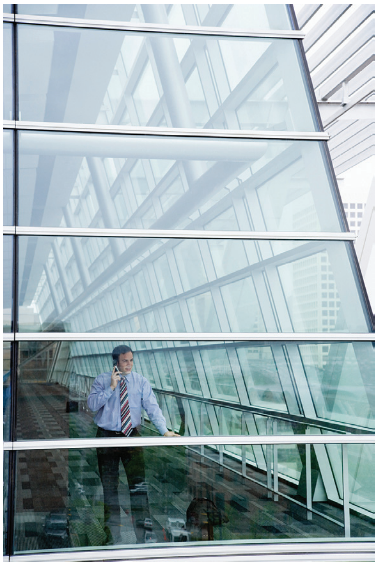
ONSET®


# Measure $CO_2$ to Improve Ventilation/IAQ

*A $CO_2$-Logging Primer for Facility Managers and Building Engineers of Offices, Schools, Healthcare Facilities, and Residential Communities*

## Introduction



Scientific and medical research correlates poor indoor-air quality (IAQ) and elevated carbon dioxide ($CO_2$) levels to occupant discomfort and productivity loss in offices, schools, healthcare facilities, and dwellings [1-5].

$CO_2$ is a trace pollutant that impairs cognitive and respiratory function. Sustained concentrations exceeding 600-700 parts per million (ppm) over outside levels are associated with inadequate ventilation and, thus, serve as a convenient proxy for overall indoor-air health [6].

The U.S. Environmental Protection Agency (EPA) identified IAQ as one of the top five most urgent environmental risks to public health [7]. Facility managers and building engineers are often responsible for ensuring optimal ventilation in work and living spaces, yet many are unfamiliar with the scientific rationale or methods to achieve such control. Wireless data loggers that measure $CO_2$, together with temperature and humidity, provide critical real-time awareness—essential to enforcing high environmental standards for occupants.

With long-term $CO_2$ monitoring, building operators gain insights to support better decisions regarding ventilation control and HVAC upgrades—projects that can lead to significant energy savings and improved overall indoor-air quality. Comprehensive, location-specific $CO_2$ data in building environments also helps to focus HVAC improvements on the most effective and cost-efficient solutions.

Fortunately, battery-powered $CO_2$ data loggers easily measure indoor concentrations. These compact hand-held devices—roughly the same size and shape as a wall-mounted home thermostat—may reside anywhere throughout a building where $CO_2$ data is needed. Measurements typically range from 0–5,000 ppm. Today's newer options enable users to access data from mobile devices and quickly download data directly to a laptop, or from the cloud.

This primer explains risks of elevated $CO_2$ with a global perspective, and how data logging can be a cost-effective indicator of degraded IAQ and sick-building syndrome (SBS). Practical measurement and logger-selection tips help facility managers and building engineers make informed deployments, including proper sensor calibration and placement in service.

## Highlights

- Tight-building standards increase risk of sick-building syndrome and poor occupant health
- Offices, schools, healthcare facilities, gyms, and dwellings frequently exceed healthy $CO_2$ levels
- Indoor $CO_2$ concentration over 1,000 ppm correlates to cognitive impairment and dysfunction
- Global $CO_2$ exposure limits vary by country, some more stringent than US standards
- Bluetooth, long battery life, LCD display with alarms, and USB options facilitate data collection
- Automated $CO_2$ logger calibration and proper placement improve measurement accuracy

## High Indoor $CO_2$ Concentration Impairs Occupant Productivity and Well-being

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) defines acceptable indoor-air quality as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction" [6].

A key marker of indoor-air quality is carbon dioxide, a natural byproduct of human and animal respiration, decaying organic matter, and combustion of wood, carbohydrates, and fossil fuels. At low densities, $CO_2$ is odorless and tasteless. However, its differential indoor concentration is a surrogate for certain air-quality metrics, particularly occupant perception of odorous bioeffluents (body odor) [8]. Not only does inadequate building ventilation promote excess moisture and mold, but elevated $CO_2$ increases complaints of stale air while impairing occupant productivity and decision-making.

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In a groundbreaking controlled study [9], according to the Lawrence Berkeley National Laboratory, "On nine scales of decision-making performance, test subjects showed significant reductions on six of the scales at $CO_2$ levels of 1,000 parts per million (ppm) and large reductions on seven of the scales at 2,500 ppm. The most dramatic declines in performance, in which subjects were rated as 'dysfunctional,' were for taking initiative and thinking strategically" [10].

This research challenges conventional wisdom that $CO_2$ concentrations of 5,000 ppm are acceptable occupational limits in the work environment. Imagine the impact on office workers, instructors, students, and medical professionals when critical cognitive and decision-making functions degrade. Although this study did not test learning ability versus $CO_2$ concentration, it clearly demonstrated impaired cognitive and decision-making abilities, which could impact student reasoning and test scores. This is a wake-up call for educators globally, and warrants further research.

