White Paper

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POOR HVAC COMMISSIONING & MAINTENANCE UNDERMINE EFFORTS TO IMPROVE IAQ

The relationship between indoor air quality (IAQ) and the K12 student experience has been a topic of study for decades. Researchers have found that creating a comfortable, well-lit and sufficiently ventilated classroom is critical to learning. Not only can a quality environment have a measurable impact on student health, attendance and performance, it can also give educators a competitive advantage in the recruiting and retaining of teachers.[1] As a result, many K12 districts across the country have taken steps to improve indoor air quality by upgrading the heating, ventilation, and air-conditioning (HVAC) units within their buildings. Yet, new research suggests these schools may not be getting what they paid for.

In 2019, researchers at the Lawrence Berkeley National Laboratory in California (also known as Berkeley Lab) and the University of California-Davis studied 104 classrooms across 11 schools that had, within the previous three years, been retrofitted with new HVAC equipment. Within each classroom and over a period of four weeks, researchers measured CO_2 concentration, room and supply air temperature, relative humidity, and instances of door opening.

The result: Researchers identified at least one problem—issues involving HVAC hardware, fan control and/or filter maintenance—in more than half (51%) of all classrooms studied. And in classrooms where equipment problems were noted, all had elevated CO_2 levels and ventilation rates below state standards.

"Our research tells us that we can't assume that things are fine, because the odds are they're not," said Theresa Pistochini. "It shows there's a pervasive problem upon installation; districts aren't getting these systems installed correctly. Unfortunately, many districts don't realize they have a problem, don't choose to address the issue or don't understand why it even matters. So we need to do a better job of creating awareness."

The report concluded, "Our analysis shows that proper installation, operation, and maintenance of HVAC systems are all necessary in order to provide adequate ventilation in classrooms. All the HVAC systems in this study were recently installed, which suggests that replacing aging equipment with new equipment does not guarantee adequate ventilation in classrooms. More oversight on the installation and maintenance of equipment is needed."[2]

Theresa Pistochini, engineering manager at the Energy and Efficiency Institute of UC Davis, participated in the study.

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- Ventilation rates in California classrooms: Why many recent HVAC retrofits are not delivering sufficient ventilation

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TEN FUNDAMENTAL BUILDING FACTORS THAT INFLUENCE HEALTH AND PERFORMANCE

1	Ventilation	Good ventilation can ensure a comfortable, healthy and productive indoor environment throughout the day, and be responsive to the number of occupants in a space.
2	Indoor Air Quality	Common indoor air pollutants in schools have been observed at levels two to five times higher than outdoor concentrations, including VOCs, which have been associated with acute and chronic health effects, cognitive function and academic performance.
3	Water Quality	Providing access to safe drinking water is critical to student health. Lead in drinking water is a primary concern, which can affect children's cognitive development, functioning and IQ.
4	Dust and Pests	Studies have shown that the concentration of molds in floor dust was associated with concentration problems, headaches and dizziness which can impact student and teacher performance.
6	Thermal Health	Thermal health, largely a function of temperature and humidity, encompasses the level of satisfaction with the indoor environment. While subjective, thermal conditions can distract occupants from their ability to stay focused and impact test scores.
7	Lighting and Views	Good-quality lighting in schools creates optimal viewing conditions for learning. Low levels of light indoors in combination with less time spent outdoors have been associated with nearsightedness, daytime sleepiness and oral reading fluency.
8	Mold and Moisture	Studies have shown that the concentration of molds in floor dust was associated with concentration problems, headaches and dizziness which can impact student and teacher performance.
9	Acoustics and Noise	Ensuring an appropriate noise level is essential to maintaining the ability of teachers to deliver instruction and for students to clearly and easily understand what is being said. Excess noise levels can impact fatigue, comprehension, stress and test scores.
10	Safety and Security	When our sense of security is threatened, it can trigger a cascade of biological "fight or flight" responses that elevate heart rate, increase blood pressure, cause depression and affect students' test scores, engagement in school activities and mental health.

Why it Matters: The Critical Connection between Adequate Ventilation and Student Performance

One of the most extensive compilations of evidence of the connection between indoor environmental quality (IEQ), student performance and attendance comes from the 2018 Harvard Foundations for Student Success, How School Buildings Influence Student Health, Thinking and Performance report, in which researchers reviewed the findings from more than 200 scientific studies. They found "overwhelming evidence of the benefits of healthy school buildings."

