Tools & Techniques

Carbon Dioxide: Still an Issue — Still Often Misunderstood

One significant feature of the seemingly defunct revision to ASHRAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality*, was that 62-89R would have removed the now-famous reference to a target level of carbon dioxide (CO_2) for buildings.

Many people mistakenly consider the 1,000 parts per million (ppm) cutoff level as an indication of whether or not a particular building complies with the standard and whether or not the air quality is acceptable. Now that Standard 62-89 has moved into "continuous maintenance" and the proposed revision is on the shelf, if not in the wastebasket, we may continue to see too heavy a reliance on CO_2 concentrations in building investigations.

Andy Persily of the US National Institute of Standards and Technology (NIST) has written an excellent paper on the uses and misuses of CO_2. That document, along with another on demand controlled ventilation (DCV) by Persily and his colleague Steven Emmerich, provides a solid background for anyone unclear on the issue. The papers can be found in *ASHRAE Transactions 1997*, Vol. 103, Part 2.

IEQS spoke with Persily about the paper and about CO_2, and he told us that the papers contained nothing revolutionary, but were simply an attempt to bring together in one place a lot of information that's already known about CO_2 and what it means for building air quality.

In addition to its role in DCV, in which the HVAC systems responds to changes in CO_2 levels to bring in more or less outdoor air (O/A), CO_2 can also be used:

- To measure whether indoor air is acceptable in terms of body odor;
- To assess building ventilation rates: through tracer-gas decay, equilibrium analysis, or mass balance analysis; and
- For continuous measurement as a building diagnostic tool.

Acceptable Air Quality

When using CO_2 to determine acceptable air quality, the only bona fide use is as a measure of whether the air in a space will be acceptable in terms of body odor to visitors to the space. Various experiments have shown a direct correlation between CO_2 concentrations and acceptable air quality from a sensory viewpoint.

The acceptability follows a curve, and researchers have determined that 80% of visitors to a space will find the odor of the air acceptable when the CO_2 concentration is 650 ppm, or less, above the O/A concentration. This translates to about 1,000 ppm, and is the basis for the misunderstood ASHRAE target level.

Whether or not the 1,000 ppm level will provide good air quality in general is a much more complicated question. Because the CO_2 concentration reflects only the "people" component of indoor air — the pollution component generated by occupants — it says nothing about pollutants generated by such things as material emissions, carbon monoxide that may be infiltrating the building, or various contaminants generated by occupant activities.

As Persily says in his paper, "If other contaminants are generated at a rate that also depends on the occupancy level in the space, then carbon dioxide may be a good indicator of the concentrations of these contaminants. However, only some contaminants are generated at a rate that depends on occupancy, and many contaminant sources are not a function of occupancy at all."

This has several ramifications. If occupant-independent pollutant generation is low, then elevated CO_2 concentrations will not necessarily mean poor IAQ. The only outcome will be an excess of body odor, perhaps, but the air will be free from harmful contaminants.

In a space where there are significant nonodorous contaminants and low-occupant density, CO_2 concentrations are likely to be extremely low and the air might seem acceptable from a sensory perspective. But, the air might contain high concentrations of harmful contaminants — something that would not be detected by simply measuring CO_2 concentrations.

We continue to see case studies in which investigators rely heavily on CO_2 measurements as an absolute indicator of IAQ. We even see cases in which investigators measure the CO_2 concentrations in an unoccupied building and eventually declare the building acceptable because they find low levels.

Assessing Building Ventilation

Investigators can use CO_2 concentrations in various ways to evaluate building ventilation. Among these are: using CO_2 to determine the percent of O/A being brought in at the air handler, using CO_2 as a tracer gas and measuring its decay rate to determine air change rate, and using equilibrium analysis to determine air exchange rate.

To measure the percent of O/A at the air handler, someone would have to measure CO_2 in the recirculation airstream (C_r), in the supply airstream (C_s), and in the outdoor air (C_{out}), and then use the following formula:

$$\% \text{ OA} = \frac{100 \times (C_r - C_s)}{(C_r - C_{out})}$$

This approach involves several caveats. While minor temporal variations aren't a problem, measurements should be taken within 10 minutes of each other. A more important consideration is that this will only show how much O/A is coming in at the air handler. It says nothing about how much O/A is reaching the breathing zone in any particular part of the building. This will depend on ventilation effectiveness and mixing within the space.

Tracer Gas Method

One method to measure air change rates in a building is to use a tracer gas, and CO_2 can serve as a convenient tracer gas for the purposes of ASTM Standard E741, which covers this sort of measurement.

By releasing a tracer gas into a building and then measuring how long it takes to decay, an investigator can calculate how much O/A is entering the building. This relies on several assumptions. The most important of these is that there is no other source of the gas in the building. When using CO_2 as the tracer gas, it's important to account for occupants still in the building. These occupants may be adding CO_2 to the air, potentially skewing results.

