Championing the Changemakers in Sustainable Design & Building

BuildingGreen

Considerations for Continuous Air Quality Monitoring:

Simple tips for getting it right, according to IAQ consultants

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Contributors

This whitepaper was developed primarily by design professionals in the Sustainability Leaders Peer Networks facilitated by BuildingGreen, Inc. The following individuals took a leading role in drafting and reviewing this whitepaper (in alphabetical order):

Michelle Amt – *VMDO*

Kena David – *BCCI Construction*

Sarah Gudeman – *Morrissey Engineering*

Meredith Hendricks – *Entegrity Partners*

Luke Leung – *SOM*

John Mlade – *Wight & Company*

Ashley Mulhall – *OWP*

Jim Newman – *Linnean Solutions*

Candace Pearson – *BuildingGreen*

Kim Shinn – *TLC Engineering*

Special thanks to our reviewers: Shona O'Dea and Josh Roth.

About BuildingGreen

BuildingGreen, Inc. is a consultancy and information company trusted by thousands of AEC professionals for insight and guidance on sustainable design, resilience, and health in buildings and communities. BuildingGreen also supports and facilitates peer networks for sustainability leaders interested in learning from each other and launching initiatives, including this whitepaper.

About BuildingGreen Peer Networks

BuildingGreen's Peer Networks offer shared space where leaders support one another and work together toward sustainable solutions as a community -- intent on moving projects, the industry, and the world forward in the best possible way. We recognize the need and value in transcending competition as we work together, professionally and collectively, to advance our common cause, with a shared commitment to collaboration and improvement.

Introduction

In recent years, Indoor Air Quality (IAQ) has emerged as a leading consideration for building design, construction, and operations. Worsening air pollution, record setting forest fires, the global Covid-19 pandemic, and increased awareness about the lack of ventilation in existing buildings, have all prompted the industry to respond in kind.

There are now a variety of ways to evaluate indoor air quality: occupant surveys, point-in-time laboratory air quality testing, and continuous air quality monitoring devices. Each of these methods are valuable tools to meet building operator needs. Continuous air quality monitoring in particular has become much more accessible, seen robust uptake, and continues to grow and evolve.

Leading building certification systems, including LEED, WELL, and RESET have driven adoption of continuous air quality monitoring. There are also many projects that have chosen to deploy continuous monitoring to a lesser extent, with far fewer sensors than required by these certifications. This is especially true for those who may not have control over their base building HVAC, but still have a desire to understand their indoor environment. In both situations, the authors of this report noticed that quick-changing technology, installation or placement mistakes, and complex output data has sometimes hampered users from fully leveraging continuous air quality monitoring.

This report summarizes the basic considerations that building practitioners take into account when advising clients on implementing continuous IAQ monitoring. Our aim is to make this technology more accessible to more projects in less time, regardless of whether a building certification is being pursued.

Evaluating Indoor Air Quality: Survey vs Testing vs Monitoring

The dynamic variability of mechanical ventilation and the and imprecise science of potential contaminants make it difficult to define and quantify "good air" in buildings. Coupled with the lack of consensus on industry-wide indoor air standards, understanding air quality can be fraught with ambiguity. To provide context and multiple data points, occupant surveys, direct point-in-time IAQ testing, and continuous air quality monitoring can all be used by building operators to better understand IAQ and improve outcomes.

Survey Resources

A fairly easy and inexpensive way to collect building IAQ information is to survey building occupants about their perception of the indoor air. Occupants are often first to notice unpleasant odors or stuffiness, which are indicators of poor IAQ. For most building operators, occupants are the primary customer to satisfy, making surveys a viable option. Survey results from a sufficient number of occupants can provide valuable insight into IAQ conditions and prompt the operator to conduct additional tests as needed. A 25-50% survey response rate from occupants is considered a good benchmark.

