achievement Through Indoor Air Quality

COLLABORATIVE FOR HIGH PERFORMANCE SCHOOLS
CHPS SCHOOLS

Introduction

The COVID-19 pandemic that has affected every corner of the globe in 2020 will have profound, long-lasting impacts on the design of schools and other physical environments. This has often been the case throughout history as the response to disease and building occupant safety have shaped the way we live. Staples of our modern environment as diverse as city parks and the clean lines and smooth surfaces of modern architecture were in part a response to epidemics of cholera, typhoid fever and other diseases in the late 19th and early 20th centuries. In many cases the response to disease gave increased importance, support and visibility to movements that were already underway.[1] As we begin to look toward recovery from this epidemic and the prospect of living with it for a prolonged period, the Collaborative for High Performance Schools (CHPS) hopes there will be a similar outcome. We hope to bring renewed focus to the role that the quality of learning environments, particularly IAQ, plays in student and teacher health, achievement and wellness. The goal of this paper is to outline the learning and wellness benefits of improved IAQ in schools and to provide actionable design strategies to achieve those benefits as well as connections to further resources.

About CHPS

Founded nearly 20 years ago, the Collaborative for High Performance Schools (CHPS) has a mission to improve student health and achievement, conserve resources, and protect the environment through better school buildings. To help school districts and designers implement strategies proven to benefit student health, learning and the environment, CHPS has created a set of research-based standards and guidelines called *The CHPS Criteria*. *The CHPS Criteria* is organized into seven important categories — with the largest weight dedicated to Indoor Environmental Quality (IEQ). Within each category there are individual credits and prerequisites, such as daylighting, low volatile organic compounds and increased ventilation. Each one includes specific metrics for guiding and evaluating school designs to determine whether they can achieve the performance that research has shown to benefit students and teachers. All 101 prerequisites and credits work together to ensure that every CHPS project meets minimum standards for sustainability and performance in key areas such as acoustics and water use reduction while also allowing the flexibility to accommodate each project's constraints. This balance creates a rigorous and usable tool to guide and evaluate the design of high-performance schools. *The CHPS Criteria* makes it easy for school districts to set clear, research-based standards for the design of their facilities and to set requirements for their designers to ensure their school buildings meet these standards.

[1] Campbell, Margaret. "What tuberculosis did for modernism: the influence of a curative environment on modernist design and architecture." *Medical history* vol. 49,4 (2005): 463-88. doi:10.1017/s0025727300009169

Background Science

Connection between Indoor Air Quality and Learning

There is a broad and growing body of research establishing a strong link between the quality of a school's learning environment and the performance of its students. Although it is not often thought of this way, the learning environment — along with more widely recognized factors such as the teacher, family situation and socioeconomic status — is a significant factor in explaining the achievement gap between different students. A recent report by the World Bank, "The Impact of School Infrastructure on Learning," concluded that "Recent studies have shown that students' performance is enhanced in schools with better physical learning environments. As this report will show, the empirical argument for investing in learning environment is strong."[2]

An important study demonstrating a strong connection between the quality of the learning environment and student achievement was conducted by the University of Salford in the UK. This peer-reviewed study conducted detailed surveys of 153 classrooms in 27 diverse schools and collected academic performance data for their students. Using multilevel statistical analysis, the authors determined that "Differences in the physical characteristics of classrooms explain 16% of the variation in learning progress over a year for the 3766 pupils included in the study."[3] This shows that the quality of the environment is a significant factor in how students learn. The study further assessed the level of impact from seven different environmental characteristics: light, temperature, air quality, ownership, flexibility, visual complexity and color. The research team produced a user-friendly report that provides actionable strategies for teachers and designers.

In 2019 the Harvard T.H. Chan School for Public Health published a comprehensive report on how school buildings influence student thinking, health and performance called Schools for Health: Foundations for Student Success. The report "..reviews findings from more than 200 scientific studies and identifies more than 70 Health Performance Indicators."4 The report discusses the unique needs of children and how facilities can help meet them. The authors conclude that, "The evidence is unambiguous. The school building impacts student health, thinking and performance. Investing in school buildings is an investment in our future."

One of the most impactful areas identified in the University of Salford and Harvard reports is Air Quality. There have been numerous additional studies linking indoor air quality, specifically

[2] Barrett, Peter; Treves, Alberto; Shmis, Tigran; Ambasz, Diego; Ustinova, Maria. 2019. "The Impact of School Infrastructure on Learning : A Synthesis of the Evidence." *International Development in Focus*;. Washington, DC: World Bank. © World Bank. https://openknowledge.worldbank.org/handle/10986/30920 License: CC BY 3.0 IGO."