In reviewing 30 years of scientific study, Harvard researchers identified 10 fundamental building factors that influence health and performance.[3] Of the 10 factors identified in the Harvard study that impact student health and performance, more than half are linked to ventilation and the quality of the air inside classrooms.

The Harvard study adds to a growing body of evidence pointing to the value of adequate ventilation and its impact on the student experience.

"More and more evidence is coming out that there's a strong connection between student performance and ventilation, and it's been seen in both cross-sectional studies where you study different classrooms and different ventilation rates; and also intervention study, which is a stronger study design, where you're studying the same classroom, you change the ventilation rate, and you see improvement in student performance,"

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said Berkley Lab research scientist Wanyu Rengie Chan, Ph.D. "Overall we're seeing strong evidence suggesting an association between the two."

In one recent Berkeley Lab study, a research team examined the relationship between ventilation rates (VRs) and illness absences in 162 fifth- and sixth-grade California elementary school classrooms over two years. The study was co-authored by Senior Scientist and then-leader of the Indoor Environmental Group, William Fisk.

"We hypothesized that low ventilation rates would have various adverse effects on children, including possibly increasing the rate of infectious disease transmission since some of that transmission is due to airborne small aerosols; and that higher ventilation rates would dilute and reduce those concentrations," said Fisk. "Essentially, we were looking for a statistical association between ventilation rate—which we measured via CO2 concentration exhaled by building occupants—and the rate of absence from illness among the student population."

The team did find a statistically significant association between ventilation rates and illness absence. Where ventilation rates were lower, absence rates were higher—including after controlling for other factors that may influence absence such as grade levels, demographic and socioeconomic information. [4]

"It's a modest impact on illness absence, but it's large enough to be economically important for the schools because in some states, such as California, reimbursements are linked to the number of days of student attendance," said Fisk. "It's also important from a performance standpoint; absence has been shown to be predictive of academic outcomes for students."

CHANGE IN ILLNESS ABSENCE WITH INCREASED VENTILATION

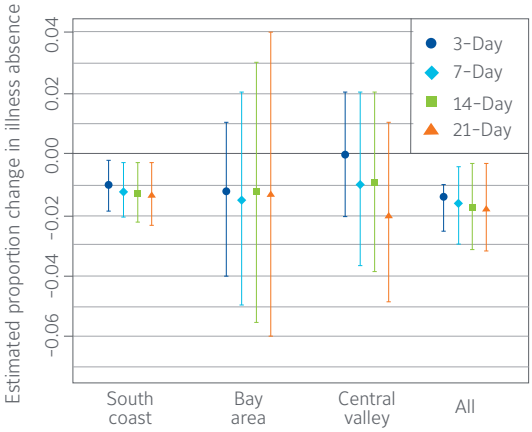
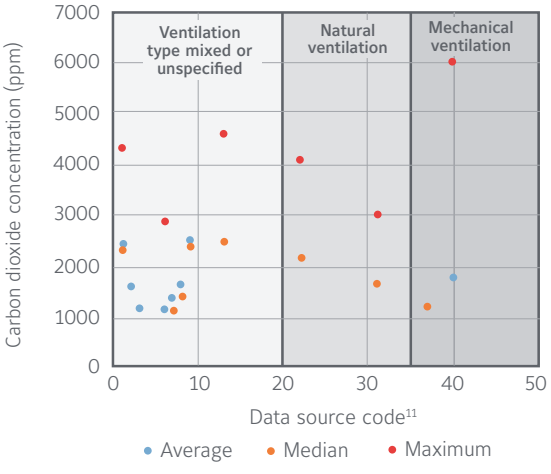


Fig. 1 Estimated proportion (%) change in illness absence with increase of 1 1/s-person of VR, within observed range 1-20 1/s-person, by district and for combined districts, for four VR-averaging metrics (ventilation-averaging metrics end on day prior to day of illness absence assessment)

The Prevalence of Low Ventilation Rates

Although many states specify minimum ventilation rates in their building codes and guidelines, actual ventilation rates in K-12 classrooms often fall far short, as evidenced by the results of the Berkley Lab/UC Davis 2019 study of California schools.

