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Measuring Carbon Dioxide Inside Buildings – Why is it Important?

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Within WSU
We are part of the College of Agricultural, Human and Natural Resource Sciences. We report directly to the WSU Vice President of Agriculture and Extension.

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The quality of air inside a building depends on the concentrations of contaminants – such as gases and particles – and how much fresh air is brought into the building through its ventilation system to dilute and remove these pollutants. It is essential to monitor indoor air quality (IAQ) to provide for occupant health, productivity and comfort.

This factsheet:

- Explains how carbon dioxide (CO_2) levels in a building can be used to monitor IAQ and the ventilation rate.
- Provides guidance about accurately measuring CO_2 levels.

See the companion factsheet, *"Good Ventilation is Essential for a Healthy and Efficient Building,"** to learn about how much fresh air should be brought into a building to keep the environment healthy and comfortable without using excessive energy.

Using CO_2 levels as an indicator of IAQ

The complex mixture of gases and particles in indoor spaces is difficult to measure. However, CO_2 levels, which are easy to measure, can be used in place of other measurements to indicate IAQ.

** Available on the Washington State University Energy Program website: http://www.energy.wsu.edu/PublicFacilitiesSupport/ResourceConservation.aspx.*

CO_2 is produced when people breathe. Each exhaled breath by an average adult contains 35,000 to 50,000 parts per million (ppm) of CO_2 – 100 times higher than is typically found in the outside air (OSA).

The CO_2 concentration in an occupied indoor space indicates if the building's air exchange balance is appropriate – that is, if the optimal amount of OSA is being mixed with air that has been circulating in the building.

Using a CO_2 meter

A CO_2 meter lets you easily and inexpensively measure CO_2 levels in specific areas of your building.

But, because the outdoor CO_2 concentration is included in the amount of CO_2 indoors, you must measure outdoor CO_2 levels when assessing indoor concentrations. Outdoor CO_2 levels are typically around 380 to 500 ppm.

Most CO_2 meters are accurate enough to indicate if ventilation in offices and schools is adequate. Some of these instruments measure only CO_2; others simultaneously measure temperature, relative humidity and other gases, such as carbon monoxide. A new generation of CO_2 monitors can measure volatile organic compound concentrations and infer CO_2 concentrations from these measurements.

What is CO_2?

CO_2 is a natural component of the atmosphere. The amount of CO_2 in an air sample is expressed as parts per million (ppm) – the number of CO_2 molecules per million molecules of air.

The CO_2 levels in the air outside a building are usually 380 ppm or higher, depending on:

- Local conditions – vehicle traffic, industry and other sources of combustion.
- Weather conditions – wind and temperature inversions can cause combustion gases to build up in a local area.

An elevated indoor CO_2 concentration is directly related to the number of occupants in the building, the building's ventilation rate, and the CO_2 level in the outside air.

Indoor CO_2 can accumulate if ventilation is not adequate to dilute and remove the CO_2 that is continuously generated by building occupants.

Instruments that record data internally or are coupled to an external data logger (as opposed to only giving instant readouts) provide valuable data for identifying trends, trouble-shooting and verifying solutions.

How much CO_2 is too much?

Current ventilation guidelines, such as those from the American Society of Heating Refrigerating, and Air Conditioning Engineers (ASHRAE), recommend that indoor CO_2 levels not exceed the local outdoor concentration by more than about 650 ppm. Good practice indicates that the ASHRAE Standard 62.1 target CO_2 level in indoor air is about 1,030 ppm, as follows:

380 ppm CO_2 typically found in OSA
\+ 650 ppm CO_2 (ASHRAE target maximum level)

= 1,030 ppm CO_2 (ASHRAE maximum recommended indoor level of CO_2)

It is important to adhere to these guidelines. The performance of individuals in schools and offices with elevated CO_2 concentrations can be affected because occupants may become lethargic and drowsy. Additionally, as CO_2 builds up, so do other indoor air contaminants, which increases occupants' exposures to irritating, distracting and potentially unhealthy gases and particulates.

Interpreting indoor CO_2 measurements

Interpreting CO_2 data is often a more significant source of error than instrument accuracy. Meaningful assumptions about ventilation rates based on CO_2 values require that the building or zone be occupied long enough to allow the CO_2 levels to reach a balance with the ventilation rate. This balance is known variously as equilibrium, unity or steady-state.

In an occupied building with a very low ventilation rate, the CO_2 levels will likely increase throughout the day, Low CO_2 readings do not necessarily indicate adequate ventilation.

never reaching a steady-state concentration. Conversely, a high ventilation rate and good mixing of OSA may prevent CO_2 from accumulating much beyond outdoor levels, so CO_2 concentrations stay low throughout the day.

Unless equilibrium has been reached, CO_2 measurements will not accurately reflect the building ventilation rate. For example, if a CO_2 measurement is taken in a classroom during the first class of the day, CO_2 will not have accumulated to the point where equilibrium has been reached. Therefore, OSA ventilation rates based on this CO_2 measurement will be overestimated.