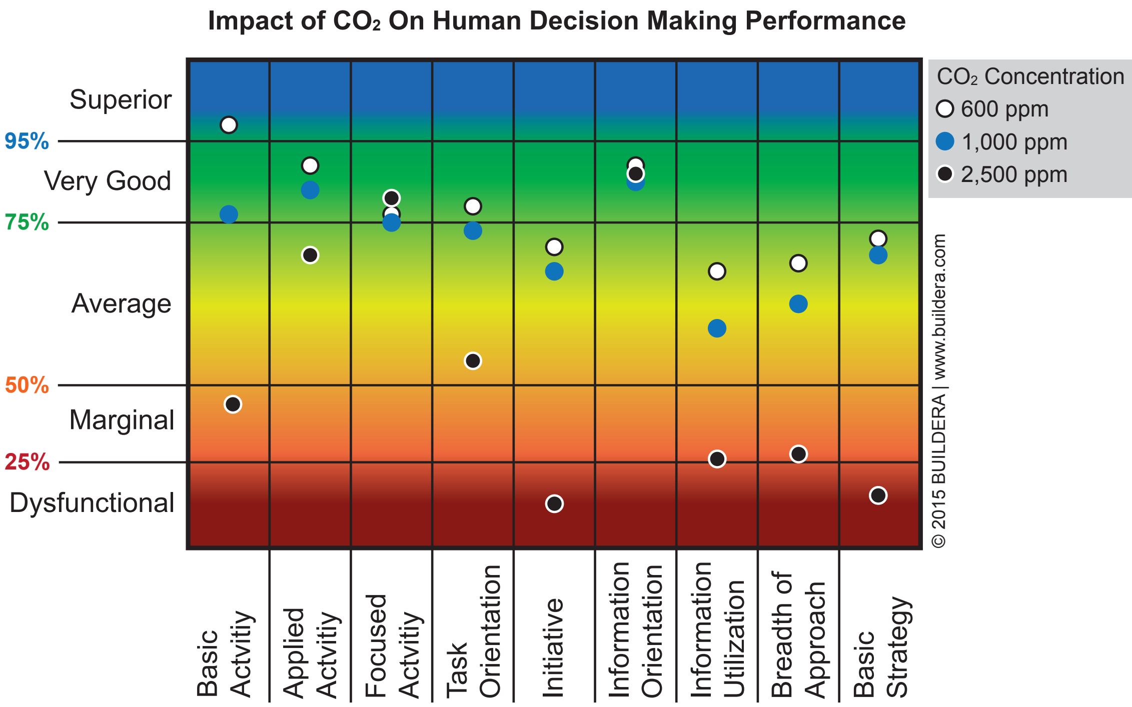



Figure 1. Moderate to elevated levels of indoor $CO_2$ result in lower scores on six of nine scales of human decision-making performance (adapted from Satish et al. 2012) [9].

## Energy Conservation vs. Indoor-Air Quality

**Existing ventilation standards are typically minimum recommendations, and may not result in optimal air quality or cognitive function, particularly during peak occupancy.**

Recent and emerging global building standards dictate tight building envelopes that purposely restrict outside-air infiltration in an effort to conserve energy and reduce carbon footprint. Ironically, these well-intentioned conservation measures compete with the need to reduce indoor-air pollutants, including volatile organic compounds (VOCs), tobacco smoke (where existing), carbon monoxide (CO), and $CO_2$ buildup from anthropogenic sources. Moreover, existing ventilation standards are typically minimum recommendations, and may not result in optimal air quality or cognitive function, particularly during peak occupancy.

Newer, modern structures rely increasingly on adaptive demand-controlled ventilation (DCV) that modulates air exchange according to real-time measurement of $CO_2$ concentration—a proxy for occupant load. When properly deployed and calibrated, auxiliary $CO_2$ loggers are useful throughout such DCV facilities to ensure that the ventilation system is working as intended, and to identify potential duct blockages or control-system issues.

| Typical Candidates for Demand-Controlled Ventilation Testing |
| --- |
| • Restaurants and bars |
| • Lecture halls and schools |
| • Shopping malls and department stores |
| • Conference centers and sports halls |
| • Reception halls, banking floors, airport check-in areas |
| • Assembly halls, conference rooms, theaters, and cinemas |
| • Hotels and residential buildings |
| • Other spaces with varying occupancy levels |

Table 1. Demand-controlled ventilation (after Siemens) [11].

Unfortunately, most existing offices, schools, and smaller healthcare facilities do not enjoy such advanced ventilation technology. They rely instead on fixed mechanical systems and natural ventilation, blind to dynamic occupancy levels and other environmental factors. At certain times of the year, when inside-outside temperature differentials are large, windows may be shut to conserve energy, promoting high $CO_2$ concentration and trapping unhealthful indoor pollutants.

As a result, marginal or poor indoor-air quality is commonplace in conference rooms, auditoriums, school classrooms, healthcare facilities, and residential dwellings. Studies from around the world consistently document elevated indoor $CO_2$ concentrations ranging from under 1,000 ppm to extremes over 6,000 ppm [12-19]—far exceeding the threshold of cognitive dysfunction previously noted [9].

Moreover, venues where metabolic rates are high—such as gyms, fitness centers, and aerobic-workout rooms—frequently exceed acceptable standards. In a study of fitness centers in Lisbon, Portugal, 54% exceeded acceptable $CO_2$ limits in at least one or more rooms, with a peak concentration of 5,617 $mg/m^3$ (3,120 ppm)—more than twice the 2,250 $mg/m^3$ (1,250 ppm) limit value established by Portuguese legislation 353-A/2013 [20].

While fossil-fuel combustion and plant photosynthesis largely drive atmospheric $CO_2$ concentration, indoor $CO_2$ concentrations vary widely due to factors such as number of occupants, ventilation rate, air volume, unvented combustion, and organic decay from food and garbage [21-22]. Without proper ventilation, sick-building syndrome spreads.

| Key Factors Affecting Indoor $CO_2$ Levels |
|---|
| • Number of occupants in a room or space |
| • Occupant activity level (metabolic rate) |
| • Amount of time occupants spent in the room |
| • Combustion (cooking, experiments using Bunsen burners) |
| • Ventilation rate (exchanges per hour with fresh outside air) |
| • Outdoor $CO_2$ concentration |

Table 2. Factors affecting indoor $CO_2$ levels.

