How to Evaluate Building Ventilation Using Carbon Dioxide Monitors

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Carbon dioxide (CO_2) is a colorless, odorless gas that we exhale during the respiration process. Measuring CO_2 in indoor spaces, like classrooms, can—when done properly—serve as a screening tool to determine when ventilation in that space needs further investigation and potential improvement. Measuring CO_2 does not function as an absolute measure of safe or unsafe air quality or determine whether COVID-19 or other hazards, such as asbestos or carbon monoxide, are present.[1] However, too much CO_2 in the air can indicate ongoing problems with indoor air quality (IAQ) and ventilation.

The National Education Association (NEA) created this document to provide guidance on what to look for in CO_2 monitors; explain how to effectively use them and interpret the results; and outline cautions when using results to make decisions about IAQ. It includes a checklist for selecting CO_2 monitors and a table to track CO_2 measurements. This guidance is part of a walkthrough toolkit that features hazard mapping, health surveys, and comprehensive checklists for building walkthroughs in educational settings related to mold, IAQ, building ventilation, and construction and renovation.

CO_2 OUTDOOR AND INDOOR LEVELS

People are the primary source of carbon dioxide in indoor spaces, and certain activities increase the concentration of CO_2 gas, such as choir practice in music class or people gathering to eat in a cafeteria. CO_2 is found naturally in outdoor air at low levels and does not generally pose a health risk at normal concentrations. As of 2022, the outdoor level of carbon dioxide is usually 420–450 parts per million parts of air (ppm), but it can be higher in areas with high traffic and industrial activity.[2] Carbon dioxide levels are usually greater inside a building than outside, especially when sources of natural ventilation in a building, such as windows and doors, are closed.

Elevated CO_2 concentrations serve as indicators of inadequate ventilation; they suggest that natural ventilation—such as open windows—and mechanical ventilation—like that provided through a heating, ventilation, and air conditioning (HVAC) system—are insufficiently moving stale air out of a space. Inadequate ventilation can increase the concentrations of all contaminants within indoor spaces.

Generally, if indoor carbon dioxide levels are 800–1,000 ppm or greater, building occupants may experience headaches, dizziness, fatigue, sleepiness, and eye and throat irritation.[3] At extremely high levels, CO_2 can cause shortness of breath, confusion, neurological and cardiac disturbances, and worse;

[1]U.S. Environmental Protection Agency. "Clean Air in the Building Challenge." Accessed April 8, 2022. Retrieved from epa.gov/system/files/documents/2022-03/508-cleanairbuildings_factsheet_v5_508.pdf.
[2]NOAA Climate.gov. "Climate Change: Atmospheric Carbon Dioxide." Accessed April 29, 2022. Retrieved from climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide.
[3]Tsai, D.H., Lin, J.S., Chan, C.C. "Office workers' sick building syndrome and indoor carbon dioxide concentrations." *Journal of Occupational and Environmental Hygiene.* 2012, 9(5):345-51. doi: 10.1080/15459624.2012.675291. PMID: 22530709.

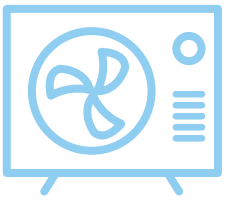
however, levels this high would not be likely in a classroom setting. When occupants experience acute health effects in buildings where CO_2 levels are elevated, they are usually due to a combination of factors, with higher CO_2 levels present as well as other contaminants in the air that build up as a result of poor ventilation.

It is important to keep in mind that even low CO_2 levels—below 1,000 ppm—do not indicate the absence of other contaminants in the air. For example, if educators are reporting moldy odors in a room, a low CO_2 level should not dismiss their concerns. However, an elevated CO_2 level could support their concerns by indicating that poor ventilation, often associated with mold problems, is present.

Elevated CO_2 levels are often found in crowded spaces, such as cafeterias after lunch, and can serve as an indicator that the ventilation system is not delivering or efficiently circulating adequate fresh outdoor air. This can happen when HVAC air changes—the measurement of how many times the air in the space is exhausted and replaced with a combination of filtered and outside air—are insufficient for the number of occupants and activities in the space.

CO_2 is sometimes confused with carbon monoxide (CO), which is also a colorless, odorless gas. Carbon monoxide is produced by burning carbon fuels and can be found in automobile or furnace exhaust. Carbon monoxide is very dangerous, and exposures can be fatal even at low levels. Carbon dioxide monitoring does not address carbon monoxide levels.

