CO_2 MONITORING FOR EDUCATIONAL ENVIRONMENTS

A tool for analyzing specific indoor air-quality conditions, to help individuals determine air ventilation needs

Honeywell

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INTRODUCTION

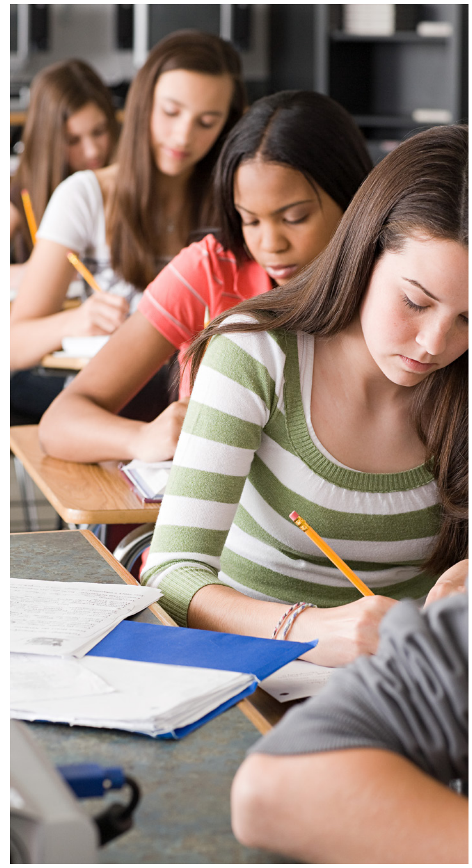
During the COVID-19 pandemic, a large population has become more acutely aware of the air they breathe. This is due to infectious disease being proven to spread most commonly through airborne transmission. When an infected person talks, coughs, sneezes, yells or sings, droplets or tiny particles (aerosols) carry the virus into the air from the individual's nose and/or mouth.

The quality of indoor air, especially, is a topic of serious concern - particularly air quality in public spaces, such as retail stores, offices, municipal buildings and educational institutions.

This white paper focuses specifically on air quality in schools and presents a case for using CO_2 monitoring in educational settings with one goal in mind:

TO HELP CREATE THE BEST ENVIRONMENT FOR STUDENTS TO LEARN AND TEACHERS TO TEACH.

THE PURPOSE OF CO_2 MONITORING IN EDUCATIONAL ENVIRONMENTS



> Multiple studies suggest that insufficient ventilation increases disease transmission.[1]

Therefore, it stands to reason that optimal ventilation practices may do just the opposite – i.e., decrease disease transmission. The Centers for Disease Control and Prevention (CDC) supports this theory by recommending ventilation interventions to help reduce the concentration of virus particles in the air.[2]

HIGH CO_2 LEVELS INDICATE POOR VENTILATION

CARBON DIOXIDE (CO_2) IS OFTEN USED AS AN INDIRECT MEASURE OF VENTILATION. When a building is occupied, the CO_2 concentrations indoors are elevated by occupants exhaling. When occupants leave and no other CO_2 sources are present (e.g. people, combustion sources, etc.), the rate of decay of the carbon-dioxide concentration can be used to estimate how fast air from outdoors (at approximately 400 ppm CO_2) replaces the indoor volume of air.[3]

CARBON DIOXIDE SENSORS HAVE BECOME BETTER AND LESS EXPENSIVE IN THE RECENT YEARS. Technology advancements have increased the sensing and data capabilities for CO_2 monitoring, while also allowing real-time displays with refresh rates that offer actionable information. CO_2 monitoring products can provide information on the specific air-quality conditions inside a classroom or other enclosed spaces. These measurements can then be leveraged to assist with ventilation analysis and adjustments.