[3] Barrett, Peter, et al. "The Holistic Impact of Classroom Spaces on Learning in Specific Subjects." Environment and Behavior, vol. 49, no. 4, May 2017, pp. 425–451, http://doi:10.1177/0013916516648735

[4] Eitland, Erika, et al. "Schools for Health: Foundations for Student Success." *For Health*, Harvard University T.H. Chan School of Public Health, 2019, schools.forhealth.org/.

carbon dioxide (CO_2) levels, to learning and cognition. One of the most widely cited was completed by Harvard, Syracuse and SUNY universities in 2016.[5] This study used a laboratory-simulated office environment to test the cognitive performance of office workers under different levels of CO_2 and volatile organic compounds (VOCs). The CO_2 and VOC levels were adjusted to simulate a typical office environment, a “Green” indoor environment with lower CO_2 and VOC levels and a “Green+” environment with even lower levels. The study concluded that, “On average, cognitive scores were 61% higher on the Green building day and 101% higher on the two Green+ building days than on the Conventional building day.”[6] This shows the major impact that indoor air quality has on our ability to understand and process learning. Although this study was conducted on adults, the impact on children is likely bigger, since they breathe a larger volume of air relative to body size.

Another study in 2014 looked at changes in student test scores in one Texas school district where all the classrooms were renovated specifically to improve indoor air quality over a five-year period.[7] The renovations were specifically authorized to address indoor air quality problems such as mold, high VOC levels and poor ventilation at 66 elementary schools across the district. Although the scale of the improvements at each school was not large, typically $300,000 to $500,000, they produced measurable improvements in student achievement. By correlating test data with the timing of the renovations at each school, the researchers were able to demonstrate an improvement in standardized testing pass rates of 2-4%, depending on the scope of the renovations with more extensive projects typically producing a larger improvement. “Results indicate that performance on standardized tests significantly improves.... Rough calculations suggest that IAQ-renovations may be a more cost-effective way to improve standardized test scores than class size reductions.” Another study of schools in California showed a similar link between improved indoor air quality and ventilation and improved academic performance.[8]

In addition to improving academic performance, research has also shown that improving classroom IAQ also improves student and teacher attendance. A study of 162 elementary school classrooms from different regions of California showed a significant link between improving ventilation rates and indoor air quality and a decrease in illness-related absence.[9] This study noted that average ventilation rates in the classrooms studied were far below state-required levels and if they were raised to the required minimum they “...would decrease IA [illness absence] by 3.4%, increase attendance-linked funding to schools by $33 million annually, and increase costs by only $4 million.

---

[5] Allen JG, MacNaughton P, Satish U, Santanam S, Vallarino J, Spengler JD. 2016. Associations of cognitive function scores with carbon dioxide, ventilation, and volatile organic compound exposures in office workers: a controlled exposure study of green and conventional office environments. Environ Health Perspect 124:805–812; http://dx.doi.org/10.1289/ehp.1510037

[6] Allen and MacNaughton 805.

[7] Isabella Annesi-Maesano, Nour Baiz, Soutrik Banerjee, Peter Rudnai, Solenne Rive & on behalf of the SINPHONIE Group (2013) Indoor Air Quality and Sources in Schools and Related Health Effects, Journal of Toxicology and Environmental Health, Part B, 16:8, 491-550, DOI: 10.1080/10937404.2013.853609

[8] Haverinen-Shaughnessy, U., Moschandreas, D.J. and Shaughnessy, R.J. (2011), Association between substandard classroom ventilation rates and students’ academic achievement. Indoor Air, 21: 121-131. https://doi:10.1111/j.1600-0668.2010.00686.x

[9] Mendell, M.J., Eliseeva, E.A., Davies, M.M., Spears, M., Lobscheid, A., Fisk, W.J. and Apte, M.G. (2013), Association of classroom ventilation with reduced illness absence: a prospective study in California elementary schools. Indoor Air, 23: 515-528. https://doi:10.1111/ina.12042

Further increasing VRs [ventilation rates] would provide additional benefits." Reducing student absence improves academic achievement and provides additional funding to many school districts whose funding is tied to average daily attendance. Studies of schools in Washington, Idaho and Scotland have shown similar results. Additionally, a literature review published in 2017 looked at 26 studies from around the world and presented evidence of a strong association between ventilation rates, student performance and attendance.[10] Increasing student attendance not only boosts learning, but in 7 states, including California, Texas and New York, where a significant portion of funding is distributed based on average daily attendance this translates to an increase in funding.