CO_2 SENSORS IN BUILDING HVAC SYSTEMS



Since the late 1990s, building HVAC systems, especially demand-controlled systems,[4] often have integrated CO_2 monitors and sensors installed to keep ventilation rates within system-designed requirements and more readily identify areas with poor ventilation. Sometimes, these systems are computerized and operated from a central engineering office in the district, on campus, or at a third-party location. When CO_2 monitors are integrated into an HVAC system, it is important for those investigating IAQ to confirm that the system has been properly maintained, calibrated, and monitored; that false reports are not common; and that system reports are available for review.

Any system modifications and installation and monitoring of CO_2 sensors must be done by a knowledgeable, trained HVAC professional. There are many ways that poor placement or inadequate calibration of CO_2 sensors can cause false readings. An industrial hygienist or other health and safety professional can be helpful in interpreting the meaning of assessment reports and CO_2 levels in air. As part of an IAQ initiative, users should consider requesting information on the district's HVAC maintenance records, system assessments, and CO_2 sensor reports and maintenance plans to ensure the ventilation system works properly.

[4] "Demand-controlled systems" adjust ventilation levels based on the number of people in or expected to be in a particular space during a particular time period.

CO_2 MONITORS IN EDUCATIONAL SETTINGS

There are various types of CO_2 monitors available in the marketplace, but the simplest and most common technology is the non-dispersive infrared (NDIR) sensor. These CO_2 monitors are small, portable units that can be handheld, placed in a room on a table or desk, or mounted to a wall.

CO_2 monitors can range in price from a few hundred dollars to a few thousand dollars. A recent study found that many low-cost monitors performed well.[5] Some monitors only measure CO_2, while others include additional sensors that monitor temperature, humidity, and specific hazards, like the presence of carbon monoxide.

When selecting a CO_2 monitor, the user should check that its range of measurement is appropriate for the designated class or workspace. In most indoor spaces, CO_2 levels will range between outdoor concentrations of less than 450 ppm to stuffy indoor environments of about 3,000 ppm. In contrast, some CO_2 monitors are intended to function as personal safety devices in occupational settings with potentially very high exposures, up to 50,000 ppm; these devices should not be used for typical indoor environments, such as classrooms.

Some CO_2 monitors provide a real-time measurement of CO_2 concentrations that can fluctuate wildly every few seconds as air moves around. Some monitors display CO_2 concentrations averaged over a set period of time to smooth out some of this "noise." Averaging periods of five to fifteen minutes are ideal for providing useful information without random fluctuations.

Some CO_2 monitors have a data-logging function, which continuously monitors CO_2 levels over adjustable time periods. The data can be downloaded to a computer or mobile device and graphed to show how CO_2 concentrations change over the course of the day or with varying occupancy. Being able to automatically capture and record data from monitors over time—including the day, time of day, and emission level—is important for IAQ analyses and studies. This information can be used to show the times of day or activities that impact high CO_2 levels the most, which can help members advocate for increased air changes and better ventilation during those periods.

The monitor should come with adequate instruction, including the recommended maintenance and calibration frequency required to ensure accurate results over time. Users should follow the manufacturer's instructions to understand how to use the monitor correctly. They should also practice using it beforehand to check that the monitor is working properly and to gain experience with how levels will vary depending on how close the CO_2 monitor is placed to people, open windows, and air conditioning or HVAC vents.

Selecting a Carbon Dioxide Monitor

- [ ] Is non-dispersive infrared (NDIR) CO_2 sensor
- [ ] Measures levels 0–10,000 ppm (a maximum level of 5,000 ppm is acceptable)
- [ ] Averages readings over five to fifteen minutes
- [ ] Has a data-logging function for tracking levels over hours or more
- [ ] Provides clear manufacturer instructions for use, including calibration and maintenance
- [ ] Has additional sensors measuring temperature and humidity (optional)

[5]Demanega, I., Mujan, I., Singer, B.C., Anđelković, A.S., Babich, F., and Licina, D. "Performance assessment of low-cost environmental monitors and single sensors under variable indoor air quality and thermal conditions." United Kingdom. Volume 187, January 2021. Retrieved from https://doi.org/10.1016/j.buildenv.2020.107415.