One downside to occupant surveys is that it is difficult to ascertain whether occupant satisfaction is attributable to good air quality or other enhancements like air movement (fans), quality daylight, office perks, etc[1]. When asked about air, thermal comfort (temperature and humidity) is generally occupants' primary concern. Nonetheless, high quality survey results can provide insight into excessive humidity, stale air, mold, and odors, all of which should garner further investigation and may result in corrective action. Other indicators of poor air quality can be headaches, illness, or lethargy, though these effects are uncommon and even harder to correlate to air quality.

1 Graham, L. T. (2021, March 17). Lessons learned from 20 years of the CBE occupant survey. Center for the Built Environment. Retrieved February 23, 2022, from https://cbe.berkeley.edu/centerline/lessons-learned-from-20-years-of-cbe-occupant-surveys/

Summary: Pros and Cons of Surveys

PROS	CONS
Inexpensive way to collect data	Occupants might not be able to distinguish air quality from other indoor environmental conditions
Can help target further testing or monitoring	Seasonal variation in air quality may necessitate additional surveys

IAQ Testing

IAQ testing is a point-in-time measurement of the air. It relies on either on-site measurements using specifically calibrated equipment, sending air samples to a laboratory for analysis, or active sampling of air on-site with media analyzed by a laboratory—all of which are considered to have scientific grade accuracy. The laboratory equipment used to evaluate air quality samples and handheld calibrated devices used for on-site measuring are superior to the continuous IAQ monitors available on the market today. They provide more accurate accounting of a broader range of specific contaminants, such as component VOCs or microbiological components of bacteria, mold, fungi, or viruses. The applicable laboratory test will depend both on the types of contaminants being evaluated and the relevant standard on process (ISO standards, or EPA compendium of methods, for example). These standards address the appropriate number, location, and frequency of sampling. Importantly, the project must determine which contaminants or compounds to test for ahead of time, as this dictates the test methods, the amount of time needed, and the pricing. Leading green building standards and frameworks offer guidance on conducting this kind of IAQ testing.

Summary: Pros and Con of IAQ Testing

PROS	CONS
Most accurate accounting of point-in-time contaminants	Expensive
Measures the broadest range of contaminants	Requires frequent testing to understand trends over time
	Usually requires third party consultant

Continuous IAQ Monitoring

With continuous IAQ monitoring, measurements are usually taken every minute by a smart device that feeds data to the cloud. Monitors containing multiple IAQ sensors are installed in a space, enabling regular measurements of contaminants over time.

Compared to IAQ testing, continuous IAQ monitoring has a limited profile of contaminants that can be measured. The indicators that are typically measured are temperature, relative humidity, particulate matter (usually PM 2.5), carbon dioxide (CO2), and total volatile organic compounds (TVOC), although options for other sensors are emerging.

By taking measurements repeatedly over time, continuous air quality monitors are able to reveal trends, which can help identify IAQ issues and causes. They can also be configured to work with the building automation system (BAS) and mechanical HVAC systems. Some monitors can be configured to provide IAQ data to occupants on a real time basis, thereby engendering trust and fostering transparency. It is worth noting that results are most valuable as a comparative metric, and not necessarily a quantitative one.

Summary: Pros and Cons of IAQ Monitoring

PROS	CONS
Inexpensively identify trends in IAQ	Limited profile of contaminants
Ability to work in tandem with mechanical systems	Less accurate than lab testing
Report data easily to occupants	Constantly evolving technology

Continuous Monitoring in Rating Systems and Certifications

Building rating systems or certifications provide good frameworks for continuously monitoring indoor air quality for your project. Even without pursuing certification, these programs can offer guidance on acceptable contaminant levels. However, there are major differences between programs, and the monitoring requirements might be out of reach for some projects.