CHANGE IN CARBON DIOXIDE CONCENTRATION BASED ON VENTILATION TYPES



Fig, 2 Peak carbon dioxide concentrations in classrooms

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In a separate study, a team of researchers led by Fisk reviewed published literature from 26 studies, conducted in U.S. and abroad, that measured CO2 concentrations in occupied classrooms—an indicator of ventilation rates.

In the United States, a commonly used minimum ventilation standard for classrooms is 7 Ls-1 (15 cfm) per occupant. At that ventilation rate, peak indoor CO2 concentrations would be 1000 parts per million (ppm) or less. As shown, the research results indicate CO2 concentrations up to four times the recommended levels.[5]

"What we find is very clear evidence that the majority of classrooms in the study provided less ventilation than specified in the current state guidelines," said Fisk.

Experts suggest a number of factors likely combine to create situations where classroom ventilation rates fall short of the standard.

Lack of expertise: As shown in the 2019 study results, Pistochini says the installation, commissioning and maintenance of HVAC systems is often not done correctly. "That's partly the result of the challenging financial situations that school districts face; and a lack of expertise that school districts' staff have to maintain HVAC systems."

Lack of awareness: Some schools don't know they have an air quality problem, according to Pistochini, who studies how and why mechanical equipment functions. "Some of the work we've done recently suggests that you can have pretty significant indoor air quality problems that go undetected. Teachers know when the temperature is too hot or too cold, but it's hard for them to judge whether they're getting enough outdoor air."

Lack of funding: "I can only hypothesize schools tend to be underfunded," said Berkeley Lab's William Fisk. "They're struggling to pay teachers and they have so many priorities I think this just hasn't raised to the top of their priority list."

Addressing the Issue of Cost: The Quantifiable Value of Ventilation

The costs associated with improving ventilation rates is a challenge acknowledged by authors of the Harvard Foundations for Student Success study.

"Despite growing recognition of the importance of environmental health in schools, the national investment in public school facilities in the United States continues to fall short by $46 billion a year. Consequently, many

ESTIMATED ENERGY USE AND COSTS FOR COOLING AND HEATING THE VENTILATION AIR PROVIDED TO K-12 CLASSROOMS IN CALIFORNIA

	Energy use		Costs			Benefits	
	Electricity use (GWh) [% of total][b]	Gas use (GWh) [% of total][c]	Electricity costs ($)	Gas Costs ($)	Total increase in energy costs ($) over 4 l/s-person	Increased state revenue to school districts ($)	Reduced caregiving by families ($)
At existing ventilation rate of 4.0 l/s-person	29 [1.5]	68 [5.2]	3.5 M	1.9 M	0	0	0
From increasing ventilation rate from 4.0 to 7.1 l/s (15 cfm) per person	22 [1.2]	52 [4.3]	2.6 M	1.4 M	4.0 M	33 M	80 M
From increasing ventilation rate from 4.0 to 9.4 l/s (20 cfm) per person	40 [2.1]	92 [7.6]	4.7 M	2.6 M	7.3 M	66 M	160 M

Table 1 Energy use and costs associated with ventilation air. GWh, gigawatt-hour; M, million.
a 6 224 000 students in 9900 schools in 2009–2019 (from http://www.cde.ca.gov/ls/fa/sf/facts.asp, accessed Mart 15, 2020)
b Percentage of total classroom electricity use
c Percentage of total classroom gas use

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schools are left underfunded and unable to make much-needed upgrades to deteriorating buildings."[6]

However, reports from Berkeley Lab suggest the cost to take action is significantly lower than the cost of inaction. As shown in Figure 3, researchers found that while increasing ventilation rates from the California average (4.0 l/s-person) to the state standard (7.1 l/s-person) would cost an estimated $4 million in energy costs, the move would increase attendance-linked funding to California K-12 schools by $33 million annually, and reduce family caregiving costs (the result of student absence illness) by $80 million.[7]

Increasing classroom VRs even further—from 4.0 l/s-person to 9.4 l/s- person—would increase attendance-linked funding to schools by $66 million annually, reduce caregiving costs by $160 million and increase costs by only $7.3 million.

"As you provide more ventilation, there will be some associated cost with energy spent per classroom; but if you consider the benefits of avoiding illness absence in schools and getting better test scores among students, you can see that is the right thing to do," said Wanyu Rengie Chan. "It's going to be cost effective."

A more recent report also found the cost to improve ventilation rates was minimal when considered within the context of total public school per-pupil spending.

