ACHIEVING COST-EFFECTIVE INDOOR AIR QUALITY IMPROVEMENTS IN SCHOOLS

From understanding and assessment to planning and implementation

WHITE PAPER

Summary

Improving the indoor air quality (IAQ) of schools can help reduce the transmission of airborne pathogens while boosting attendance and enhancing students' cognition. By taking a comprehensive and cost-effective approach, you can achieve substantial air-quality improvements in existing facilities and new construction. The process starts with assessing your school's current IAQ to determine the performance of your system and identify where improvements are needed, followed by the development of a plan tailored to your needs and budget. While every school is different, the most effective implementations typically take a multilayered approach that includes increasing the intake of outdoor air, improving air filtration efficiency, and adding supplemental air cleaning.

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Done right, an initiative to improve your school's indoor air quality (IAQ) has the potential to enhance students' cognition and academic performance, boost attendance, and help limit the spread of infectious airborne diseases, such as COVID-19 and seasonal flu.

This white paper will help you understand some basic principles of indoor air quality, assess the current state of your school's facilities and equipment, and begin to develop a plan designed to deliver maximum results for every dollar spent.

ISSUES AND OPPORTUNITIES

So why improve IAQ, anyway?

While the COVID-19 pandemic increased awareness of the critical importance of air quality in public buildings, the advantages of higher IAQ in schools extend well beyond any specific event or phenomenon.[1] Measurable and sustained increases in the air quality of classrooms and other indoor areas of schools have been shown to offer continual benefits for students, teachers, and staff, such as:

Higher cognitive functioning.[2] An in-depth series of studies[3] showed that better IAQ can raise occupants' cognitive function test scores, potentially enabling students, teachers, and staff to stay better focused, think more clearly, retain and use information more fully and effectively, make better decisions, and respond more successfully to crises. Improved cognitive functioning may impact students' performance on standardized tests, which may be linked to funding in some locations.

Reduced absenteeism. The worst of the recent pandemic may be past us, but flu, colds, and other airborne pathogens – including COVID variants – are still circulating seasonally and year-round. In some areas, each time a student takes a sick day, the school's funding is reduced.[4] And when ill students come to class anyway, they may have trouble paying attention during lessons – and risk passing their illness on to others, starting chains of transmission to other students, teachers, and staff that compound the problem.

A healthier learning environment. In addition to transmissible illnesses, wildfire smoke, local air pollution, seasonal allergens, dust and other particulate residue, and off-gassing from building materials and cleaning agents may all affect the health and the ability to concentrate of students, teachers and staff.

Upgrading your current system to support higher levels of IAQ and avoid "sick building syndrome" (SBS)[5] may also present opportunities to improve your system's energy efficiency and reduce utility, maintenance, and other operating costs. These financial benefits – both immediate and long-term – can help to offset the initial cost of upgrades and help secure approvals and funding.

COGNITIVE FUNCTION	GREEN COGNITIVE SCORE PERCENT CHANGE as Compared with Conventional	ENHANCED GREEN COGNITIVE SCORE PERCENT CHANGE as Compared with Conventional
INFORMATION USAGE	172%	299%
STRATEGY	183%	288%
CRISIS RESPONSE	97%	131%
FOCUSED ACTIVITY LEVEL	51%	48%
BREADTH OF APPROACH	21%	47%
APPLIED ACTIVITY LEVEL	4%*	36%
BASIC ACTIVITY LEVEL	14%	36%
TASK ORIENTATION	3%*	15%
INFORMATION SEEKING	9%*	11%

*A **green building** has significantly lower levels of volatile organic chemicals (VOCs) than a typical school or commercial building. An **enhanced green building** has low levels of VOCs combined with high rates of ventilation.*

Contaminants that reduce IAQ are typically emitted from human bodies (airborne microbial pathogens and bioeffluents) as well as from building materials and cleaning products. They may also enter school buildings from the external atmosphere in the form of air pollutants and allergens, and (particularly in the case of radon) the earth beneath the building. Contaminants of concern include particulate matter, volatile and total volatile organic compounds (VOC and TVOC), formaldehyde (HCHO), and excessive levels of carbon dioxide (CO_2).