If a CO_2 measurement is taken in the same classroom at the end of the day and the room's ventilation rate and occupancy have remained fairly consistent throughout the day, it is reasonable to assume that CO_2 equilibrium has been reached. Assumptions about OSA ventilation rates based on this CO_2 measurement will likely be useful for estimating the ventilation rate.

However, errors in CO_2 measurements do occur, often caused by:

- Ventilation systems that modulate the amount of OSA allowed into the building over the course of a day,
- Occupancy rates that fluctuate significantly,
- Instrument or calibration problems,
- Measurement location, and/or
- Poor mixing of the air within the space.

Using CO_2 monitors to automate fresh air ventilation

Once you have evaluated the building's ventilation system and determined if adjustments are necessary, consider installing CO_2 sensors to continuously monitor the CO_2 levels in the building. The HVAC control system can use the CO_2 values to automatically modulate the volume of OSA that is brought in so indoor CO_2 is maintained at or below a preset target concentration.

This strategy is known as Demand Controlled Ventilation (DCV). DCV systems are especially useful for spaces that experience variable occupancy rates, such as cafeterias, gymnasiums, classrooms and conference rooms, because the ventilation rate changes automatically in response to changes in the occupancy density.

DCV systems with CO_2 control sensors have been demonstrated to save 5 to 27 percent** of HVAC energy usage in a typical office environment, depending on occupancy type and use. Savings can be even greater when DCV is installed in spaces with high variability in occupancy, such as conference rooms, cafeterias and gyms.

It is relatively inexpensive to install CO_2 sensors, and they usually bring a very attractive return on investment. These sensors cost between $500 and $5,000, depending on their features:**

- For an HVAC system that has an air-side economizer with a motorized damper already installed in the OSA duct, the cost of adding CO_2 sensors will be close to $500.
- For HVAC systems that need to have a motorized damper added to their outside and return air ducts, along with the associated controls, the cost of adding CO_2 sensors will be higher.

Summary

CO_2 measurements are useful to help you:

- Determine if a building has adequate ventilation.
- Verify that enough OSA is coming in to ensure good IAQ.

It is important that building operators check manufacturers' specifications for calibration frequencies and routinely check the sensors to ensure that they remain calibrated.

When the ventilation system is calibrated correctly, the appropriate volume of OSA is mixed with recirculating air to:

- Dilute indoor air pollutants and CO_2 ,
- Create a healthy and productive environment, and
- Save energy by heating or cooling only the volume of OSA that is required.

Monitoring CO_2 levels also leads to significant energy savings by

***See Resources 7 and 8.*

CO_2 levels to know

- **35,000 to 50,000 ppm** – Amount of CO_2 in each exhale by an average adult
- **5,000 ppm** – Maximum allowable CO_2 level in an industrial workplace
- **380 ppm** – Typical CO_2 level in outside air (OSA)
- **650 ppm** – Indoor CO_2 levels should not exceed the local OSA concentration by more than 650 ppm, as recommended by ASHRAE.
- **1,030 ppm** – Given an average outdoor CO_2 concentration of 380 ppm, indoor CO_2 levels should not exceed 1,035 ppm (380 ppm + 650 ppm = 1,030 ppm).
- **If the outdoor CO_2 is around 380 ppm**, the relationship of the ventilation rate (cubic feet per minute of fresh air delivery) per person and the steady-state CO_2 concentrations should be close to these values:
  - 600 ppm = 25 cfm OSA per person
  - 800 ppm = 20 cfm OSA per person
  - 1,000 ppm = 15 cfm OSA per person
  - 1,400 ppm = 10 cfm OSA per person
  - 2,400 ppm = 5 cfm OSA per person

alerting operators:

- When the building is over-ventilating during hot or cold weather conditions, and
- About whether economizers can provide ample ventilation with OSA when in cooling mode.

Resources

1. American Society of Heating, Refrigerating, and Air Conditioning Engineers, "ASHRAE Standard 62.2.2012: Ventilation for Acceptable Indoor Air Quality," Atlanta, GA.
2. ASTM Standard D-6245 – 12, "Using Indoor Carbon Dioxide Concentrations to Evaluate Indoor Air Quality and Ventilation," May 2012.
3. ASTM Standard Guide E741-11, "Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution."
4. *IAQ Diagnostics Reference Manual: Hands-On Assessment of Building Ventilation and Pollutant Transport*, University of Tulsa, College of Engineering and Applied Sciences, Department of Chemical Engineering.
5. Indoor Air Quality Scientific Findings Resource Bank, Lawrence Berkeley National Laboratory: *http://energy.lbl.gov/ied/sfrb/*.
6. National Institute for Standards and Technology, *1994 Manual for Ventilation Assessment in Mechanically Ventilated Buildings*, NISTR #5329-1994.
7. *Demand-Controlled Ventilation: A Design Guide*, Northwest Energy Efficiency Alliance: *http://www.oregon.gov/ENERGY/CONS/BUS/DCV/docs/DCVGuide.pdf*.
8. *Energy Savings and Economics of Advanced Control Strategies for Packaged Air-Conditioning Units with Gas Heat*, Pacific Northwest National Laboratory: *http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20955.pdf*.

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