"The annual incremental energy and capital costs of increasing ventilation rates as needed to meet or exceed current standards range from a few dollars to about ten dollars per person. For reference, these costs can be compared to the US per-student annual spending of $10.3k in 2009 for public elementary and secondary schools. Thus, the energy and capital costs of increasing ventilation rates would be less than 0.1% of education spending. Such expenditures seem like a small price to pay given the evidence of health and performance benefits."[8]

Improving the Air Quality in Your Classrooms

Do you know how your classroom environments measure up? In the Berkeley Lab/UC Davis study, slightly more than half of the classrooms studied fell short of the state standards for ventilation rates; the result of incorrect installation, commissioning and maintenance of HVAC systems. Could yours be one of them?

To ensure sufficient ventilation, the report recommends:

- Better oversight to ensure the right HVAC equipment is purchased and installed properly in classrooms. The HVAC system must be configured to continuously provide outdoor air when the classroom is occupied regardless of heating or cooling needs.
- Routine filter maintenance and periodic testing of ventilation systems and/or continuous real-time CO_2 monitoring (either by stand-alone monitors or incorporated into thermostats) to enable the detection and correction of ventilation problems.

Fortunately, sensing technology is evolving quickly and in ways that will make it easier for districts to monitor and understand the quality of air inside their schools so they can take steps to improve the learning environment. That's something Johnson Controls Vice President, Global Sustainability and Regulatory Affairs, Clay Nesler, says the industry has an obligation to address.

"If there's a strong correlation between indoor environmental quality and health, we ought to be measuring it. And we now have the ability to use low-cost, ubiquitous sensors to measure ventilation rates and a broad range of pollutants," said Nesler. "We can sense conditions that indicate inadequate ventilation on an on-going basis. We can sense, for example, when a flask of volatile organic compounds breaks in a chemistry lab, and should be isolated and quickly exhausted. We can detect when someone has changed the flooring in the library and the level of formaldehyde is high. We can detect when

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a delivery truck is idling at the loading dock and those fumes are being introduced into the ventilation system and student's classrooms."

Though these enabling technologies are available today, Nesler adds they have not yet made their way into the mainstream of building designs, codes, standards and best practices. But there's no better time than now for K12 districts to proactively pursue the monitoring of indoor air quality.

Creating a Competitive Advantage

By taking proactive steps to ensure the quality of the classroom environment, districts will be better positioned to recruit teachers, attract students and generate revenue during the next decade of predicted K12 growth.

The National Center for Education Statistics projects that public elementary and secondary school enrollment will increase by 3 percent, from 48.2 million in 2015 to 52 million by 2027.[9] Enrollment in private elementary and secondary schools is projected to increase by 7 percent, from 5.8 million in 2015 to 6.2 million by 2027.[10] National charter school enrollment increased by more than 150,000 students between fall 2016 and fall 2017—a five percent increase. In addition, more than 300 new charter schools opened across the country in fall 2017.[11]

As existing buildings are retrofitted and new schools are built to accommodate the rise in enrollment, the condition of the classroom environment—in particular the value of adequate ventilation, its connection to indoor air quality and the impact on students—will become more important than ever.

Ventilation has a positive impact on performance.
High concentrations of CO_2 in the classroom, the result of lower-than-recommended ventilation rates, also affect schoolchildren's cognitive function. There is compelling evidence of an association of increased student performance, by a few percent to as much as 15%, with increased ventilation rates based on both cross sectional and intervention studies.[12]

Ventilation has a positive impact on attendance.
Researchers at Berkeley Lab found that where ventilation rates were lower, absence rates were higher. Nearly 1 in 13 children of school age has asthma, the leading cause of school absenteeism related to chronic illness. Addressing poor indoor air quality may be one of the many solutions to reduce this epidemic and increase student attendance.[13]

Ventilation has a positive impact on the bottom line.
As the Berkeley Lab report suggests, an investment of $4 million to increase ventilation rates in California classrooms would increase attendance-linked funding by $33 million annually, and reduce family caregiving costs (the result of student absence illness) by $80 million annually.[14] (This does not include the capital cost to re-commission or, in some cases, replace ventilation systems.)

The quantifiable benefits of sufficient ventilation are becoming increasingly clear. We urge educators to take steps to ensure their classroom environments meet the standards set forth by their individual states. It's more than a matter of regulatory compliance. Quality indoor environments will positively impact the future success of students, teachers, schools and communities.

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