The CDC recommends using a portable CO_2 monitor and installing it near the breathing zones in occupied areas of each room. This allows collection of data regarding air quality. Based on these measurements and occupancy levels, the intake of outdoor air can be adjusted to increase interior flow of air.[4]

TWO KEY BENEFITS OF CO_2 MONITORING

Benefit #1: Alert Users to the Presence of Air Conditions That May Increase the Risk of Exposure to Airborne Viral Transmission

A PROMINENT RESEARCH STUDY[5] CONFIRMED THAT CO_2 MONITORS CAN ALERT USERS TO THE PRESENCE OF AIR CONDITIONS THAT MAY INCREASE THE RISK OF EXPOSURE TO AIRBORNE VIRAL TRANSMISSION.
Conducted by Zhe Peng and Jose-Luis Jimenez, two University of Colorado scientists, the study demonstrated that CO_2 monitoring can be used to evaluate the increased risk of airborne viral transmission.

OBJECTIVE OF THE STUDY

The researchers sought to demonstrate that exhaled CO_2 can be used as a COVID-19 infection risk proxy for indoor environments and activities. According to a summary of the overview from the University of Colorado[6], the scientists relied on a simple fact already accepted by other researchers for more than a decade: Infectious people exhale airborne viruses at the same time as they exhale CO_2. That means CO_2 can serve as a "proxy" for the airborne viral concentration.

METHODS

In this study, the researchers derived the analytical expressions of the probability of indoor COVID-19 infection through room-level aerosol transmission only (i.e., assuming social distance is kept so that close proximity aerosol and droplet pathways are eliminated; fomite transmission is not included), human-exhaled CO_2 concentration and subsequently a few CO_2-based quantities as infection risk proxies. Based on available data, these expressions were applied to common indoor settings to meet the objective mentioned above.

The University of Colorado summarizes the methods as follows[6]: Jimenez and colleagues turned to commercially available carbon dioxide monitors, which can cost just a few hundred dollars. First, laboratory testing confirmed that the detectors were accurate. Then, a mathematical "box model" was created to reproduce how an infected person exhales viruses and CO_2, the manner in which others in the room inhale and exhale, and how the viruses and gas accumulate in the air of a room or are removed by ventilation. The model takes into consideration infection numbers in the local community, but does not detail air flow through rooms, as modeling at that level of detail requires expensive, custom analysis for each room.

WHAT IS CONSIDERED AN AVERAGE LEVEL OF INDOOR CARBON DIOXIDE?

The Harvard study specifies that a CO_2 level of approximately **950** ppm (parts per million) is common in indoor spaces and mentions that this level satisfies the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) ventilation rate guidance for acceptable indoor air quality.

RESULTS AND CONCLUSIONS

The study's scientists reported the following key findings:

- **HIGHER CO_2 LEVELS INDICATE HIGHER RISK:** Thus, keeping CO_2 as low as feasible in a space allows optimization of the protection provided by ventilation. (The researchers also showed that the carbon-dioxide level corresponding to a given absolute infection risk varies by greater than 2 orders of magnitude for different environments and activities.)
- **INFECTION TRANSMISSION IS MORE DANGEROUS INDOORS:** Transmission is much easier indoors than outdoors, which is most consistent with aerosols. As individuals spend more of their time in indoor environments, where air volumes are limited and virus-laden aerosols may easily accumulate, mitigation of indoor COVID-19 transmissions is a subject of high interest. Practical, affordable and widely applicable measures to monitor and limit indoor transmission risks are urgently needed.
- **DIRECT MEASUREMENTS OF VIRUS-CONTAINING AEROSOLS ARE NOT PRACTICAL.** These types of measurements are extremely difficult and slow.
- **CO_2 MONITORING IS PRACTICAL:** CO_2 concentration was suggested as an indicator of indoor space ventilation quality in the 19th century, and more recently as a practical proxy of respiratory infectious disease transmission risk, because pathogen-containing aerosols and carbon dioxide are co-exhaled by those infected. Also, since background (ambient) CO_2 level is almost stable and indoor excess CO_2 is usually only from human exhalation, measurements of indoor carbon-dioxide concentration by low-cost CO_2 sensors can often be strong indicators of infection risk and suitable for mass deployment.
- **FORTUNATELY, CO_2 CAN BE MEASURED EASILY:** Carbon dioxide is the only known quantity that can be easily measured by fast low-cost sensors as an infection risk proxy.
- **THE GOAL IS TO KEEP THE CO_2 LEVEL LOW:** Regulatory authorities may derive carbon-dioxide thresholds for different types of indoor spaces. However, even when parameters are unknown, the University of Colorado study suggests that simply maintaining the CO_2 level, and the physical intensity and vocalization activity levels, as low as practically feasible in indoor environments will still reduce transmission risk.