Improved Indoor Air Quality

- Higher Cognitive Function
- Reduced Absenteeism
- Healthier Learning Environment

Factors affecting indoor air quality

Ventilation

Barring outdoor pollutants, replacing the air in an indoor space with fresh outside air as frequently as possible will improve IAQ by diluting or removing airborne viral and bacterial contaminants from occupied areas. This frequency is measured by **air changes per hour** (ACH).

All other things being equal, increasing ACH will improve indoor air quality, though in areas with poor outdoor air quality it can actually *increase* indoor levels of particulate and gaseous contaminants if filtration is not sufficient. As we will see, dramatic increases in ACH through brute force ventilation can also have other downsides and may not always be possible.

HVAC filtration

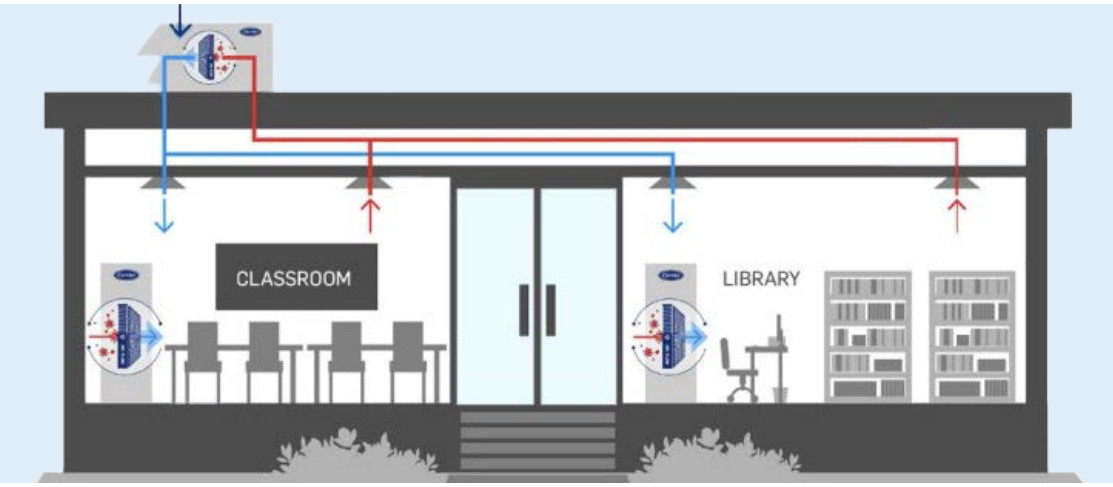
Because satisfactory IAQ cannot typically be achieved entirely through replacement by outdoor air, ventilation usually must be supplemented by purifying the indoor air, most commonly by filtration.

While adding or enhancing existing heating, ventilating, and air-conditioning (HVAC) filtration is an excellent way to improve IAQ, using higher efficiency filters may require equipment upgrades, and can result in higher short- and long-term replacement and energy costs.

Effective air changes per hour

Unlike simple ACH, **effective air changes per hour (eACH)** measures how often the air in an indoor space is replaced with clean air. In addition to outdoor air, this can also include indoor air that has been cleaned through duct-mounted filtration in properly designed HVAC equipment or by supplemental air cleaners to remove or neutralize significant amounts of contaminants. It is important to understand this distinction, as in some cases the ability to increase outside air intake or improve duct-mounted filtration may be limited or nonexistent.

This combination of outside air intake, filtered return air, and supplemental air cleaning is defined as eACH,[6] which more accurately measures the combined contribution of three of the major contributors to IAQ as it affects building occupants, and should be used wherever possible.



Comprehensive initiatives to improve IAQ in schools typically include a combination of higher ventilation (which brings fresh outdoor air into the building) and enhanced filtration (which lowers the percentages of pathogens and other particulate matter in indoor air).