Number of contaminants

The first major difference between frameworks are the contaminants that must be monitored. RESET Air requires continuous air monitoring of particulate matter (PM2.5), total volatile organic compounds (TVOC), carbon dioxide (CO2), temperature and relative humidity. In contrast, the WELL Building Standard allows you to choose three of seven allowable pollutants to monitor – PM 2.5 or PM 10, carbon dioxide, carbon monoxide, ozone, nitrogen dioxide, TVOC's, or formaldehyde. While a wider array of pollutants are available for monitoring in WELL, nitrogen dioxide is not generally considered an indoor air contaminant, and there is limited ability to continuously monitor formaldehyde. LEED for Existing buildings, via the ARC performance pathway certification, requires testing for only TVOC and CO2 (at this time).

Number of monitors

The second major difference is the number of monitors that are required for a given space. WELL requires one monitor for every 3,500 sf of occupiable space, whereas RESET requires one for every 500 square meters (5,382 sf). However, the RESET requirement may vary based on the number of occupants, number and types of spaces, and level of certification desired.

While many monitors provides robust data reporting, the initial cost and abundance of data may overwhelm and dissuade some clients from working to meet the associated requirement. LEED for Existing buildings (v4 EB: O+M) offers a much lower entry point, requiring annual indoor air quality testing at one location for every 25,000 sf of building. The ARC performance pathway requires a single measurement of CO2 and TVOC in locations representative of occupied spaces. Both EB: O+M and ARC don't require continuous monitoring at all, as such data could be obtained through yearly testing, though these requirements may change over time.

Choosing a Monitoring System

Regardless of whether a certification or rating system is pursued, choosing a monitoring system is a complex decision. This section offers some best practices for comparing options and picking your monitor.

Measurement parameters

When evaluating continuous monitoring of IAQ for a building or space, there are many brands of monitors on the market to consider. Some of the leading manufacturers include Airthings, Arbnco, Awair, Kaiterra, Senseware, Wynd, Tongdy, and others. Since COVID-19, there are an increasing number of IAQ sensors on the market each day. Most of them measure for temperature, relative humidity, CO2, PM2.5, and TVOC with pre-calibrated sensors. Some also measure more general indoor environmental quality parameters such as occupancy, noise, light levels, or other IAQ metrics like PM10, CO, or radon. Some devices also claim the ability to estimate microbials or viral risk, which they infer using other parameters such as PM1.0 or PM2.5 as a proxy. Caution should be taken when reviewing technologies that make such claims. Best practice is to select a monitor from the RESET Accredited Monitor List, Grade B, as these devices have been tested and confirmed to a base level of reliability and accuracy.

Power and data storage

Most monitors are supplied with a plug and cord and can be deployed anywhere with an electric outlet. Others allow for direct-wiring or power over ethernet (PoE). Some also include battery backup or stand-alone battery power options. Some certifications may require hard-wired devices so that they aren't inadvertently unplugged, causing data loss.

The purpose of cloud applications is to gather a dataset over a long period of time, observe trends, and provide actionable trends to operators and occupants. If the monitor loses power or stops feeding to the cloud because of a connectivity issue, there is a risk of losing part of a dataset forever. Worse yet, the project could fail to certify if it is pursuing a performance-based standard. There are many causes for these types of failures. Some are as simple as someone unplugging a device, a power outage, changing a WiFi password, or modification of service IP address. Whatever the reason, the impact can be significant and, in some cases, cause an organization to miss their monitoring goals.

To prevent loss of data, select monitors with:

- **In-Unit Memory** – Some monitors have data logger capabilities so they can continue to gather and store IAQ data. Even if the monitor loses connection with the cloud, it still populates the database when connectivity is restored. This type of unit can also be used for applications when connecting to a network is not allowed due to security reasons.
- **Power** – Most monitors powered by line voltage or PoE, are likely not available with battery powered option. However, some monitors come with a backup battery as a stopgap measure if the device loses power for a short period of time. This has been a valuable backup option when power is lost. More battery-powered options are likely to appear on the market in the future.

Some cloud applications require a monthly or annual subscription. If device storage is utilized or displays are read manually, results would need to be carefully recorded at consistent intervals in order to identify trends over time.