These studies are examples of the growing body of research that demonstrates a strong connection between the quality of the learning environment and what happens within those spaces. They specifically show that significant benefits to student achievement and learning and to student attendance are correlated to improvements in indoor air quality and ventilation. At a time when schools are facing unprecedented COVID-19-related funding challenges, improving ventilation in classrooms and other learning spaces is an important and often overlooked strategy to improve student learning and, in many cases, even increase school funding in some states.

Connection between Indoor Air Quality and Disease Transmission

There is a very active research effort into how the coronavirus is transmitted and what can be done to reduce its transmission. Much of this research is ongoing and not yet conclusive. However, the evidence collected so far seems sufficient — and similar enough to diseases that have already been studied — to allow some conclusions and recommendations for best practices for schools.

The first thing we know is that one of the primary ways the virus is transmitted is through airborne respiratory droplets. The American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) has stated, "Transmission of SARS-CoV-2 through the air is sufficiently likely that airborne exposure to the virus should be controlled. Changes to building operations, including the operation of heating, ventilating, and air conditioning systems, can reduce airborne exposures."[11] A 2003 literature review following previous epidemics of similar viruses concluded that, "There is strong and sufficient evidence to demonstrate the association between ventilation, air movements in buildings, and the spread of infectious disease."[12]

Although researchers do not have sufficient data to specify ventilation requirements that will prevent disease transmission, it is clear that proper ventilation is an extremely important

---

[10] Fisk, WJ. The ventilation problem in schools: literature review. Indoor Air. 2017; 27: 1039– 1051. https://doi.org/10.1111/ina.12403

[11] "COVID-19 (Coronavirus) Preparedness Resources." *COVID-19: Resources Available to Address Concerns*, American Society of Heating Refrigeration and Air Conditioning Engineers, 2020, www.ashrae.org/technical-resources/resources.

[12] Li, Y., Leung, G.M., Tang, J.W., Yang, X., Chao, C.Y.H., Lin, J.Z., Lu, J.W., Nielsen, P.V., Niu, J., Qian, H., Sleigh, A.C., Su, H.-J.J., Sundell, J., Wong, T.W. and Yuen, P.L. (2007), Role of ventilation in airborne transmission of infectious agents in the built environment – a multidisciplinary systematic review. Indoor Air, 17: 2-18. doi:10.1111/j.1600-0668.2006.00445.x

strategy for reducing that risk. The CDC recommends that schools “Ensure [that] ventilation systems operate properly and increase circulation of outdoor air as much as possible, for example by opening windows and doors.”[13] Increasing ventilation rates means exchanging the air inside the space for fresh outside air more often. This removes airborne respiratory droplets from an infected person from the space more quickly and lessens the risk they will infect someone else.

A recent study that got a lot of media attention was a case study of transmission of COVID-19 in a restaurant in Guangzhou, China. Although most of the media attention focused on how the direction of airflow within the space affected the virus transmission, another important consideration was the lack of ventilation in the space. The exhaust fans had been turned off so there was no outside air ventilation as part of the HVAC system, which led to very low ventilation rates. This led to the authors’ conclusion that, “Aerosol transmission of SARS-CoV-2 due to poor ventilation may explain the community spread of COVID-19.”[14] Based on past and emerging research it is clear that the performance of a building’s ventilation system has a significant effect on indoor airborne virus transmission.

For a more detailed discussion of the science behind ventilation and disease transmission please refer to a recent detailed whitepaper from Taylor Engineering which provides more detailed discussion of these topics.[15]

State of Indoor Air Quality in Schools

As we have established above, a healthy IAQ is important for student and teacher performance and wellness. Unfortunately, many classrooms are not providing healthy or even adequate IAQ to students and teachers. The 2017 literature review by WJ Fisk noted that in all 20 of the studies that provided CO2 data from 20 or more classrooms “...the reported average and median values of the peak CO2 concentration exceeded 1000 ppm, and in many instances 2000 ppm was exceeded. … These CO2 data indicate a widespread failure to provide the minimum amount of ventilation specified in standards for classrooms.”[16] (CO2 concentration levels are often used as an effective proxy for overall indoor air quality which includes CO2 and other particulates and pollutants. 1000 ppm is approximately equal to the ASHRAE-recommended ventilation rate and the code-required rate in California and many other jurisdictions of 15 cubic feet per minute). The 2013 study by Mendell et al. evaluated 152 classrooms in California and found that more than half did not meet the minimum requirements, including 95% of those in an all-air-conditioned district in the Central Valley.[17] This means that in

[13] “Considerations for Schools.” *Centers for Disease Control and Prevention*, 19 May 2020, www.cdc.gov/coronavirus/2019-ncov/community/schools-childcare/schools.html.