GYMNASIUMS MAY BE ESPECIALLY PRONE TO HIGHER RISK

Outdoor CO_2 levels are usually at 400 parts per million and it's best not to be in spaces that exceed 1,000 parts per million. Even then, someone who is in a gym — with people breathing heavily and often — will be at a higher risk than someone sitting in a library. "But if you can lower the carbon dioxide level as much as possible, it can be much safer than it usually is,"[7] said Zhe Peng, one of the University of Colorado scientists who conducted the study mentioned above. Peng and co-author Jose-Luis Jimenez recommend using an activity-dependent approach, which means keeping physical intensity and vocalization activities as low as practically feasible.

Benefit #2: Enhance students' cognitive learning

A 2015 study by the Harvard T.H. Chan School of Public Health[8] showed that higher ventilation rates and lower CO_2 levels can positively affect cognitive function and performance.

The study demonstrated that people who work in well-ventilated environments with below-average levels of indoor pollutants and CO_2 have significantly higher cognitive functioning scores in crucial areas such as responding to a crisis or developing strategy than similar individuals who work in offices with typical pollutant and CO_2 levels.

In fact, the study's participants had significantly improved cognitive function scores when working in well-ventilated environments compared with scores obtained when working in a conventional environment.

OBJECTIVE OF THE STUDY

The researchers simulated indoor environmental quality (IEQ) conditions in "Green" and "Conventional" buildings to evaluate the impacts on an objective measure of human performance: high-order cognitive function.

METHODS

Twenty-four participants spent six full work days (0900-1700 hours) in an environmentally controlled office space, blinded to testing conditions. On different days, they were exposed to IEQ conditions representative of Conventional [high concentrations of volatile organic compounds (VOCs)] and Green (low concentrations of VOCs) office buildings in the United States. Additional conditions simulated a Green building with a high outdoor air ventilation rate (labeled Green+) and artificially elevated CO_2 levels independent of ventilation.

During the study, the researchers tested the nine cognitive function domains listed in Table 1.

TABLE 1. DESCRIPTION OF THE COGNITIVE DOMAINS TESTED

Cognitive Function Domain	Description
Basic activity level	Overall ability to make decisions at all times
Applied activity level	Capacity to make decisions that are geared toward overall goals
Focused activity level	Capacity to pay attention to situations at hand
Task orientation	Capacity to make specific decisions that are geared toward completion of tasks at hand
Crisis response	Ability to plan, stay prepared, and strategize under emergency conditions
Information seeking	Capacity to gather information as required from different available sources
Information usage	Capacity to use both provided information and information that has been gathered toward attaining overall goals
Breadth of approach	Capacity to make decisions along multiple dimensions; use a variety of options and opportunities to attain goals
Strategy	Complex thinking parameter that reflects the ability to use well-integrated solutions with the help of optimal use of information and planning

RESULTS

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 ($p < 0.0001$). VOCs and CO_2 were independently associated with cognitive scores.

The researchers found that the largest improvements occurred in these three crucial cognitive function domains:

- √ Crisis Response: Ability to plan, stay prepared and strategize under emergency conditions
- √ Strategy: Complex thinking parameter that reflects the ability to use well-integrated solutions with the help of optimal use of information and planning
- √ Information Usage: Capacity to use both provided information and information that has been gathered toward attaining overall goals

CONCLUSIONS

Cognitive function scores were significantly better under Green+ building conditions than in the Conventional building conditions for all nine functional domains. Exposure to CO_2 and VOCs at levels found in conventional office buildings was associated with lower cognitive scores than those affiliated with levels of these compounds found in a Green building.