## Carbon Dioxide ($CO_2$) Hazard Scale

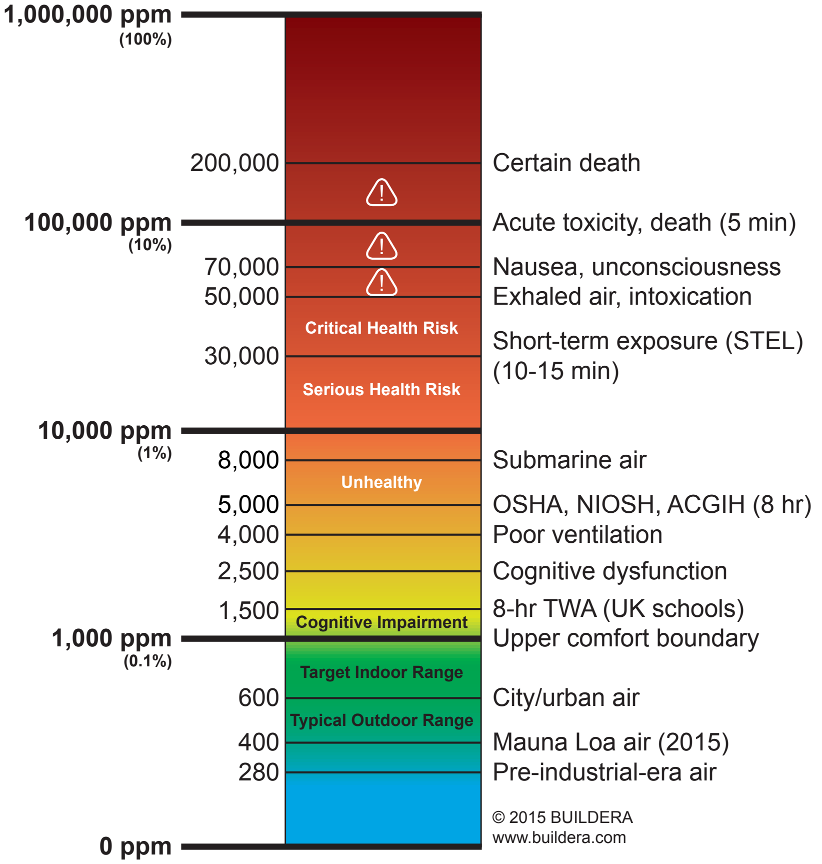



Figure 2. Carbon dioxide health hazard versus concentration.

| $CO_2$ Exposure Limits for Selected Countries | | | |
|---|---|---|---|
| Country | Agency/Standard | Maximum Level | Notes |
| America (USA) | ASHRAE 62.1-2013 Appendix C | 700 ppm above outside levels | This is a measure of occupant discomfort, not an absolute health guideline. The ASHRAE 1,000 ppm guideline has since been redacted. |
| | Occupational Safety and Health Administration (OSHA) | 5,000 ppm (PEL-TWA)<br>30,000 ppm (STEL) (CAL/OSHA) | TWA=Time-weighted over five 8-hour work day average for industrial environments |
| | CDC/NIOSH | 5,000 ppm (REL-TWA)<br>30,000 ppm (STEL)<br>[15 min] | Non-narcotic central nervous system effects (eye flickering, psychomotor excitation, myoclonic twitching, headache, dizziness, dyspnea, sweating, restlessness) |
| | ACGIH | 5,000 ppm<br>30,000 ppm [15 min] | |
| Australia | Safe Work Australia; Workplace Exposure Standards for Airborne Contaminants (2011) | 5,000 ppm (TWA)<br>30,000 ppm (STEL) | 12,500 ppm TWA allowable in coal mines with 30,000 STEL |
| Canada | Federal-Provincial Advisory Committee on Environmental and Occupational Health | 3,500 ppm (ALTER) | Exposure guidelines for residential indoor-air quality |
| Germany | Deutsche Forschungsgemeinschaft (DFG) | 5,000 ppm (MAK) | 8-hour work day average |
| | DIN 1946-6<br>DIN 1946-2 | 1,000 ppm (recommended)<br>1,500 ppm (upper limit) | Recommended Outside Air: $30m^3$/h per person;<br>Minimum $20m^3$/h per person |
| Japan | Japan Society for Occupational Health (2004) | 1,500 ppm | |
| New Zealand | Ministry of Business, Innovation and Employment | 5,000 ppm (TWA)<br>30,000 ppm (STEL) | Workplace Exposure Standards and Biological Exposure Indices 7th Edition (2013) |
| Sweden | Occupational Exposure Limit Values, AFS 2011:18 | 5,000 ppm (LLV)<br>10,000 ppm (STV) | Sweden sets a Short-Term Value (STV) 3x below most nations |
| UK | Health and Safety Commission (HSE) – UK | 5,000 ppm (LTEL)<br>15,000 ppm (STEL)<br>[15 min] | Industrial environments per EH40/2005 Workplace Exposure Limits |
| | UK Building Bulletin 101 | 1,500 ppm | School average levels for full day not to exceed (UK) |

Table 3. $CO_2$ occupational exposure limits for select countries.

ALTER = Acceptable Long-Term Exposure Range (Canada), TLV® = Threshold Limit Value, REL = Recommended Exposure Level, PEL = Permissible Exposure Limit, TWA = Time-Weighted Average, STEL = Short-term Exposure Limit, C = Ceiling limit, LTEL = Long-term Exposure Limits, WEL = Workplace Exposure Limits, MAK = Max. Arbeitsplatz-Konzentration (Maximum Permissible Concentration) (Germany), ACGIH® = American Conference of Governmental Industrial Hygienists, OSHA = Occupational Safety and Health Administration.

Table 3 compares acceptable $CO_2$-concentration thresholds established by ASHRAE and other global governments and standards bodies. In most cases, these figures do not factor in the most recent research correlating even modest $CO_2$ levels with cognitive function. Conversely, these figures define levels at which human health may be impacted without regard to impairment of cognitive abilities or perception of poor indoor-air quality. Figures specifically exclude sensitive individuals who would benefit from even lower concentration levels. Furthermore, studies show strong correlation of even 100 ppm over outside air to be positively correlated to increased likelihood of sore/dry throats, wheezing, and other respiratory issues.

When assessing indoor levels, it is important not only to measure absolute $CO_2$ ratios, but also compare them to outdoor levels. Ventilation effectiveness relates to the difference between indoor and outdoor levels, whereas health considerations and cognitive function correlate both to overall ventilation, as well as the absolute $CO_2$ levels present in a structure [23-24].