Calibration schedules

When sensors go out of calibration, they start to report inaccurate measurements. This “sensor drift,” or the time taken for the sensor to go out of calibration, depends on what is being measured. For instance, a CO2 sensor may have a lifetime of 15 years while a TVOC sensor needs calibration every year. When a sensor is out of calibration, there is a risk of reporting a problem that may not exist, so it is paramount to consider your recalibration plan even before purchasing your device.

When dealing with a monitor that includes multiples sensors, the following are the most common recalibration options:

- **Factory Recalibration** – This involves sending the monitor back to the factory for cleaning and recalibration. This option is costly as it would involve removing installed devices from wall mountings, paying a professional to tie off the power source, and shipping the device back and forth (likely to China), not to mention the risk of import/export duty. If this is the only option for your device, it likely will be more economical to simply replace the device with the newer model, prompting sustainability concerns.

- **Remote Calibration** - Many manufacturers will offer the option of remote calibration, which removes the inconvenience of shipping the monitor back to the manufacturer. This involves applying a compensation factor to the drifted sensed data, which will bring the data artificially back to the correct range. In these cases, the device’s inner workings may be dirty and the sensor may be picking up inaccurate readings. This is a low-cost or no-cost solution, but not a long term one.

- **Automatic Recalibration** – Some devices automatically recalibrate based on historical sensed data, which sounds great in theory but can artificially disregard a progressive build-up of toxins by identifying it as a calibration issue.

- **Modular Sensors** – The best-case scenario is to be able to replace each sensor in the necessary frequency. Some newer monitors offer the ability to replace sensors in a modular way like the ink in a printer. This does mean moving parts around and inserting and removing sensors, which has a risk associated with it, but it produces the best results. It is recommended to replace the same kind of sensor in all monitors at the same time to ensure they remain of the same vintage. Otherwise, based on the rapid evolution of sensor technology, you may wind up with different sensors in your monitors, which will skew the data when comparing it.

Monitor Placement

Getting useful information from continuous air quality monitors depends on the quality of the data collected. Low quality monitors or monitors that collect the wrong data reduce the quality of the data. Similarly, poorly placed monitors can have a negative effect on data quality. Thus, placement and installation are critical.

Key placement concepts

Monitor placement should reflect the occupants' experience of indoor air quality or help monitor potentially problematic areas. Installed wall-mounted monitors should be placed:

- in the "Breathing zone," 3 to 6 feet above the floor; (Some manufacturers have combined IAQ sensors with occupancy sensors, which are installed on the ceiling. This is not recommended.)
- in areas of highest occupant density;
- away from air vents or diffusers, and potentially near air returns/exhaust to sample the dirtiest air;
- ar from filtration in centralized systems;
- in alignment with thermal hvac zones, in order to identify and help fix hvac-based issues;
- near to contaminant sources, like printers, chemical storage, other contaminants from activities in the space;
- near combustion appliances, to monitor for CO;

For deployments at scale in existing buildings, existing CAD or REVIT drawings might not exist, digitizing a PDF plan might be cost prohibitive, and provided floor plans might not be up to date. This makes integrated sensor deployment very difficult. In such cases, consider providing training to the hardware integrators/installers to help them understand how to make on-site location changes as necessary and require the person who designed the system to be on-call or on-site.

Further placement requirements

Monitor placement requirements for RESET Air Certification and WELL Certification further define monitor placement in order to support the collection of high-quality data. Air quality monitoring that is built into a Building Automation System for the purpose of controlling ventilation will also have more stringent placement requirements based on system control needs.

Practical Considerations

There are also some practical considerations for monitor placement that are worth considering. Monitors can fail, get dirty, or require setting adjustments. Placing monitors somewhere accessible to facilitate easy replacement, repair, or cleaning is useful, but be aware of the potential for theft or vandalism. A number of specific brands of monitors need to be plugged into a receptacle, which might constrain placement. As a general approach, try to pick locations that are densely occupied and away from air supplies, doors and windows, in order to get an accurate understanding of the quality of air that most occupants are breathing.