Achieving cleaner, healthier indoor air

In its July 2022 report,[7] the Lancet COVID-19 Commission Task Force recommends a four-step process for achieving healthier indoor air. While developed in response to the COVID pandemic, the same steps apply to any comprehensive project to improve IAQ, and the task force highlighted additional important benefits beyond reducing infectious disease transmission.

These steps, which we will cover in more detail, include:

- Commission or Recommission Building Systems
- Maximize Outdoor Air
- Upgrade Air Filters to Minimum Efficiency Reporting Value (MERV) 13
- Supplement With Portable Air Cleaners Where Needed

ASSESSING YOUR SCHOOL'S CURRENT IAQ

Determining the performance of your current facilities

Before making a detailed plan on how to improve your school system's indoor air quality, it's essential to have a clear picture of the operational status of your buildings and their HVAC systems. In what ways and to what extent are the currently installed systems and components contributing to the quality of indoor air, and in what ways are they insufficient or even contributing to poor indoor air quality?

Equipment may no longer be performing as originally intended due to age, and even if it is still functioning properly, it may not be capable of meeting current IAQ requirements or targets. In other cases, the goalposts may have shifted; in the past, designing buildings and HVAC systems with a singular focus on energy efficiency led to insufficient levels of ventilation and air filtration.

You need to identify what's already meeting your goals, what needs to be supplemented or retrofitted, and what must be replaced or added.

But it's not enough to take an inventory of your buildings and installed equipment – you need insight into how your current building systems are *actually performing* day to day.

Commissioning

The first step, **commissioning** – or, for previously commissioned systems, **recommissioning** – is the process of verifying that your school's building systems are operating as intended – that is, according to their design and performance specifications. If it's been more than three to five years since your systems were commissioned, it's time for recommissioning.

Commissioning includes confirming that:

- All fans, outside air intakes, economizer equipment, and controls are operating correctly
- Properly sized filtration with an appropriate MERV rating is installed correctly and sealed around frames to avoid leakage
- Schedules are properly aligned with occupancy

The commissioning and assessment process should also include an analysis of any currently installed building automation system (BAS) and sensors, and identify opportunities for improvements through replacement or enhancement.

The Lancet Task Force notes that commissioning saves significant money over time, leading to a median payback time of 1.7 years among 656 commissioning projects in existing buildings. Benefits of commissioning included:

- Cost savings
- Energy savings
- Improved occupant thermal comfort
- Improved indoor air quality
- Extended equipment life

Performing measurements with instrumentation

To gain insight into the actual indoor air quality of your school buildings and the effectiveness and efficiency of your installed systems, be sure to take advantage of any existing BAS, other currently installed sensors, or temporary instrumentation while you're assessing the performance of your current system.

Absent a BAS with appropriate sensing devices, the most precise means of assessing ventilation is via airflow measuring hoods. Technicians should begin by performing baseline measurements of outside air, supply air, and return airflow, followed by computations of baseline air-change rates, including:

- Outside air intake volume
- Return air volume
- Zone air volume

While actual airflow measurements are preferred, CO_2 decay methods for air change computations may also be used, and can be conducted with readily available, portable CO_2 sensors that can be easily moved from room to room.[8]

In addition to CO_2 measurements, instrumentation should also be used in all commonly occupied areas of the building to measure the levels of indoor environmental quality (IEQ):

- $PM_{2.5}$ particulates
- HCHO
- Specific Volatile Organic Compounds (VOC) or Total Volatile Organic Compounds (TVOC)
- Temperature
- Humidity

Occupancy and IAQ

Measuring spatial and temporal rates of occupant density – that is, identifying the days and hours when high concentrations of students, teachers, and staff are present in each of the building's spaces – is particularly important in identifying opportunities to help limit airborne disease transmission.