KEY TAKEAWAY: These findings have wide-ranging implications because this study was designed to reflect conditions that are commonly encountered daily in many indoor environments.

Additional information about how poor indoor air quality affects cognitive learning can be found in APPENDIX B.

AN EFFECTIVE EASY TO USE CO_2 MONITORING SOLUTION

Honeywell partners with schools to help create the best environment for students to learn and teachers to teach

Teachers, administrators, staff, and students deserve to learn and work in a healthy, safe environment. The Honeywell Transmission Risk Air Monitor (HTRAM) is a key component in achieving that goal. The device is ideal for indoor CO_2 monitoring in educational environments.

WHAT IS IT?

The HTRAM is a cost-effective, user-friendly solution to monitor indoor environments in real time, analyzing specific air-quality conditions and alerting users to the risk of potential exposure to airborne viral transmission.

HOW IS IT USED IN SCHOOLS?

An easy-to-deploy, portable device, the HTRAM measures CO_2 and features a proprietary risk alerting system based on activity levels within a room. This allows teachers and other staff members to proactively improve indoor ventilation to:

- Enhance students' cognitive learning
- Sustain in-person attendance
- Alert to increase indoor ventilation to help reduce the risk of exposure to airborne viral transmissions

CAN SCHOOLS GET ADVICE ON HOW TO USE IT?

Absolutely. Honeywell can provide guidance and technical support regarding where and how to use the HTRAM device within educational environments.

RESEARCH BASED, EXPERTLY ENGINEERED

The HTRAM was designed and created in direct response to the University of Colorado research study described earlier, on page 5.

The Honeywell Transmission Risk Air Monitor helps you monitor indoor environments in real time for conditions that may increase exposure to airborne viruses.

DID YOU KNOW THIS?

U.S. schools have been allowed to use American Rescue Plan (ARP) education funds to improve indoor air quality for in-person instruction, including through purchasing CO_2 monitors to assess ventilation.

SOURCE: U.S. Department of Education

DEVICE INDICATION

	GREEN	YELLOW	RED
Low activity setting	<800 ppm 0.043 % infection risk	800 ppm 0.043 % infection risk	1100 ppm 0.051 % infection risk
Medium activity setting	<700 ppm 3.40 % infection risk	700 ppm 3.40 % infection risk	1000 ppm 5.41 % infection risk
High activity setting	<500 ppm 7.32 % infection risk	500 ppm 7.32 % infection risk	800 ppm 25.25 % infection risk
Custom setting	The end user can also choose custom settings on the device to set the alarm threshold levels based on the user's parameters and local, regional and state requirements. **Note: If custom settings are used, the user is solely responsible for validating that those alarm settings meet their specific requirements.**		
Recommended action	–	▪ Open windows ▪ Turn on HVAC fan ▪ Move out of room ▪ Additional actions as needed	▪ Ventilate room immediately ▪ Reduce activities ▪ Move out of room ▪ Additional actions as needed
Alarm	–	One beep	Two beeps

Integrated Software

Click here to download the user quick start guide

Datasheet

Click here to download

CONCLUSION

Carbon dioxide monitoring can be used to alert employees to the presence of air-quality conditions that may have two possible negative implications: increased risk of exposure to airborne viral transmission, and an adverse effect on cognitive learning.

One simple and cost effective solution for detecting and counteracting elevated CO_2 levels is to use reliable, portable CO_2 monitors, which can be used to measure and monitor CO_2 levels in populated areas in real time. By using portable CO_2 monitors in this manner, teachers and other staff members can evaluate indoor air quality and gain instant indications as to whether improved air exchange is advisable.

The HTRAM analyzes specific air quality conditions and alerts the user when conditions are present that may increase the risk of exposure to airborne viral transmission. The device does not prevent or reduce virus transmission nor mitigate viruses that may be present, nor does it detect or warn against the presence of any virus, including but not limited to COVID-19. Even at lower risk levels caution is required to prevent viral transmission. The HTRAM does not repel or destroy any microorganism, viruses, bacteria, or germs.