[14] Lu J, Gu J, Li K, Xu C, Su W, Lai Z, et al. COVID-19 outbreak associated with air conditioning in restaurant, Guangzhou, China, 2020. Emerg Infect Dis. 2020 Jul [date cited]. https://doi.org/10.3201/eid2607.200764

[15] https://taylorengineers.com/taylor-engineering-covid-19-whitepaper

[16] Fisk, WJ. 1041

[17] Medall, M.J. 523

many if not most classrooms children are not getting the required minimum amount of fresh air and their academic performance is negatively affected.

This problem is not limited to older classrooms with out-of-date mechanical systems in need of replacement or repair. A 2019 study conducted by Lawrence Berkeley National Laboratory evaluated the CO2 levels in 104 classrooms in 11 schools across the state with recently retrofitted or installed HVAC systems.[18] The study found that "Only around 15% of the classrooms had a median of daily VR [Ventilation Rate] estimates that met the 7 L/s-person code requirement." The study also included a detailed inspection of the mechanical equipment of the classrooms and documented a wide variety of issues that caused these new HVAC systems to underperform. These included "Improperly selected equipment, lack of commissioning, incorrect fan control settings and maintenance issues (heavily loaded filters)..."

These and other studies have shown that in many cases our students and teachers are learning and working in facilities that do not provide even the recommended levels of fresh air and as a result have high levels of CO2 and VOCs, making it more difficult to teach and learn. This is especially troubling in the context of the study referenced earlier by Allen JG et al. on the cognitive function of office workers. That study showed that improving indoor air quality above the code-required minimum levels improved cognitive function by up to 100%. Most of our school classrooms are significantly below the baseline level of this study. There is a great opportunity to benefit teachers, students and the education system at large by making targeted investments in improved indoor air quality.

Research like this has informed the creation and continued updating of the CHPS Criteria for more than twenty years. Indoor Environmental Quality and especially Indoor Air Quality have been a particular focus for CHPS because of their impact on learning. This is reflected in the CHPS Criteria as further discussed below.

Benefits of Improved IAQ in Schools

- Improved student learning and achievement on test scores
- Reduction in illness-related absences by students and teachers
- Increased school funding based on increased average daily attendance (ADA) *(in states using ADA to determine state funding)*
- Reduced teacher absenteeism and substitute teacher costs
- Improved working environment helping teachers better do their job
- Reduced liability from mold and other contaminant-based health issues
- Improved student disciplinary rates

[18] Wanyu R. Chan, Xiwang Li, Brett C. Singer, Theresa Pistochini, David Vernon, Sarah Outcault, Angela Sanguinetti, Mark Modera, Ventilation rates in California classrooms: Why many recent HVAC retrofits are not delivering sufficient ventilation, Building and Environment, Volume 167, 2020, 106426, ISSN 0360-1323, https://doi.org/10.1016/j.buildenv.2019.106426

Evidence-Based Strategies for Operations

As we saw above, many classrooms are not adequately ventilated. Many of these will need to be addressed quickly to prepare for fall classes during the ongoing COVID-19 epidemic. Existing buildings require a unique strategy as most institutions cannot afford to replace all their HVAC units mid life cycle. ASHRAE has published detailed guidelines for schools, including checklists for reopening and recommended practices during the year.[19] The following recommended strategies have been shown to help remediate indoor air quality in schools. We know that schools have limited resources, staff and time to address these issues. For that reason, we are presenting recommended measures prioritized with those that we have found to be most effective first.

Filter Changes - MERV 13

Filtration is an effective tool in removing respiratory droplets from the air, a critical aspect part of healthy classrooms. It is recommended that all filters in HVAC systems be changed to a minimum MERV 13 filter of the greatest depth allowed by the equipment, typically 2". When selecting the filter, review the pressure drop data and select a new filter that is similar to the old filter so that system performance won't be affected. This is often a concern with switching existing systems to MERV 13 filters, but commonly available filters have different pressure drop ratings and they can be very similar to the values for MERV 7 filters. Narrow filters will have less particle holding capability and need to be changed more frequently. Review your maintenance practices and stock filters for prompt change out. It is important to make sure the filters are sealed as leaks allow a significant amount of air to bypass the filter. through leaks. Also, make sure that maintenance staff wear PPE and take appropriate caution when replacing filters that may be contaminated.

Daily Air Flush Out

One simple change that facilities departments can do is to change the controls settings and schedules to increase the times that the ventilation systems and fans are running. With the improved filtration mentioned above it is important to make sure that air is moving through the system and being filtered. ASHRAE has recommended running ventilation systems for a minimum of 2 hours in occupied mode, with the peak outside air rate, before teachers arrive each day. Increased HVAC operation will result in higher energy costs. For this reason we are recommending extender operations rather than continuous system operation.