Air-quality concerns also exist for passenger airline cabins, which by their very nature, are subject to high occupant density in a confined space. A 2012 study of 83 flights and 4,306 passengers found that cabin $CO_2$ levels ranged from 863 to 2,056 ppm [25]. While below the maximum occupational limits, interior levels above 1,000 ppm have now been shown to impair decision-making ability.

## Relating $CO_2$ Concentration to Ventilation Rates

Table 4 estimates internal carbon dioxide levels for a given ventilation rate per person [26]. Figures are based on sedentary metabolic rates and are considered minimum acceptable values.

| Carbon Dioxide | Outside Air Per Person | $CO_2$ Differential (inside-outside) |
|---|---|---|
| 800 ppm | 20 cfm or less | 400 ppm |
| 1,000 ppm | 15 cfm or less | 600 ppm |
| 1,400 ppm | 10 cfm or less | 1,000 ppm |
| 2,400 ppm | 5 cfm or less | 2,000 ppm |

Table 4. Adapted from Washington State University Extension Energy Program [26]. Figures are approximate based on a constant number of sedentary adult occupants, a constant ventilation rate, and an updated outdoor air $CO_2$ concentration of 400 ppm (was 380 originally).

ASHRAE 62.2-2013 *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*—the latest edition of the standard at the time of writing—does not establish $CO_2$ limits in low-rise residential buildings [27]. It does state, however, that minimum ventilation rates shall be:

$$Q_{tot} = 0.03A_{floor} + 7.5(N_{br} + 1)$$

Where,

$Q_{tot}$ = total required ventilation rate, cfm
$A_{floor}$ = floor area of residence, $ft^2$
$N_{br}$ = number of bedrooms (not to be less than 1)

Thus, a 2,500-$ft^2$ residence with four bedrooms would require at least 113 cfm of whole-building ventilation. Specific areas such as bathrooms and kitchens have a minimum additional demand-controlled ventilation of 100 cfm (50 L/s) and 50 cfm (25 L/s), respectively. Ventilation rates for multifamily buildings are slightly higher, and include a provision of 0.06 cfm per $ft^2$ (30 L/s per 100 $m^2$) of floor area for common areas within the conditioned space.

However, these minimum levels may not be sufficient to keep $CO_2$ levels to acceptable thresholds, particularly in high-occupancy facilities. Thus, the need to deploy data loggers carries more importance as facility managers and engineers pay attention to $CO_2$ risks in their buildings.

### European Harmonization of Ventilation Standards

In an effort to harmonize European ventilation standards, the Comité Européen de Normalisation (CEN) approved the European standard *EN 13779:2007 Ventilation for non-residential buildings – performance requirements for ventilation and room conditioning systems* [28]. An updated standard, prEN 16798-3:2014 is pending approval by CEN and will ultimately supersede EN 13779:2007. EN 15665 and CEN/TR 14788 cover performance of ventilation systems in residential buildings.

The following countries have agreed to adopt the new standards: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, and the United Kingdom.

Unlike typical fixed concentration limits, Table 5 illustrates how EN 13779 divides air quality into four qualitative tiers from High to Low. Each tier compares a range of acceptable indoor $CO_2$ mixing ratios relative to prevailing outdoor levels. The effect of this method is that as outside $CO_2$ levels continue to rise, the differential-level requirement remains constant.

| Air Quality Category | $CO_2$ Level Above Outside Air | Absolute $CO_2$ Level OA=400 ppm | Perceived Indoor Air Quality (% dissatisfied) | Rate of Outside Air per person $m^3$/h (cfm) |
|---|---|---|---|---|
| IDA 1 (High) | ≤400 | ≤800 | ≤15 | >54 (32 cfm) |
| IDA 2 (Medium) | 400-600 | 800-1200 | 15-20 | 36-54 (21 – 32) |
| IDA 3 (Moderate) | 600-1000 | 1000-1400 | 20-30 | 22-36 (13 -21) |
| IDA 4 (Low) | >1000 | >1400 | >30 | <22 (13) |

Table 5. EN 13779 Ventilation for non-residential buildings, 2004 and CR1752. Does not apply to rooms where smoking is permitted. Limited to human metabolism only. Assumes outdoor $CO_2$ concentration approximately 400 ppm. Adjustment may be required for urban areas due to higher average $CO_2$.

## Choosing the Right $CO_2$ Data Logger

**With user-programmable alarm notifications, a $CO_2$ data logger issues an audible alert and displays a visual warning on its LCD screen during a qualified trigger event, such as a $CO_2$ concentration that exceeds a healthy threshold.**

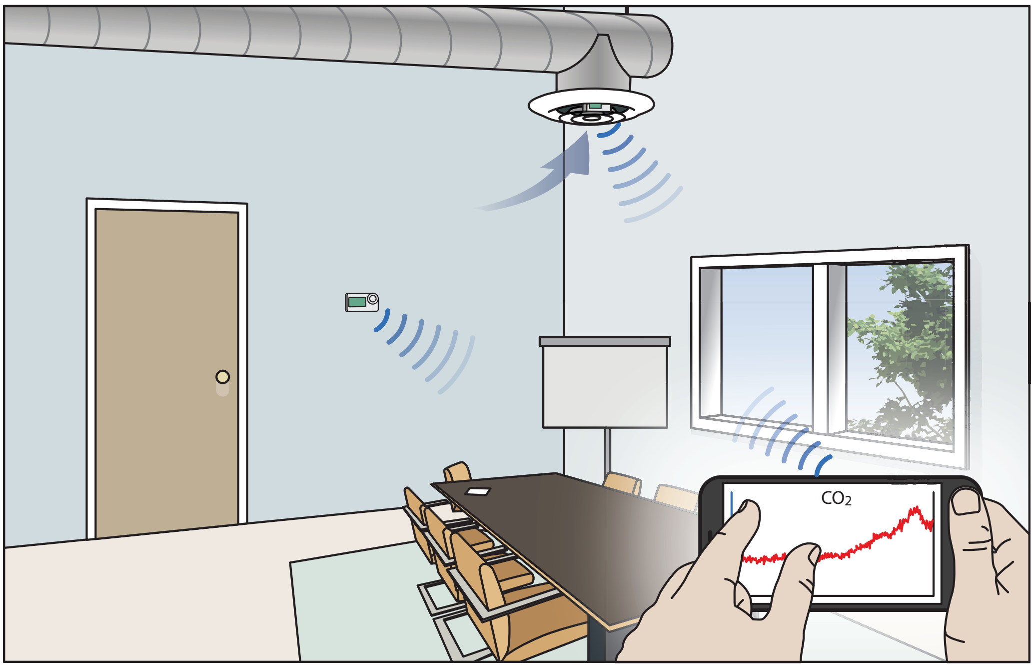
In light of the foregoing, $CO_2$ data loggers are an economical solution to detect and manage the risk of elevated $CO_2$—essential to developing an abatement strategy that may include:

- Improved mechanical ventilation and air flow
- Injection of fresh outdoor air via energy-efficient heat exchangers
- Judicious use of operable windows
- Ceiling fans to promote better air circulation
- Reduction or mitigation of internal $CO_2$-producing sources

Yet, choosing the right logger can be daunting without first understanding key differentiators between available devices. Although many loggers today offer comparable measurement range and sensor accuracy, usability factors including connectivity options, alarming, battery life, and long-term calibration costs vary more widely.

**Bluetooth Capability**

Smart wireless technology provides unprecedented user benefits including efficient data collection, easy management with data sharing, and overall user-friendly operation. Leveraging today's latest advancements in low-power wireless communication, some $CO_2$ data loggers now incorporate Bluetooth Low Energy (BLE) technology that retrieves data and logger status faster and more conveniently than ever before—all using a modern mobile device, such as Apple® and Android® phones and tablets.




A BLE $CO_2$ data logger records and transmits wirelessly to mobile devices on demand, enabling users to access measurements from the logger remotely up to a 100-foot range (line-of-sight). By eliminating the requirement to log on to the Internet, pair devices, install computer software, or connect the logger to a computer for downloading data, building managers can streamline indoor-air-quality studies—decreasing the time and costs associated with $CO_2$ monitoring programs.

BLE solutions are particularly advantageous when deploying multiple $CO_2$ data loggers inside buildings, or in hard-to-reach locations where physically downloading data from the logger would otherwise prove difficult. Ventilation-system monitoring is one example where loggers may reside out-of-reach (to avoid tampering), or inside a return-air duct.

**LCD Display with Alarm Notifications**

Facility managers and building engineers should also look for a $CO_2$ data logger that features an LCD display with programmable alarm notifications.

An LCD display depicts current $CO_2$ levels, logging status, battery use, memory consumption, and other parameters such as ambient temperature and relative humidity. Users with little time to waste appreciate the time-efficient benefit of working with a screen that is integrated and responsive.

With user-programmable alarm notifications, a $CO_2$ data logger issues an audible alert and displays a visual warning on its LCD screen during a qualified trigger event, such as a $CO_2$ concentration that exceeds a healthy threshold.

When evaluating $CO_2$ data loggers with this feature, look for options that provide both audible and display-based alarm notifications so that building managers remain alert to problems as they occur, aiding efficient corrective action.


**Six-Month Battery Life**

Long battery life is an important factor to consider when comparing $CO_2$ data loggers.

While many products on the market run for a short time on battery power—or require an expensive proprietary battery—options are now available that allow up to six-months of continuous logging at five-minute intervals using standard alkaline or lithium AA batteries. Selecting a $CO_2$ data logger with extended battery life, users benefit from the flexibility, increased spatial coverage, and the ability to set up $CO_2$ monitoring in locations where no AC power exists, such as in—or near—HVAC return-air ducts.

**Integrated USB**


When choosing a $CO_2$ data logger, USB support is another key factor. USB ports improve flexibility of data access and analysis. Through a USB port, users may connect a $CO_2$ data logger directly to a computer running graphing and analysis software, enabling quick plotting, comparison, and data extraction. This information visually reinforces presentations and recommendations with a compelling engineering foundation.

A USB port also offers the advantage of greater power versatility, supporting a wider range of application scenarios. Specifically, this includes the use of an off-the-shelf USB charger to power the $CO_2$ data logger for longer deployments. Optionally, when faster sampling rates/alarm responses are required, the USB port is a handy remote-power option for uninterrupted 24/7 operation when using a recirculating memory cache.

**Depending on the sensor design, the transmitter and detector can drift over time, causing long-term errors and under-reporting of actual $CO_2$ concentrations.**

### Easy Calibration Without Special Gases

When assessing calibration and operating costs, aim for products that offer both manual and automatic calibration methods, as well as elevation/altitude compensation. The sensor subsystem inside most $CO_2$ loggers requires periodic calibration to a known reference and careful placement to avoid erroneous results. Some of the most advanced devices also include automatic temperature and dynamic pressure compensation, but are typically less common on mid-range products.

Many commercial $CO_2$ loggers—including the Onset® MX1102 $CO_2$ Logger with BLE technology—use maintenance-free non-dispersive infrared (NDIR) sensing technology shown in Figure 3. This consists of a gas chamber, IR source transmitter, optical filter, and IR detector. The detection wavelength is tuned to measure the concentration of $CO_2$ molecules to a reasonable degree of precision. Depending on the sensor design, the transmitter and detector can drift over time, causing long-term errors and under-reporting of actual $CO_2$ concentrations [29]. While optimal calibration methods require calibrated gas concentrations and sealed test chambers, this is not cost effective or practical for maintenance personnel, particularly where a large number of devices may be operating.