Although occupants tend to increase the level of carbon dioxide in indoor spaces, CO_2 as a proxy for occupancy is not recommended as a driver of demand-control ventilation (DCV) strategies due to response lag. Although CO_2 measurements can indicate overall ventilation effectiveness when properly used, CO_2 levels in and of themselves do not indicate that a space is "safe" from an infectious disease-limitation perspective. Spaces with effective levels of filtration and air cleaning may in certain cases provide robust disease transmission mitigation despite high CO_2 levels, but as previously noted, high levels of CO_2 are an indicator of poor ventilation, which has a negative impact on the cognitive functions of occupants, including students and teachers.

PLANNING AND IMPLEMENTATION

Maximizing results for every dollar spent

Due to its impact on the health, safety, and even the learning ability[9] of the children entrusted to its care, the quality of air in classrooms and other learning spaces is paramount.

Nevertheless, few school systems have the financial resources to dedicate unlimited funds to the improvement of IAQ. Strategic decisions need to be made to ensure the greatest improvement per dollar spent, both up front and in the coming months and years, and the identification of immediate and long-term opportunities to save money should be a priority.

In most cases – and at the most basic level – the best results will be achieved by an approach that leverages the three primary ways indoor air quality can be improved in any building, including schools:

1. Increase the intake of outdoor air

Benefits:

Increasing the amount of outside air intake whenever possible can improve cognitive functioning and reduce infectious disease transmission by diluting or removing indoor particulates and building material off-gasses, and by controlling CO_2 levels.

Caveats:

While effective at improving IAQ, an excessive reliance on increasing ventilation can have significant downsides, including potential impacts on occupant comfort and energy consumption.

Imagine simply opening all the windows in your school, installing new ones in solid exterior walls, and strategically placing high-speed exit fans in some of them. Airborne contaminants will be removed from classrooms and hallways before they have a chance to build up, and IAQ should improve dramatically, assuming outdoor contaminant levels are minimal.

But now imagine that the outdoor air those fans are pulling in through the windows is below freezing, or above 90° F, or filled with heavy rain, snow, or smoke from a fire two blocks away.

Similarly, increasing the percentage of outdoor makeup air in a central HVAC system to boost ACH can reduce energy efficiency, increase operating costs, and compromise comfort unless mitigated by energy recovery ventilators (ERVs) and proper control strategies.

Higher ventilation may also be difficult to implement in some systems and buildings, increasing the importance of other approaches.

While enhanced ventilation should be a key part of most plans to improve the IAQ of schools, it is unlikely to be sufficient by itself.

> Until recently there has been no broadly recognized ventilation standard or code designed to ensure the levels of IAQ necessary to address infectious disease mitigation or to deliver cognitive benefits. Existing ventilation standards such as ASHRAE 62.1[10] were developed to deliver what was considered to be minimally acceptable IAQ in an earlier era. However, ASHRAE Standard 241 "Control of Infectious Aerosols," which is designed to reduce the risk of disease trasmission, has now been approved.[11]

2. Increase the efficiency of the HVAC system's air filtration

Benefits:

Increasing the filtration of indoor air before it returns to occupied spaces can help limit the reintroduction of airborne viral and bacterial pathogens into controlled spaces. By providing improved control of PM2.5 particulates, which have both short- and long-term negative health impacts, it can also lead to higher cognitive functioning among students, teachers, and staff.

Carrier Aero® 39CC Custom Air Handling Unit

Caveats:

Most viruses are smaller than bacteria and PM2.5 particulates and require increased levels of filtration to remove them – the Lancet COVID-19 Commission Task Force recommends MERV 13 or higher. But simply replacing current filters with more efficient ones can create issues in systems not originally designed for them.

When increasing filter effectiveness, keep in mind that changes in duct-mounted filtration may require changes at the control level, such as adjusting fan speed and airflow setpoints, installing or upgrading differential pressure switches used to monitor filters, etc.

Increases in filter effectiveness may also require more frequent filter replacement, and a filter status switch can help determine when filter changes are needed. Many factory- and field-installed controllers support the use of such switches as retrofits when they were not installed in the original system.