Using CO_2 Monitors

CO_2 levels vary throughout the day, depending on building occupancy, activities, and ambient outside conditions. A well-ventilated building can show a range of CO_2 levels throughout the day, which average 800–1,000 ppm. If carbon dioxide levels are greater than 1,000 ppm, this indicates potential ventilation problems, and complaints—such as headaches and fatigue—may be more common. Users should consider CO_2 levels greater than 1,000 ppm as an indicator that the ventilation system requires investigation and possible improvement. However, being at the 800–1,000 ppm level or below is only a guideline and should not be used to dismiss other ventilation-related concerns.

Placing CO_2 Monitors

CO_2 levels vary within an indoor space. Monitors should be placed in open air at seated height and away from windows, doors, and air supply openings. They should be positioned away from people because exhaled breath contains CO_2 and can alter results. If monitors are too close to people or openings, they may give an inaccurately high reading. If using handheld monitors over a period of time, readings should be taken from the same sampling location—or locations—with similar numbers of occupants and similar activities to effectively compare results.

Users should take several measurements in a space to identify the best sampling location for the monitor. In larger spaces, such as auditoriums or cafeterias, more than one sampling location might be needed to collect data.

Getting Accurate Measurements

Users should follow the manufacturer's instructions, including those on how to calibrate the monitor. To create a baseline, users should begin by testing the outdoor air with the CO_2 monitor.

Single or 'snapshot' readings can be misleading. When measuring inside, several measurements should be taken throughout the day when the room is occupied to represent changes in activities, the number of people present, and ventilation rates. Many factors can impact CO_2 readings in addition to occupant load, such as outside environment; external traffic or contaminants; weather conditions, like sustained winds; location within the building; and time of day.

As seasons change, it might be necessary to repeat monitoring due to differences in ventilation levels; for example, when occupants open windows and doors.

A record of the following should be maintained:

- CO_2 readings, the number of occupants, the type of activity happening in the space, and the type of ventilation being provided at the time;
- The date, location, time of day, and any abnormal conditions, like storms;
- Subjective sense of heat, humidity, odors, and general "stuffiness" in the space;
- Comments from occupants, including complaints about room-related headaches or other concerns that might be due to carbon dioxide; and
- Sudden adjustments made in an area before the reading, such as an HVAC system being turned on at the time of the reading or windows that were just opened, etc.

This information will help determine if an area requires further investigation and possible improvement.

CAUTIONS AND LIMITATIONS ON INTERPRETING CO_2 MONITORING

Carbon dioxide monitoring does not measure whether COVID-19, other pathogens, or hazards—such as asbestos or carbon monoxide—are present in the air. While there are methods for testing for asbestos, carbon monoxide, and other chemical or physical hazards, there is currently no easy methods of testing for COVID-19 in the air. Please note, if a classroom with elevated levels of CO_2 is using a portable air cleaner to remove SARS-CoV-2 virus from the air, CO_2 levels will remain elevated because portable air cleaners with HEPA filters are not designed to remove CO_2.

Carbon dioxide monitoring is meant as a screening tool, not as an absolute measure of safe or unsafe air quality. If CO_2 levels regularly approach or exceed 1,000 ppm, then the ventilation in the area should be investigated further.

Carbon dioxide is not an effective indicator of ventilation adequacy if the ventilated area is not occupied at its usual occupant density at the time CO_2 is measured. If the building or room occupancy is less than specified in the HVAC system design—which was the case when schools and institutions of higher education reduced student occupancy early in the pandemic—then carbon dioxide monitoring should not be used or the level of CO_2 raising concern should be lowered. Without enough occupants exhaling CO_2 into the building air at the expected rate, CO_2 monitoring is not a proper measure of ventilation.

Carbon dioxide levels should be monitored throughout the day and at times when the space of consideration is fully occupied. CO_2 levels are generally low for the first few hours of full occupancy and rise afterward until the end of the day. Users should not rely on early measurements alone to identify problems with air changes and inadequate ventilation and should remember to include measurements of CO_2 levels taken after periods of high occupancy and activity.

Carbon dioxide monitoring is a useful tool to ensure delivery of adequate ventilation and successfully investigate health complaints connected to IAQ in educational settings. For more information on this topic, reach out to Eunice Salcedo, senior health and safety specialist, at healthandsafetyprogram@nea.org.

Tracking Carbon Dioxide Readings

Worksite Address _____

Room No. _____ Date _____

	Number of Occupants	Temperature and Relative Humidity	Outside Weather Conditions	Carbon Dioxide Readings (ppm)	Type of CO_2 Monitor	Location of CO_2 Monitor	Occupant Concerns (Smells; symptoms when in the room)	Conducted By
Date: Time:								
Date: Time:								
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