- It is buyer's sole responsibility (1) to determine the suitability of the HTRAM for use in its application, (2) to operate the HTRAM in accordance with the user manual and any other instructions provided by Honeywell and in compliance with all applicable laws, rules and regulations and (3) to determine, based on buyer's experience, expertise and other available tools, the suitability of any product or service it may offer or recommend to the end user.
- Buyer is responsible for determining whether the product is appropriate for use under certain international, federal, state or local guidelines and is likewise responsible for determining whether the HTRAM is subject to any government programs, including without limitation, reimbursement plans.
- Any recommendations or assistance provided by Honeywell regarding the use or operation of the HTRAM – through our literature, the Honeywell website, or otherwise – shall not be construed as representations or warranties of any kind, express or implied, and such information is accepted at buyer's own risk and without any obligation or liability to Honeywell.
- The HTRAM does not detect for levels of CO_2 that would make for an unsafe or unsuitable breathing environment.
- The information we supply in this white paper is believed to be accurate and reliable as of this writing. However, specifications may change without notice, and Honeywell assumes no responsibility for its use.
- For more information and the most recent User Manual, go to https://airmonitoring.honeywell.com/#/doc/help

SOURCES

1 Natural Ventilation for Infection Control in Health-Care Settings, World Health Organization (2009)

2 Ventilation in Buildings, CDC (2021)

3 How School Buildings Influence Student Health, Thinking and Performance, Harvard T.H. Chan School of Public Health (Joseph Allen et al., 2020)

4 Key Considerations for CO_2 Monitoring in Educational Settings, Honeywell Safety and Productivity Solutions

5 Exhaled CO_2 as a COVID-19 Infection Risk Proxy for Different Indoor Environments and Activities, Environmental Science and Technology Letters (Zhe Peng and Jose L. Jimenez, 2021)

6 Carbon Dioxide Levels Reflect COVID Risk, Cooperative Institute for Research in Environmental Sciences at the University of Colorado Boulder (2021)

7 CU Boulder Study Links CO_2 Levels to Coronavirus Risk, Boulder Daily Camera (2021)

8 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; Harvard Library Office for Scholarly Communication

APPENDIX A

Real-World applications demonstrate that CO_2 monitoring can be used successfully in educational settings

Various countries, regions and metro areas have become increasingly concerned and vigilant about the airflow within educational settings – and have determined that CO_2 monitoring should be prescribed as a proactive strategy for assessing air quality. A University of Texas scientific paperA1 confirms this practice, stating that carbon dioxide (CO_2) is often used as a surrogate for evaluation of the adequacy of classroom ventilation, particularly as related to the dilution of pollutants emitted from human metabolic activity.

Examples include:

GERMANY: Classrooms have been equipped CO_2 sensors, which are being used to train teachers and students to be mindful of shared air and to periodically open windows.[A2]

ENGLAND: In 2021, the Department of Education announced it would deliver approximately 300,000 CO_2 monitors to schools in England to help regulate ventilation levels and prevent the spread of COVID-19.[A3]

SLOVENIA: A research study involving kindergarten classrooms in Slovenia demonstrated that CO_2 monitoring plus improved air-quality protocols led to a 30% improvement in the average daily concentration of CO_2.[A4]

MINNESOTA: The Minnesota Department of Health mandates CO_2 vigilance in school settings. It requires use of CO_2 as a proxy for ventilation effectiveness in rooms with high occupancy rates and also informs educators that CO_2 levels are easy to check with a low-cost, auto-read instrument.[A5]

NEW YORK: In 2020, New York City distributed portable CO_2 monitoring devices to every public school.[A6] The city stresses that properly ventilated classrooms are key to school safety.[A7]