3. Add supplemental air cleaning wherever needed

Benefits:

In some schools, architectural issues, limitations of the installed system, or budgetary constraints may make it difficult to increase outside air intake and improve HVAC filtration sufficiently to meet IAQ targets. Supplemental air cleaning equipment can help achieve targeted eACH rates.

Portable room air cleaners with high-efficiency HEPA filters have become increasingly popular ways to quickly boost IAQ in classrooms and other indoor areas, and are excellent for use in areas of the building or campus where it may be difficult or excessively costly to adequately extend the reach or enhance the capabilities of the central HVAC system.

In addition, the ventilation and filtration capacities of the central HVAC system itself can sometimes be supplemented with additional equipment. For example, using high-wall UV-C lights may be particularly helpful for pathogen mitigation in systems where upgrading filters to MERV 13 or higher may not be feasible.

Caveats:

Portable room air cleaners take up floor space, and may be somewhat louder than central HVAC equipment.

While UV-C lights can reduce levels of viable airborne pathogens, they cannot remove particulates from the air.

Retrofit vs. replacement

Your school may have one or more central HVAC systems currently in place. For financial reasons, it often makes sense to continue using as many components of the currently installed system as possible, but in each case this should be weighed against the potential energy savings, reductions in maintenance costs and system downtime, and better integration into modern building automation systems that replacement with more modern components can provide.

If your system was installed in the last few years, commissioning and other testing may reveal that it is already meeting post-pandemic IAQ standards or needs only an upgrade in filtration efficiency or some supplemental room air cleaning equipment. If it's a very old system, complete replacement may actually be the most cost-effective option.

More likely, though, your system falls somewhere in between. Few schools will need to replace everything down to the ductwork, but most will benefit from recent technological advances, particularly in building automation systems and controls.

Filling the gap between what you have now and what you need

In weighing whether to keep or replace each component – or the system as a whole – it's important to consider not just first costs, but also ongoing costs, including potential savings on energy, maintenance, and other operating expenses, along with warranties, service plans, and available new-equipment perks that can help keep costs not only manageable, but predictable, and protect you from unexpected expenses and spikes in operating costs.

These issues can be complex, and it's easy to overlook important details or give too much or too little weight to specific factors. While we can give you some general guidance here, the details of each school's facilities can vary considerably, and we recommend that you consult with a qualified HVAC engineering firm, contractor or sales engineer with expertise in IAQ before making final decisions.

System performance and energy, equipment, and design considerations

Filtration and ventilation

Although increasing filtration efficiency and introducing more outside air have the potential to increase energy costs in many climate zones, these can often be mitigated by measures such as:

- Combining MERV 8 air filters with room air cleaners, which may similarly enhance IAQ (for example by mitigating particulate matter) but with lower energy costs than higher-efficiency MERV 13 filters combined with increased outside air intake.
- Properly deploying energy recovery ventilation and heat recovery ventilation (HRV) systems, which can offset much of the additional energy consumption associated with increased ventilation by capturing energy in the exhaust air stream.

Building automation, controls, and sensors

Beyond simply increasing ventilation and filtration, one of the most meaningful ways you can improve your school's IAQ delivery system is to bring your building automation system up to date.

A BAS isn't just another component of a central HVAC system. Automation and controls technology has progressed more rapidly in recent years than any other aspect of indoor air quality and climate control, and an up-to-date BAS can improve the operational performance of virtually every other HVAC component – and the entire system as a whole.

An advanced BAS can:

- Monitor IAQ in real time
- Remotely alert your facilities staff to any performance degradations or equipment malfunctions 24/7/365
- Automate, control, and coordinate the operation of your equipment to maximize energy efficiency and minimize energy and operating costs

Well-designed BAS software can also provide trending and data visualization information in graphic formats that make it easier to understand what's actually happening with indoor air quality and system performance in your building and in your equipment across weeks, seasons, and years.