Retro-Commissioning

Establish a proper baseline of the ventilation, operation, and condition of your unit by having your sites retroactively commissioned. Almost all schools are designed for adequate ventilation

---

[19] ASHRAE Epidemic Task Force - Schools and Universities, 06 May 2020, https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-reopening-schools.pdf

levels, but studies have repeatedly shown that many HVAC systems, even new ones, are not delivering the intended amount of ventilation. A qualified and certified Commissioning Agent or Testing and Balancing professional can evaluate your existing equipment, ductwork and controls to make sure it is delivering the intended ventilation rate and correct any issues. With schools likely at reduced student counts in classrooms this fall, making sure that ventilation rates meet standards will effectively increase ventilation per person beyond recommended levels. This increase in ventilation will help provide healthier indoor environments.

Measure and Monitor CO2

Measuring CO2 levels in classrooms is an inexpensive yet important way to determine in real time if adequate ventilation is being provided and identify any problems that may develop throughout the year. This can be accomplished by installing “smart” thermostats to monitor CO2 levels or by using portable CO2 monitors. Smart thermostats and monitors connected to building management systems can have the added benefit of being able to automatically adjust the operation of the unit and allow maintenance staff to remotely monitor and control the unit’s operations where compatible equipment is installed.

Open Doors and Windows

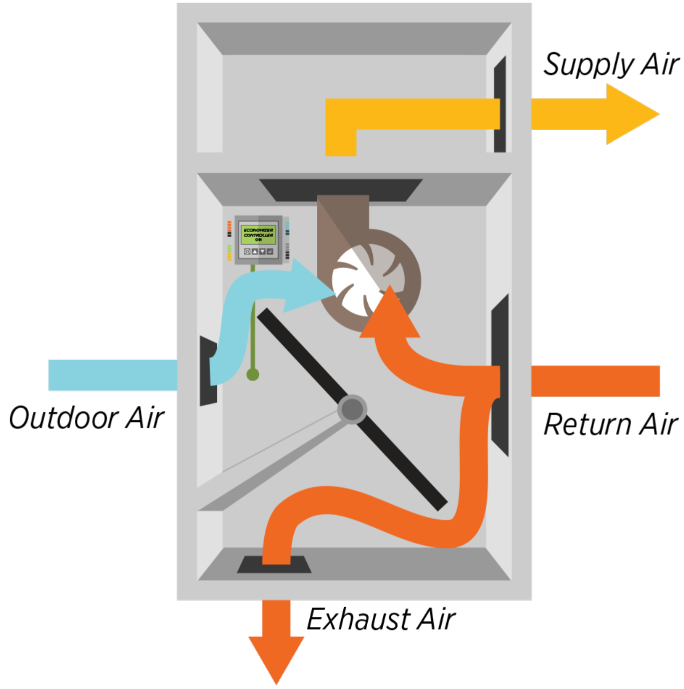
One critical and simple strategy that schools can use is to open classroom doors and windows more often. Where opening doors and windows can be done safely and without introducing outdoor air pollution, this action can significantly improve ventilation rates. It is important for teachers and students to know that fresh air is always important — but especially now — and that opening doors and windows can help. CO2 monitors can help determine the right time to open them. It is recommended that the open window and/or door area be at least 40 square feet for a standard classroom (4% of floor area) to provide ventilation without an HVAC system. It is also recommended that windows be opened two hours before occupancy. Opening doors and windows should never be done without considering important local factors such as security, air pollution, pollen and other allergen counts, outdoor temperature, and outdoor humidity.

Economizers

Economizers increase outdoor air amounts when cooling is needed and outside temperatures are favorable. This measure increases ventilation and often saves electricity too. For older HVAC systems that do not have economizers, installing aftermarket economizers can be a very cost effective way to increase ventilation and save energy, Aftermarket economizers are available for many types of units and can often be installed relatively easily and inexpensively.

Retrofit controls can also be installed by most controls manufacturers to ensure that economizers are opening when conditions allow.

For systems with economizers it is important to make sure they are operating correctly. Economizer failures are common enough that California introduced reliability requirements in its 2013 energy code, followed by 2015 IECC and ASHRAE 90.1 2016. Economizers installed prior to these codes are prime candidates for inspection and possible upgrade.



Source: UC Davis Western Cooling Efficiency Center

When working, existing economizer settings can be reconfigured to increase ventilation rates during mild weather. The "upper lockout" temperature of the economizer can be raised to expand the operation of economizers. 75F is the setting currently recommended by most codes. For units with Demand Control Ventilation the CO2 setpoint can be reduced to 700-800 ppm. This lower setting will bypass the energy saving sequence of DCV and provide more ventilation during operating hours for these systems.