In any large building, it will take some time for all occupants to leave. Also, the ASTM method requires no outdoor sources of the tracer gas, meaning that anyone who wants to use CO_2 needs to account for the outdoor concentrations, and will have to use the difference between the indoor and outdoor concentrations in the formulas.

Equilibrium Analysis

CO_2 can be used in what is known as the "constant injection" tracer gas technique, which is also known as equilibrium analysis. When used with another tracer gas, the method involves injecting tracer gas into a single-zone space at a known constant rate. An investigator can calculate the average O/A flow rate into the space using the average concentration and the tracer gas injection rate.

However, the method involves several important considerations. Among these:

- The zone under investigation must act as a single zone;
- Tracer gas concentrations at different locations can differ by more than 10%;
- The zone being tested must be isolated from other building areas;
- The carbon dioxide generation rate must be constant and known;
- Outdoor CO_2 concentrations must be measured and known;
- The O/A ventilation rate must be constant; and
- The indoor CO2 concentration must be at equilibrium.

In other words, these and similar methods are useful only when the investigator follows the protocol exactly. Not to do so will result in inaccurate figures. This was the case in some published research in which the investigators claimed to report how increasing ventilation rates had no effect in IAQ. However, as Persily points out, the researchers did not follow the procedure properly and estimated O/A exchange rates that could have been significantly higher than the actual rates.

DCV

Many people want to use CO_2 monitoring for demand-controlled ventilation — where sensors measure CO_2 concentrations and adjust O/A rates to account for variable occupancy. Persily tells ***IEQS*** that this technique has great promise of remarkable energy savings while maintaining acceptable IAQ, but only under certain conditions.

The most likely candidates for DCV systems are buildings in which designers can expect unpredictable variations in occupancy. These conditions would most likely be found in classrooms, auditoriums, theaters, courthouses, etc.

Another desirable characteristic is that the building have low pollutant emissions from nonoccupant sources. In a large, sparsely populated space, for example, the CO_2 would rarely reach a high enough concentration to trigger an increase in O/A. But, if nonoccupant sources were emitting large amounts of pollutants, the air quality could deteriorate significantly.

Ways around this include regular purges with O/A to remove nonoccupant generated pollutants from the space.

For more information, contact Andy Persily, NIST, Building and Fire Research Laboratory, Gaithersburg, MD 20899; (301) 975-6418, E-mail: andyp@nist.gov.

Humidity Software Provides Convenient Calculation Tools

Indoor Humidity Tools, a new Windows-based software program from Taitem Engineering (Spencer, New York), developer of IAQ Tools, allows engineers, industrial hygienists, and others concerned about the indoor environment easy access to online calculations for a wide variety of tasks involving humidity in indoor environments.

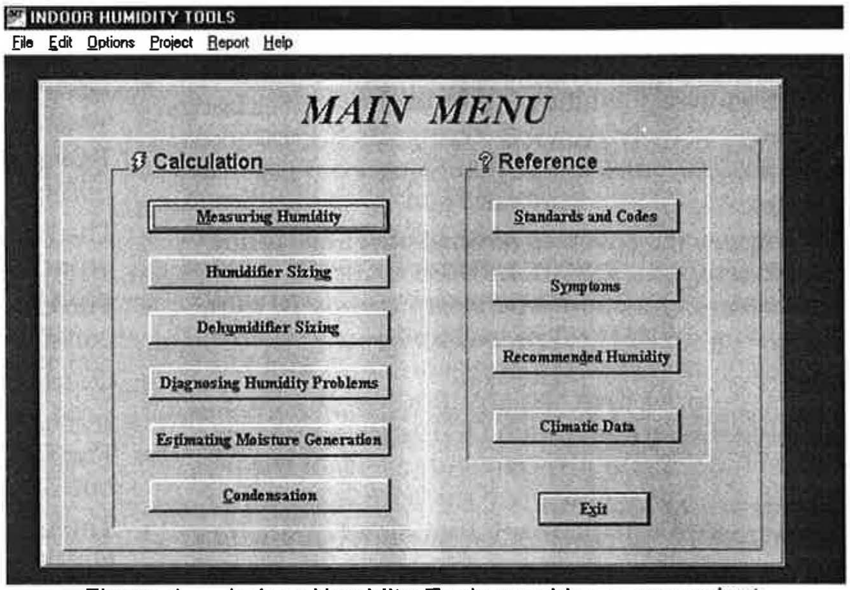

Figure 1 — Indoor Humidity Tools provides a convenient graphical interface for solving humidity calculations.