Challenges to improving existing HVAC systems

While often surmountable, issues may arise when retrofitting upgrades in an existing system and building to provide higher levels of IAQ than they were originally designed for:

- In most non-healthcare commercial HVAC systems including schools, initial system design and legacy equipment will likely limit how much outside air can be sufficiently heated, cooled, or dehumidified, reducing the ability to rely on higher levels of ventilation.
- Replacing current filters with more efficient MERV 13 or higher filters can increase pressure drop and decrease the existing system's ability to provide adequate volumes of air, which may negatively impact heating, cooling, and dehumidification performance.
- Modifying or supplementing the existing controls rather than replacing them with a more technologically up-to-date BAS system may be challenging to implement, depending on the type and age of the currently installed controls or automation system.
- Retrofit of ERV and HRV hardware may not be easy or even possible.

Possible solutions to some of these issues may include:

- **Replacement of some existing equipment** to accommodate higher ventilation capacities and add ERV/HRV capabilities, which, while requiring a higher initial outlay, may actually reduce total and ongoing costs over time due to lower energy, maintenance, and other operating costs. (See below for information about possible funding sources.)
- **Supplemental HEPA-based room air cleaners**, which can offset limitations in legacy systems' outside air intake, boost filtration, and help support strategies to improve IAQ. These can often be further supplemented by other infectious disease mitigation technologies, such as **high-wall** UV-C lights added to controlled spaces. Such solutions also typically have energy consumption benefits compared to brute-force increases in outside air intake.

Keep in mind that when it comes to improving the indoor air quality of your schools to create a healthier learning and teaching environment, **the worst thing you can do is nothing.** The results may not be as optimal as they might be with a new system in a newly constructed building, but by allocating funds and implementing newer technologies and equipment strategically, significant enhancements in IAQ can be achieved.

HVAC system design considerations in new construction

Within the limits of budgetary requirements, the construction of a new school building offers the opportunity to start fresh and build an HVAC system designed to maintain consistently high levels of indoor air quality in all spaces while minimizing operating costs and maximizing comfort.

Although the biggest gains are likely to come from an advanced building automation system – which can precisely control IAQ and comfort while optimizing energy efficiency and providing remote access and real-time alerts – other more specialized or emerging technologies may provide additional advantages, such as:

- High-resolution, fast-acting "people counting" technology to accurately monitor and adjust the system to accommodate changes in occupancy in real time
- Higher-capacity dilution-based ventilation system designs for heating, cooling, dehumidification, and enhanced filtration, combined with energy recovery ventilation and heat recovery ventilation systems
- Displacement ventilation for additional energy efficiency and improvements in airflow patterns

To ensure that your system is optimized for your building, climate, and planned levels of occupancy, we recommend involving experts in IAQ and system engineering as early in the process as possible – ideally before architectural plans have been finalized. Consider seeking third-party IAQ certification as part of the process.

Funding

While the details of securing funding for your project are largely beyond the scope of this white paper, here are a few things to bear in mind:

- At any given time and location, funding may be available from a variety of governmental and non-governmental sources. Be sure to conduct a thorough search to find out about availability, requirements, and application processes and deadlines.
- Local approvals of budgets and bond issues are likely to go more smoothly if you make your case clearly and compellingly. Make sure decision-makers and influencers such as government officials, school board members, and voters understand clearly why this is a good decision for the school and the community, and that the money will be a worthwhile investment.
- Explain how higher indoor air quality in their school can help keep kids healthier, reduce disease transmission, and improve their cognitive functioning.
- Identify financial benefits and lay them out clearly. Will your upgrades improve energy efficiency and reduce fuel bills and maintenance, in addition to improving IAQ? Try to quantify the savings – and if possible, show how quickly the lower operating costs will outpace the initial investment and deliver financial as well as health and learning benefits. An experienced HVAC design and contracting firm should be able to help you estimate these figures.

To learn where to find information about funding sources in your country or region, contact your local Carrier expert, or in the U.S., visit carrier.com/commercial/en/us/k-12/.

For additional information about solutions and support available for your school(s), contact your local Carrier expert, or in the U.S., visit carrier.com/commercial/en/us/k-12/connect-with-carrier/ or carrier.com/commercial/en/us/k-12/.

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