Integration with Building Automation Systems (BAS)

Connecting temperature, carbon dioxide, occupancy, or relative humidity sensors to the BAS is a well-established practice for HVAC control. CO2 sensors for demand-controlled ventilation (DCV) are particularly common in intermittently occupied spaces, such as conference or training rooms where DCV is required by many energy codes. In this control scheme, sensors measure carbon dioxide concentrations, and the BAS system uses that information to modulate the outside airflow into the air handling system. When CO2 rises, the outside airflow increases to provide demand-controlled ventilation and dilute indoor contaminants. Conversely, falling CO2 levels (an indicator of decreased occupancy) trigger a reduction in outside airflow to save the energy associated with conditioning this fresh air. BAS providers such as Trane, Siemens, or Johnson Controls commonly provide such control systems and typically prefer to use their own devices. Connecting independent IAQ monitors or associated sensors to a BAS is a moderately expensive endeavor and not yet widely adopted.

In contrast, integration for parameters such as TVOC and PM is not common, though it may be an area ripe for future exploration and development with significant coordination between mechanical and electrical professionals. ASHRAE Standard 62.1 Indoor Air Quality Procedure (IAQP) allows for the control of specific contaminants to establish total air changes and outside air flow rates in addition to the much more commonly-used Ventilation Rate Procedure (VRP). The IAQP requires building operators and designers to define the contaminants of concern and their emission rates to determine the dilution ventilation rates required to keep those contaminants under established thresholds. It allows the system to dynamically control the ventilation dilution—increasing airflow when contaminant concentrations increase and decreasing dilution when the concentrations fall. The LEED pilot credit for performance-based IAQ[2] is a helpful guide for the application of the IAQP, and new addenda to Standard 62.1—to be issued in 2022—will provide additional guidance on selection of contaminants to design and monitor.

However, the IAQP is not widely applied for several reasons:

- Defining contaminants of concern is usually the job of industrial hygienists and health professionals, so HVAC designers are hesitant to make these determinations.
- The emission rates of these contaminants tend to be dependent on many factors that are not well established prior to space occupancy and use.
- There is not a wide range of sensors that reliability measure all contaminants of concern. For example, there is no automated sensor for holistic airborne microbial contaminants. Sensors with enough accuracy, repeatability, and stability for use in an automated control system tend to be expensive.

2 Graham, L. T. (2021, March 17). Lessons learned from 20 years of the CBE occupant survey. Center for the Built Environment. Retrieved February 23, 2022, from https://cbe.berkeley.edu/centerline/lessons-learned-from-20-years-of-cbe-occupant-surveys/

- There is not currently widespread agreement on what constitutes acceptable calibration for IAQ sensors or devices in continuous operation.
- The prescriptive Ventilation Rate Procedure in Standard 62.1 provides designers and building operators with liability protection, while the IAQP does not.

Connecting to BAS for continuous monitoring, not control

Even if sensors are not being used to sequence HVAC control, it is reasonable to connect them to the BAS to record indoor air quality parameters. Building operators can then use this information to identify manual interventions. For instance, a particulate matter sensor could be employed to check whether the ventilation system is properly operating. An increase of PM2.5 above a certain threshold should prompt the operator to investigate the source of the PM2.5 and determine a filtration strategy to reduce the concentrations.

There is also a specialized submarket for application-specific integrated IAQ control systems, which are often separate from the BAS, but may be integrated with the BAS for supervisory monitoring. Automated control is located within the hardware of the local controllers. A typical example is a laboratory or clean room that has specific sensors for pressurization and/or contaminants of concern for that particular setting. These systems and sensors are very expensive, in the range of tens and hundreds of thousands of dollars, and require sophisticated maintenance and operating personnel. Examples of vendors for these systems are Phoenix Controls or Aircuity.

Leveraging the Data

Depending on the type of continuous air quality monitor used, air quality data is typically represented by “good, better, best” levels or associated color schemes. This makes it easier for building occupants to quickly view and understand the relative air quality in the space. Many devices also have a screen with a dashboard that is accessible to occupants. An administrator may have rights to view additional data via the dashboard or a web interface. In all known cases, data can be downloaded to a spreadsheet for further evaluation or commissioning.