Preventive Maintenance Inspections

Conduct quarterly seasonally appropriate HVAC preventive maintenance inspections to ensure units are operating properly. These will ensure that filters are changed regularly and systems continue to function as intended throughout the year to provide adequate ventilation.

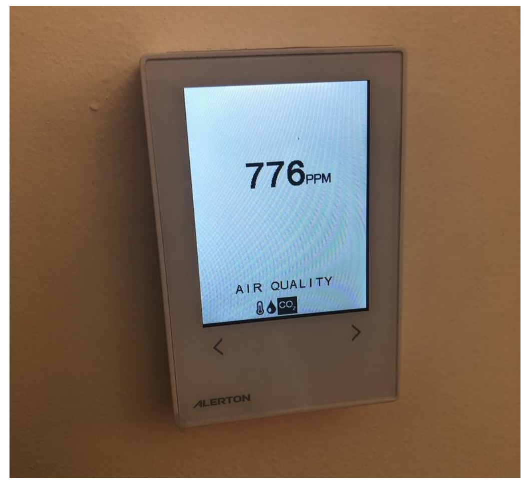
Evidence-Based Design Strategies for Renovations and New Buildings

There are many opportunities in the design of new and renovated buildings to provide better indoor air quality than in the facilities they replace. The following strategies can be employed on most projects to improve indoor air quality. References to relevant CHPS Criteria and resources are provided for further information.

Focus on Health of the Occupants

One of the primary strategies that school designers need to employ for a post-COVID-19 world is to focus on the health and wellness of the teachers and students who will be using them. Careful focus on the ventilation, VOC levels and comfort in the indoor environment will significantly improve occupant comfort, student success, health and even the district's financial bottom line. The truth is that building high-performance learning environments is critical to the success of our schools and districts. *The CHPS Criteria and the Best Practices Manual provide a guide to approaching school design from this perspective.*

CO2 Monitoring and Display



One of the most important strategies we can use to improve indoor air quality is to directly monitor and display the CO2 levels in classrooms. With advances in sensor technology this can be done relatively easily within the building energy management system. Most manufacturers offer options to monitor and display CO2 levels in thermostats. This also allows the sensor data to be used to control the amount of outside air provided to classrooms and ensure levels remain at or below the recommended level of 1000 ppm utilizing a demand-controlled ventilation approach. This data can also be used by teachers and students to take more direct action like going outside or opening exterior windows or doors to increase ventilation. *All editions of the CHPS Criteria address the benefits of having individual temperature control and thermostat in each classroom while a proposed credit for the upcoming CA-CHPS 2020 Criteria will give additional points for displaying the CO2 level and for using that data to control the amount of fresh air delivered to classrooms (see Core Criteria v3 EQ 11.1.1).*

Operable Windows and Connection to Outdoors

Two of the simplest and most effective strategies for improving air quality for students and teachers are to go outside and let the outside in. As designers, we can't control how buildings are used, but we do provide opportunities. By including operable windows in classrooms and providing connections between inside and outdoors we make it easier to let fresh air in and get children and teachers outside. In both cases it is also important to consider the quality of the exterior environment. If the surrounding neighborhood is noisy or has high levels of air pollution, these strategies may not be appropriate.

Providing operable windows in each classroom can provide a significant additional source of outside air and give the teacher and students direct control over their ventilation which can increase comfort. When providing operable windows in a classroom it is important to provide occupant training and/or controls to make sure that window use does not counteract the HVAC system during heating and cooling times and increase energy use. *The CHPS Criteria addresses operable windows including occupant training (see Core Criteria v3 EQ 11.1.2).*

Providing views to the exterior from classrooms may not seem like a strategy to improve air quality, but it can make a real difference. A visual connection to the outdoors lets the teacher supervise the indoor and outdoor spaces at the same time allowing more students to go outside throughout the day. Moreover, views of nature have been shown to have positive effects on student learning. *The CHPS Criteria provides guidelines for the amount and location of windows to provide views to students and teachers (see Core Criteria v3 EQ 13.1).*

Filtration

Providing adequate filtration of both outside air and recirculated air within the HVAC systems is critical to maintaining a healthy indoor environment. HVAC systems should be designed with a minimum MERV 13 filtration system as required by *CHPS Prerequisite EQ P1.0.* Furthermore schools should consider increasing filtration to MERV 15 systems to further reduce indoor air pollution and the potential for disease transmission as required by *CHPS CreditEQ 1.1.1.*

Increase Ventilation Rates

Increasing the amount of outside air provided to classrooms and other learning spaces will decrease the amount of CO2 in these spaces and increase the frequency that air is changed and filtered. This will improve student learning and wellness.