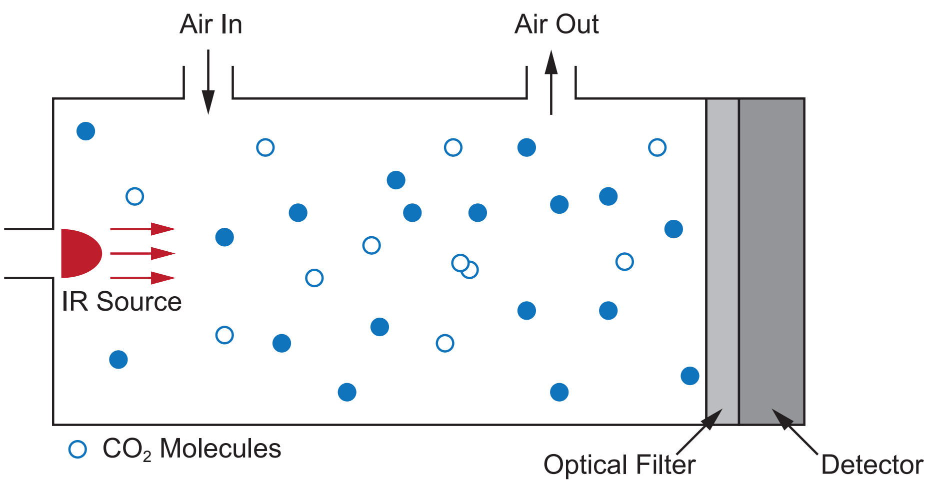



Figure 3. NDIR Sensor (adapted from CO2Meter.com) [28].

In lieu of calibrating with specialized gases, engineers have developed manual and automated calibration algorithms to improve accuracy for typical $CO_2$ logging applications, while keeping operating and maintenance costs to a minimum [30-32].

## Discussion of Calibration Options and Differential Measurements

### Manual Calibration

In the manual calibration mode, the user calibrates the logger outdoors, using exterior $CO_2$ concentration as a calibration baseline. As of the time of writing, most loggers adopt 400 ppm as the outdoor reference concentration, which is based on normalized data from global atmospheric observatories, such as Mauna Loa in Hawaii.

However, diurnal and monthly variations of 50 to over 200 ppm in urban $CO_2$ concentration [33-44] can cause potential calibration errors depending on the time of day the initial calibration occurs. For example, the Institute of Environmental Science and Meteorology (UP-Diliman, Philippines) recorded urban $CO_2$ levels ranging between approximately 425 to 625 ppm over a two-week period during May 2015. At no point did the outside levels ever return to 400 ppm, with average levels approximately 475 ppm [43] (www.iesm.upd.edu.ph/wp-content/uploads/2015/01/IESMCO2Weekly-700x350.png). Thus, reliance on manual calibration alone may not always lead to the most accurate absolute $CO_2$ measurements, particularly in populous urban areas with heavy traffic and industrial pollution.

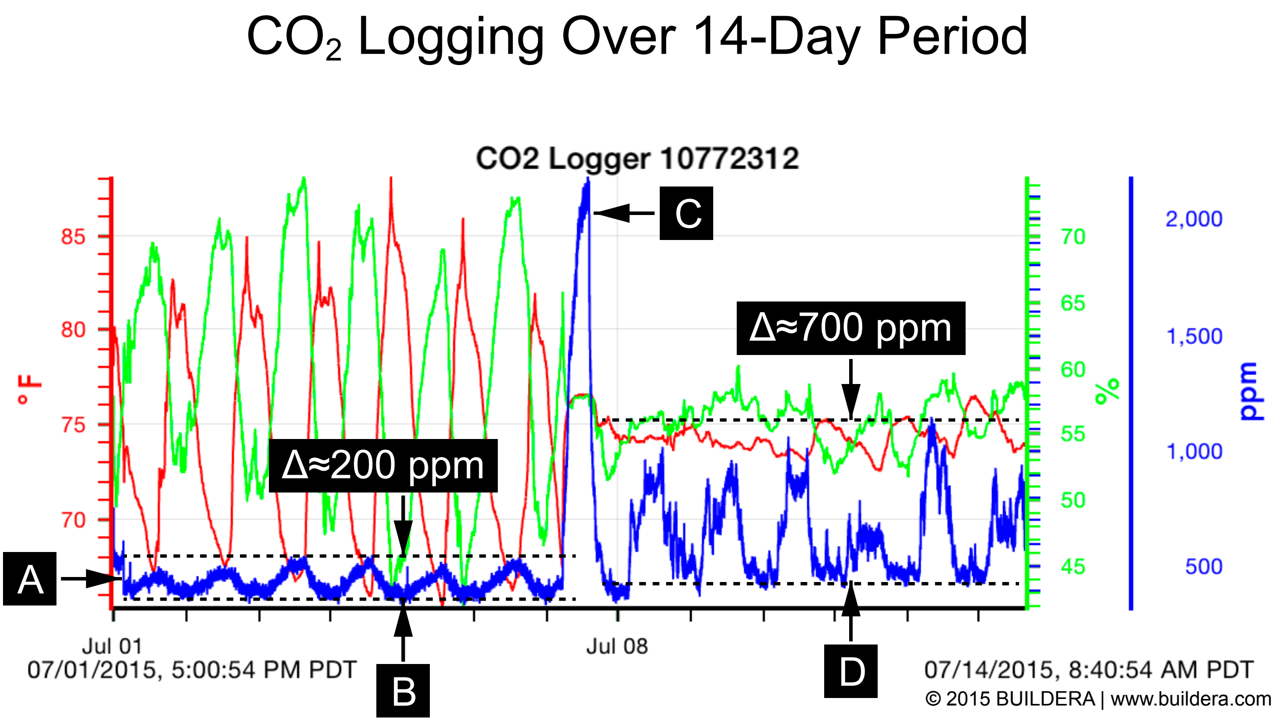



Figure 4. iPhone plot from Onset MX1102 Bluetooth logger documents temperature, humidity, and $CO_2$ concentration between July 1, 2015 and July 14, 2015 in the San Francisco Bay Area of California. [A] shows the initial baseline correction to 400 ppm on July 1, 2015 after first manual outdoor calibration. [B] sinusoidal variation in $CO_2$ represents outdoor diurnal concentration variation with approximately 200-ppm peak-to-peak variation between late afternoon (min) and early morning (max), attributed to $CO_2$ absorption from photosynthesis. [C] step-increase to unhealthy 2,178-ppm peak is indoor measurement of room within a multi-family dwelling with four occupants, windows closed. [D] shows improvement in worst-case peak-to-peak $CO_2$ concentration of approximately 700 ppm for same dwelling upon opening a window to provide natural ventilation. Sampling interval: 1 minute.