Dashboards make the data easier to visualize to identify patterns and trends, and some services do IAQ analysis for you. Frequently, it is easiest to review data as presented on a dashboard to identify high level concerns, and then analyze detailed data on a spreadsheet.

Regular Patterns

Like energy use, some air quality parameters develop regular patterns based on building use and operations. For example, CO2 may increase in the morning as employees enter, then level out as the level of CO2 triggers additional ventilation from the mechanical system. In the evening, as employees depart the building, the CO2 level may drop.

In evaluating these trends, it is important to understand how the mechanical system works. When possible, it is useful to overlay mechanical system operational data over the air quality data to identify ways to improve air quality. For example, if a nighttime setback of the mechanical system was programmed incorrectly and is shutting the mechanical system down before employees left the space, it would be reasonable to see CO2 levels rise. Such patterns, whether due to mechanical system programming or occupancy trends, should be readily identifiable through review of the data and can offer considerable insight into air quality performance.

Spikes and persistently high levels

For other parameters, such as TVOCs, there may be temporary spikes in values that are short-lived. Such spikes are likely due to a temporary condition such as a cleaning crew using strong-smelling cleaning agents or an occupant using a heavy dose of personal care product. With new furniture, furnishings, paints, coatings, sealants, or other newly installed high-VOC emitting products, the VOC values may trend at an elevated level and follow the mechanical system’s ventilation rate, but will normalize after days or weeks. This is because many of the TVOCs are being flushed out of the space through mechanical exhaust or otherwise diluted through air mixing when the ventilation system is turned up. When the mechanical system is turned down, these functions cease and the products continue to emit, increasing the associated TVOC levels in the space.

Persistently high TVOC levels are likely due to inadequate ventilation or a persistent source of VOCs, such as a high-volume copy machine, improperly stored cleaning products, or entrainment of outdoor pollutants. While the mechanical system will help reduce the concentration of many contaminants, it should not be relied on as the sole method of improving air quality. The underlying sources of contaminants should be addressed so that the mechanical system can operate efficiently to provide both good air quality and reduce energy demands. Controlling the source of indoor pollutants is always preferable to relying upon a mechanical system to ventilate it out of the occupied space. Such steps might include updating the cleaning contract to use only green cleaning products and ensuring exterior contaminants from loading docks or outdoor smoking areas are not circulated through the building.

Elevated levels of CO are likely due to either incomplete combustion or entrainment of CO through the air intakes. Whenever possible, remove indoor combustion sources, including gas powered: cooktops, appliances, and mechanical equipment. Otherwise, ensure they are properly ventilated and provided adequate air for combustion.

Limitations

It is important to remember that current indoor air quality monitor technologies do not identify specific VOCs, mold/mildew, or outdoor air contaminants such as NOx/SOx. More detailed indoor air quality contaminant assessments can be attained through air sampling and laboratory testing. Such steps may be necessary to identify specific contaminants and associated sources if corrective action based on the continuous air quality monitor data analysis is not effective. In addition, visual inspections for water intrusion, leaks, cooling coil condensation, mold, mildew, and pests is an important for maintaining good indoor air quality.

Conclusions

Continuous air quality monitoring has revealed significant insights about the connection between air quality and human health and cognitive function. It has allowed building operators to see trends, diagnose malfunctions, and identify potential emission sources, all leading to improved indoor air for occupants. With a basic understanding of what to consider when selecting monitors, where to place them, and how to use the data, nearly every project can use this tool to improve indoor air quality.

Key references

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RESET AIR Standard: https://www.reset.build/standard/air

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WELL AQ Monitoring/Awareness: https://v2.wellcertified.com/wellv2/en/air/feature/8

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BuildingGreen, Inc.
122 Birge Street, Suite 30
Brattleboro, VT 05301

www.buildinggreen.com

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