TAIWAN: In 2019, researchers in Taiwan reported on the effect of ventilation on a tuberculosis outbreak at Taipei University. Many of the rooms in the school were underventilated and had CO_2 levels above 3,000 ppm. When engineers improved air circulation and got CO_2 levels under 600 ppm, the outbreak completely stopped. According to the research, the increase in ventilation was responsible for 97% of the decrease in transmission.[A8]

A1. Carbon Dioxide Levels and Dynamics in Elementary Schools: Results of the Tesias Study (RL Corsi et al., 2002)

A2. COVID-19 and Indoor Air: Risk Mitigating Measures and Future-proofing (Juliette O'Keeffe and Angela Eykelbosh, 2021)

A3. Covid: CO_2 Monitors Pledged to Aid School Ventilation, BBC News (Hannah Richardson, 2021)

A4. Practical Impact of the COVID-19 Pandemic on Indoor Air Quality and Thermal Comfort in Kindergartens. A Case Study of Slovenia (Vesna Lovec et al., 2021)

A5. Ventilation Guidance for Schools: COVID-19, Minnesota Department of Health

A6. The Hot New Back-to-School Accessory? An Air Quality Monitor., The New York Times (2021)

A7. School Building Ventilation Status, New York City Department of Education

A8. This Is the Safest Indoor Space to Prevent the Spread of COVID-19 (Shelly Miller, 2020)

APPENDIX B

More proof that indoor air quality (IAQ) can affect cognitive learning

- **A UC DAVIS (CALIFORNIA) SURVEY AND STUDY[B1]**
  Teachers volunteered comments about suspected health impacts of poor air quality in their classroom, for both themselves and their students. Symptoms reported included headaches, diz-ziness, migraines, allergies (e.g., sneezing and itchy eyes), sinus in-fections, and impaired cognitive function.

- **A 12-MONTH RESEARCH STUDY[B2]**
  Researchers aimed to understand whether cognitive function was associated with real-time indoor concentrations of particulate matter and CO_2. They found that higher CO_2 levels were associated with decreased performance and stated that their findings are consistent with and expand on other studies of the effects of CO_2 and ventilation on cognitive function.

- **A TEACHER SURVEY IN CHICAGO AND THE DISTRICT OF COLUMBIA[B3]**
  Nearly 70 percent of teachers responding to this survey reported that school facility conditions were an important factor in teaching quality, which can affect student learning. The most frequently cited problem was poor IAQ.

- **A RESEARCH DISSERTATION ABOUT THE RELATIONSHIP BETWEEN SCHOOL BUILDINGS AND ACADEMIC ACHIEVEMENT[B4]**
  The author's findings support findings in previous studies, particularly that the failure to control ventilation, temperature and cleanliness sabotages the facility's ability to provide an environment conducive to student learning.

- **STATEMENTS FROM THE EPA[B5]**
  The EPA acknowledges controlled studies showing that children perform school work with greater speed as ventilation rates increase and that children in classrooms with higher outdoor air ventilation rates tend to achieve higher scores on standardized tests in math and reading than children in poorly ventilated classrooms.

B1. Understanding Teachers' Experiences of Ventilation in California K- 12 Classrooms and Implications for Supporting Safe Operation of Schools in the Wake of the COVID-19 Pandemic, Davis, Energy & Efficiency Institute, University of California, Davis, California (Sanguinetti, Angela et. al., 2022)

B2. Associations Between Acute Exposures to PM2.5 and Carbon Dioxide Indoors and Cognitive Function in Office Workers: a Multicountry Longitudinal Prospective Observational Study, Environmental Research Letters, Volume 16, Number 9 (Jose Guillermo Cedeño Laurent et al., 2021)

B3. Public School Facilities and Teaching: Washington, DC and Chicago (Mark Schneider, 2002)

B4. A Study of the Relationship Between School Building Conditions and Academic Achievement of Twelfth Grade Students in Kuwaiti Public High Schools (Mutlaq M. Al-Enezi, 2002)

B5. Evidence from Scientific Literature about Improved Academic Performance, EPA

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