ASHRAE Standard 62.1, the national benchmark for the design of HVAC systems, is required by *CHPS Prerequisite EQ P1.0*. This should be the minimum standard for ventilation rates and should also be referred to for its many other guidelines and requirements for mechanical ventilation systems. All schools should be designed to meet or exceed these standards.

All mechanical systems should be equipped with economizers, whether required by local code or not, to maximize outdoor air supply and increase energy efficiency. For existing mechanical systems that have not reached the end of their useful life, consider adding economizers to the equipment and controls system.

It is further recommended that schools consider increasing ventilation rates beyond what is required in ASHRAE 62.1. Schools should consider increasing the ventilation rates by 130% as required for *CHPS Criteria EQ 1.1.2.*

Depending on the location of the school and the type of system, other considerations may be needed to maintain a properly designed system that provides ventilation along with properly controlled temperature and humidity. Also, it is important to consider the local environment and take alternative measures if exterior air pollution is a significant issue. Increasing ventilation rates can have unintended negative consequences

Dedicated Outside Air Systems

To further increase ventilation and reduce CO2 and disease transmission, schools can also consider designing Dedicated Outdoor Air Systems (DOAS). DOAS can take multiple forms but must be able to independently deliver heating, cooling, and ventilation where, and only when, it is needed and avoid the use of recirculated air. DOAS can be paired with appropriately designed controls systems, including CO2 monitors, to deliver the precise amount of fresh outdoor air directly to each space without recirculating contaminants or pathogens generated in other spaces. DOAS need to utilize energy recovery systems to reduce energy use and meet efficiency standards. *For more information about DOAS see CHPS Credit EQ C1.1.3.*

Demand Controlled Ventilation

Demand Controlled Ventilation (DCV) is the strategy of adjusting the amount of outdoor air supplied to a space based on the CO2 level in the space. Traditionally, DCV has been employed as a strategy to reduce energy use by decreasing the amount of fresh air supplied to a space to below the design level when it is not occupied or when the CO2 level is below the recommended threshold. However, DCV can also be used to ensure that adequate ventilation is always provided to meet the target CO2 levels regardless of occupancy conditions. DCV settings can also be changed to lower the CO2 threshold to below the recommended level of 1000 ppm to a lower target such as 700-800 ppm which has been shown to increase performance on cognitive tests.[20] *The CA-CHPS 2020 update underway as of publication will include criteria to encourage the use of DCV systems and lower the CO2 set point in classrooms.*

Reduce Volatile Organic Compounds

In addition to reducing the amount of CO2 and increasing ventilation, it is also important to reduce the amount of pollutants created within learning spaces. Volatile Organic Compounds (VOCs) are one of the primary indoor air contaminants. VOCs are generated primarily by off-gassing from building products and materials.

VOCs can be reduced by specifying materials and products that have a low VOC content based on their materials and manufacturing processes and that are tested for VOC emissions during application. VOCs can be released both during and after construction. Even products with no VOC content can emit VOCs after application due to chemical reactions. VOCs come from many types of materials including paints, sealants, flooring, drywall, ceiling tiles, composite wood and furniture. *CHPS Prerequisite EQ P6.0 and Credit EQ C6.1 contain detailed requirements and recommendations for low-VOC materials in different categories.*

It is also important to adequately clean and flush out the building and its HVAC system prior to occupancy. This removes any VOCs and other contaminants left behind during construction

---

[20] Allen and MacNaughton.

before teachers and students use the space. *CHPS Credit EQ C4.1 has detailed requirements for Construction Indoor Air Quality Management.*

Commissioning and Functional Checklists

All the preceding recommendations will deliver the required results only if spaces are designed and built correctly and function as intended. Unfortunately, in the construction of these complicated interconnected systems, that doesn't always happen. This is where Commissioning comes in. The role of the Commissioning Agent is to be the unbiased technical adviser to the Owner to make sure the Owner's requirements for the project are clearly articulated, addressed in the design and that the design is properly constructed and functions as intended. A Commissioning Agent should be involved throughout the design and construction process as part of the integrated design team. A critical part of the Commissioning Agent's scope of work is to complete functional checklists at the end of construction to ensure that the building HVAC, controls and lighting systems are all working together as intended and delivering the desired results. *CHPS Criteria EE P2.0 and EE C2.1 provide detailed requirements for Commissioning at basic and enhanced levels.*