**Failure to set the correct elevation could result in $CO_2$-concentration errors of 1-50% or more, depending on the elevation.**

### Automatic Baseline Calibration (ABC)

The automatic baseline calibration (ABC) method assumes that, during a given 7.5 to 8-day stretch, there are periods where few or no building occupants are present. Thus, the internal levels will return to equilibrium with outdoor concentrations approximating 400 ppm. Upon detecting minimum levels, the logger computes a new baseline under the assumption that the minimum value (without occupants) is 400 ppm. This iterative method works well in many offices or school classrooms where occupancy approaches zero overnight, or on weekends and holidays. Pre-programmed air purges during periods of non-occupancy also help to reduce residual $CO_2$ to ensure that interior levels approximate outdoor levels. However, automatic calibration is not suitable in a hospital, hotel, or other public space subjected to continuous presence of personnel and visitors. A quality logger allows the user to select which calibration modes are most appropriate for the situation.

### Altitude Compensation

As gas pressure declines exponentially versus elevation, fewer $CO_2$ molecules enter the fixed NDIR-sensor chamber at higher altitudes, despite the relatively constant 400 ppm $CO_2$-concentration ratio in the troposphere. Failure to set the correct elevation could result in $CO_2$-concentration errors of 1-50% or more, depending on the elevation. Note that altitude compensation provides a more coarse correction and does not compensate for dynamic fluctuations in ambient pressure that change rapidly, such as during storms or high winds.

### Differential Measurements Improve Relative Accuracy

To reduce the impact of calibration errors, deploying a differential measurement setup with two or more $CO_2$ loggers can help. Differential measurements are also the best indicator of ventilation performance and additive $CO_2$ from internal sources. In this configuration, one logger remains outdoors in a suitably protected area with free airflow (ideally protected from direct solar radiation), while the remaining loggers reside indoors. By subtracting time-stamped outdoor readings from inside readings, common-mode calibration errors largely cancel. This assumes that the initial manual calibrations were performed concurrently in the same outdoor location. During the initial calibration process—but prior to final placement—allow all loggers to stabilize outdoors for at least 30-60 minutes. Next, initialize the manual calibration procedure on each logger. All loggers should read approximately 400 ppm in the same outdoor location. The loggers are then ready for final installation in their target locations.

## Mounting Recommendations

Carbon dioxide is more than 60% denser than air, and tends to settle at first near the bottom of the floor. This could lead to distorted readings if the logger is placed too low on a wall. Over time, however, diffusion will occur and the total volume of air should contain similar concentrations of $CO_2$. Table 6 summarizes recommended mounting practices depending on the measurement objective. For example, when monitoring (and alarming) storage areas with compressed $CO_2$, 18 inches (45 cm) off the floor captures initial leaks due to its higher density.

For typical IAQ measurements as shown in Figure 5, mount the logger in the breathing zone, approximately 48-72 inches (122-183 cm) vertically above the floor surface—several feet away from occupants where exhalation could alter the localized $CO_2$ concentration. Stay at least 36 inches (91 cm) away from any corner, 24 inches (61 cm) from an open doorway, and well away from operable windows, outside doors, and vents.

Some manufacturers recommend mounting the loggers inside the return-air duct in the rooms of interest, assuming such a duct exists. This is more practical in commercial buildings versus residential units, as the latter typically have no more than one centralized air return.

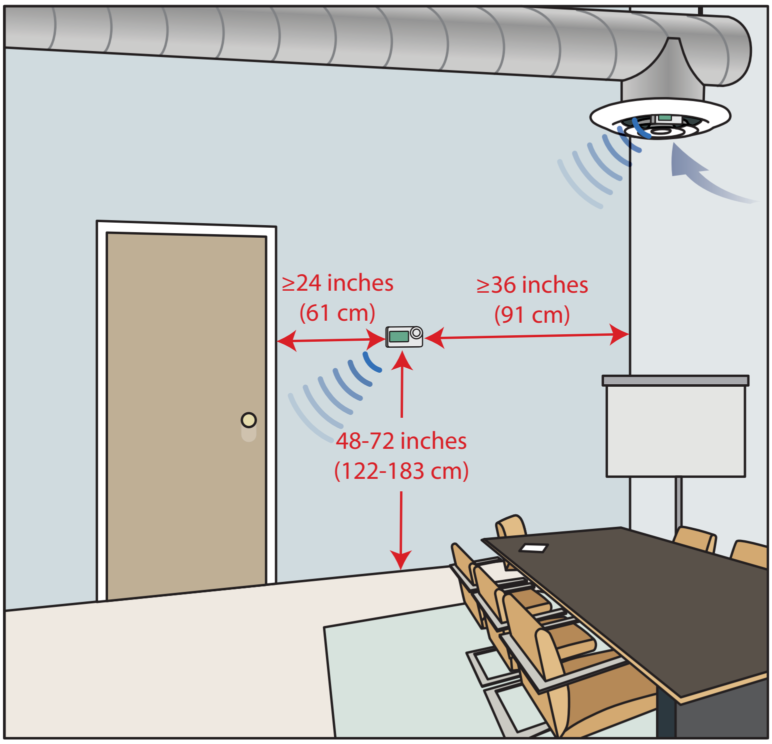


Figure 5. Typical IAQ $CO_2$ data logger mounting locations.

| Summary of $CO_2$ Logger Mounting Recommendations [45-47] |
|---|
| • 48-72 inches (122-183 cm) above floor for IAQ measurements near return-air duct if possible |
| • 12-18 inches (30-45 cm) from floor for compressed $CO_2$ storage applications |
| • ≥36 inches (91 cm) from any corner |
| • ≥ 24 inches (61 cm) from any open doorway |
| Do not mount in these locations: |
| • Interior side of exterior walls |
| • Near fixed or operable windows |
| • In areas with poor circulation, such as behind doors or alcoves |
| • Near combustion equipment |
| • Areas exposed to direct breathing, such as near water coolers or coffee machines |

Table 6. Recommended $CO_2$ logger mounting tips. Adapted from [45-47].