Recommended Owner's Project Requirements

One of the most important tools that schools and districts pursuing renovation or new construction projects can use to ensure that projects address ventilation issues is the Owner's Project Requirements (OPR). A requirement of the Commissioning process, the OPR is a detailed statement of the project's technical and performance requirements. The OPR is used by the design team to guide design decisions and by the Owner and Commissioning Agent to evaluate the design and construction throughout the project. Below is a cheat sheet for items to address in the OPR related to ventilation and indoor air quality:

Requirement	Description	References
Ventilation Rates	Require calculations proving that systems meet ventilation requirements Increase ventilation to 130% of minimum requirements	ASHRAE Standard 62.1, CHPS Prerequisite EQ P1.0, CHPS Criteria EQ 1.1.2
Demand Controlled Ventilation	Each Classroom has a CO2 sensor integrated into the thermostat and controls system Ventilation is controlled to maintain maximum CO2 levels of 1000 ppm or 800 ppm	

Filtration	Provide minimum MERV 13 filters in all systems and consider MERV 15	CHPS Criteria EQ 1.1.1
Commissioning	Require Advanced Commissioning of mechanical, controls and lighting systems	CHPS Criteria EE P2.0 and EE 2.1
Low-VOC Materials	Specify low-VOC materials for flooring, paint, sealants, ceiling tiles, drywall and furniture	HPS Criteria EQ P6.0 and EQ 6.1
Building flush out	Require construction indoor air quality plan including building flush out prior to occupancy	CHPS Criteria EQ 4.1
Windows	Provide operable windows in each classroom with views to nature where possible	CHPS Criteria EQ 11.1.2 and EQ 13.1

Funding Opportunities

With schools and Districts facing unprecedented funding challenges in the coming years, finding ways to pay for upgrades to existing buildings and new facilities projects will likely prove difficult. However, there are many opportunities to fund these upgrades with little impact on the district's general maintenance budgets. At a time when many programs aimed at improving student outcomes are likely to be cut, utilizing these funding sources to improve indoor air quality can make a positive impact on students.

Energy Efficiency Funding

Many of the solutions proposed to improve indoor air quality are also useful in reducing energy use. These include economizers, retro-commissioning, replacing aging package units, smart thermostats with CO2 monitoring and Demand Controlled Ventilation. Almost every U.S. jurisdiction has incentives and financing programs available from utilities and government agencies to help pay for energy efficiency upgrades to facilities. These can come in the form of on-bill financing programs and loans where the energy efficiency savings are used to pay over time for construction costs. In many jurisdictions direct grants are also available. The North Carolina Clean Energy Technology Center maintains a Database of State Incentives for Renewables & Efficiency (DSIRE — https://www.dsireusa.org), an easy-to-use interactive database of energy efficiency programs in every state.

Facilities Funds

Many Districts also have facilities-restricted funding, whether from state facilities funding programs, required maintenance funds, local developer fees or other sources. Dedicating these funds to improving indoor air quality can offer direct benefits to students and teachers as well as benefits to the general fund resulting from increased attendance and reduced substitute pay.

Local Bonds

Local school bonds can also be a great source of funding for IAQ upgrades. These funds are usually separate from a district's General Fund. Improving student and teacher health and wellness is likely to be a compelling message to voters in bond campaigns. Many of these upgrades also can be implemented fairly quickly and can demonstrate a district's ability to put local funding to work in improving schools and stimulating the local economy. The long-term energy cost savings from many of these improvements can also be an effective incentive to proceed with the initiative.

Conclusion and Hopes for the Future

The COVID-19 pandemic is greatly disrupting many parts of our society, but perhaps none more than our education system. As we rethink the way schools educate students using digital methods along with traditional instructional strategies, we are inventing a new educational system. As part of that transformation there is a unique opportunity to consider the significant but often overlooked impact the physical learning environment has on student learning and wellness. Improvements to indoor air quality can make a significant impact on disease transmission, illness-related absence and student cognition. These improvements have real and significant benefits for students, teachers and communities. Strategies to make these changes can readily be implemented in existing classrooms, renovation projects and new buildings. CHPS has been advocating the design of high-performance schools that address these concerns for more than twenty years with research-based and real-world-tested best practices and design criteria. In this difficult time, we look forward to the opportunity to create a better future for school facilities.

For additional information please see the CHPS website at www.chps.net or contact CHPS Board Member and lead author Aaron Jobson at aaronj@qka.com

Contributors:

Aaron Jobson, Quattrocchi Kwok Architects, aaronj@qka.com
Roger Silveria, Eastside Union High School District, silveirar@esuhsd.org
Tav Cummins, CA Division of the State Architect, Tav.Commins@dgs.ca.gov
Aaron Wintersmith, Capital Engineering, awintersmith@capital-engineering.com
Ted Tiffany, Guttmann and Blaevoet Consulting Engineers, TTiffany@gb-eng.com