**$CO_2$ data loggers provide a cost-effective method to assess indoor air quality, helping to eliminate sick-building syndrome and harmful pollutants typical of tight and poorly ventilated structures.**

## Conclusion

$CO_2$ concentration is a key indicator of indoor-air quality and ventilation effectiveness in offices, schools, healthcare facilities, dwellings, and any enclosed space subject to variable occupancy. Elevated $CO_2$ more than 600-700 ppm above outdoor levels warrants special focus on ventilation function and emission sources. Although many existing global standards stipulate maximum daily average exposure limits up to 5,000 ppm, research shows that cognitive impairment and perception of poor air quality commence at 1,000 ppm (absolute), or 600-700 ppm (differential) over outside levels. Keeping $CO_2$ levels in check typically helps to reduce other pollutants due to engineering focus on improved ventilation.

Facility managers and building engineers have a responsibility to ensure compliance with all laws, as well as commitment to recommended best practices, which frequently go well beyond minimum requirements set forth in building codes and ventilation standards.

When selecting a $CO_2$ logger, evaluate overall specifications, as well as wireless compatibility with Bluetooth-enabled mobile devices, integrated display and alarms, long battery life, flexible USB connectivity, and automatic and manual calibration modes. Quality $CO_2$ data loggers provide a cost-effective method to assess indoor $CO_2$ concentration levels, helping to eliminate sick-building syndrome and harmful pollutants typical of tight and poorly ventilated structures.

## References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## About Onset

Onset is a leading supplier of data logger and monitoring solutions used to measure, record and manage data for improving the environment and preserving the quality of temperature-sensitive products. Based on Cape Cod, Massachusetts, Onset has been designing and manufacturing its products on site since the company's founding in 1981.


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## Other informational resources available from Onset:

### Choosing a Temperature Data Logger

This paper provides guidance on features to consider when choosing a temperature data logger, including accuracy requirements, data access needs, software packages, and power requirements. It also includes real-world application examples illustrating how users have incorporated portable data loggers into their temperature monitoring projects.

Whether you are an experienced data logger user or just getting started, this guide can help you choose the ideal temperature logger for your application.

### Choosing an Occupancy and Light On/Off Data Logger – 5 Important Considerations

This paper provides guidance on features to consider when choosing an occupancy and light on/off data logger, including calibration, LCD display, logger accuracy and range, speed of deployment, and time-saving software. Learn how to select the right logger for identifying ideal locations in your building where changes in lighting could result in cost savings up to 80%.

### Utility Incentive Programs: How to Get More Money Quickly and Easily

"Utility Incentive Programs: How to Get More Money Quickly and Easily," is aimed at making the process of applying for and receiving energy efficiency incentives and rebates faster, easier, and more rewarding. Authored by Carbon Lighthouse, an energy firm that makes it profitable for commercial and industrial buildings to eliminate their carbon footprint, the paper discusses the two main types of incentive and rebate programs, how utility efficiency program managers think, and how to use data to get more incentive dollars for your projects.

### Using Data Loggers to Improve Chilled Water Plant Efficiency

Chilled water plant efficiency refers to the total electrical energy it takes to produce and distribute a ton (12,000 BTU) of cooling. System design, water quality, maintenance routines, cooling tower design, and cooling coil load all affect chiller water plant efficiency and the expense of operating the system.

### Facility Manager's Guide to Data Logging

The energy required to operate buildings in the United States is the largest sector of our energy use and represents about 40% of U.S. energy demand. Measuring building performance can help facility staff better manage this energy use. The focus of this best practices guide is on monitoring strategies and techniques that can be utilized by building professionals looking to reduce energy use and optimize performance of their facilities.

### Data Logger Basics

In today's data-driven world of satellite uplinks, wireless networks, and the Internet, it is common to hear the terms "data logging" and "data loggers" and not really have a firm grasp of what they are.

Most people have a vague idea that data logging involves electronically collecting information about the status of something in the environment, such as temperature, relative humidity, or energy use. They're right, but that's just a small view of what data logging is.

### Monitoring Green Roof Performance with Weather Stations

Data logging weather stations are the ideal tools for documenting green roof performance. A weather station can measure weather parameters such as rainfall, stormwater runoff, temperature, relative humidity, wind speed, solar radiation, and a host of non-weather parameters such as soil moisture on a continuous basis (say every five minutes, hourly, or an interval appropriate to the situation).

### Addressing Comfort Complaints With Data Loggers

This paper offers facility managers, HVAC contractors, and others with valuable tips on how low-cost data loggers can be used to validate temperature-related comfort complaints.

### Using Data Loggers Beyond Equipment Scheduling

While data loggers are a great tool for identifying equipment-scheduling opportunities in buildings, their usefulness far exceeds just that one function. This paper discusses how the use of inexpensive data loggers and some spreadsheet analysis can provide all the evidence needed to make powerful building-specific cases for saving money by replacing failed air-handler economizers. It also describes how information from data loggers can be used to accurately calculate the energy savings that can be realized from variable frequency drives (VFDs) on pumps and fans, supply air resets, and boiler lockouts.

### Analyzing Air Handling Unit Efficiency with Data Loggers

Operating a heating, ventilation and air conditioning (HVAC) system at optimum efficiency in a commercial setting is complicated, to say the least. There is a very real chance that any number of setpoints, levels, and feedbacks at boilers, chillers, pumps, fans, air delivery components and more can cause costly inefficiencies.

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 Lit. No. MKT1184-0117