Developed for Windows 95, Windows NT, or Windows 3.x, Indoor Humidity Tools:

- Diagnoses indoor humidity conditions;
- Develops moisture generation rates for different activities, and estimates generation rates from indoor measurements;
- Diagnoses condensation problems;
- Sizes humidifiers and dehumidifiers in order to meet required indoor humidity conditions; and
- Calculates relative humidity from temperature measurements.

The package also provides data on the relationship between humidity and various health symptoms and material deterioration, and allows users to look up humidity standards and recommended humidity conditions. Users can also incorporate any calculations in a report, using the report generator.

The price of Indoor Humidity Tools is $495, or it can be purchased along with IAQ Tools as a package for $740. For more information, contact Carolyn Licata, Cutter Information Corp.; (800) 964-5118 or (781) 641-5118, Fax: (800) 888-1816 or (781) 648-1950, E-mail: clicata@cutter.com.

Harvard Researchers Develop Small Active Ozone Sampler

Researchers at the Harvard School of Public Health (Boston, Massachusetts) have developed a small, active ozone sampler that they say is accurate under both laboratory and ambient conditions. Alison S. Geyh and the other researchers reported the new device in a recent issue of *Environmental Science and Technology* ("Development and Evaluation of a Small Active Ozone Sampler," *ES&T*, Vol. 31, No. 8, 1997, pp. 2326-2330).

The idea behind the sampler is that while ozone is recognized to be a respiratory irritant, personal exposure is difficult to characterize. Usually, researchers depend on data collected at stations that monitor outdoor concentrations and the researchers assume that those concentrations are uniform over a large area. Models used to predict indoor concentrations lack validation and usually depend on various factors, including ambient concentrations, air exchange rates, and ozone decay rates.

Currently, various passive samplers are available, but these depend on diffusion and results can fluctuate with air velocity variations. One active sampler, used in air quality studies in California, incorporates a flow control mechanism, but it is large, and described by the Harvard researchers as "the size of a toolbox."

The Harvard sampler bases its technology on a passive sampler developed by one of the researchers. It uses an ozone/nitrite reaction that is specific for ozone and minimizes interference from other oxidants, such as NO_2. The compelling properties of the new Harvard active sampler include its size — approximately 6 x 10 centimeters ($2\frac{3}{8}$ x 4 inches) — making it useful as a personal exposure sampler.

Validation

In order to determine whether the small, lightweight sampler would give accurate results, the researchers evaluated it under both laboratory and field conditions, using it in small and large chambers and at an ozone monitoring station run by the US Environmental Protection Agency.

The researchers report that the sampler demonstrated accuracy and precision under both laboratory and ambient conditions, in which ozone concentrations ranged from 20 to 200 parts per billion (ppb). They also found it to be insensitive to relative humidity, except in extremely dry conditions — 12% RH —rarely found in actual use. They report that the level of detection is 10 ppb/hr, which the researchers said is much lower than other small portable samplers.

For more information, contact Alison S. Geyh, Harvard School of Public Health, 655 Huntington Avenue, Boston, MA 02115; Fax: (617) 432-3349; E-mail: geyh@sparc6b.harvard.edu.

Case Study

*[In each issue, **IEQS** presents a case study on an indoor air investigation in a particular building. The information in the cases comes from various sources, including published material, reports in the public record, and, in some cases, reports supplied by the consultants involved in the case. **IEQS** presents a variety of approaches to investigation and mitigation implemented by consultants with a broad range of experience, philosophies, and expertise. Inclusion of a particular case study in the newsletter does not imply **IEQS**'s endorsement of the investigative procedures, analysis, or mitigation techniques employed in the case. **IEQS** invites readers to submit comments, suggestions, and questions concerning any case. At the discretion of the editors, correspondence may be presented in a future issue.]*

Renovations, Lack of Preventive Maintenance Lead to IEQ Problems

Often, building renovations — particularly those that involve major changes to building layout and use — can adversely affect IEQ, especially if the plans don't include necessary updates to the HVAC systems. This case concerns a government facility, in which 30 years of renovations — and the lack of an adequate preventive maintenance plan — resulted in increased adverse health effects among occupants.

The building in question is a high-security military facility in Europe, where security concerns involve limited access by maintenance personnel. Also, one major and two minor additions to the facility didn't include necessary upgrades to the HVAC system.

Built in 1963, the two-story cinderblock masonry structure comprises about 75,000 square feet (ft^2) in approximately 140 small rooms. Two small additions to the building took place between 1963 and 1977, and a major addition in 1985.

Located in an isolated area about five miles from the ocean, away from population centers and roads, the climate is semi-arid. The surrounding countryside consists of farm land and rolling hills. The building, which for security reasons contains no windows, houses approximately 400 persons during the 8 am to 5 pm shift, and about 150 during other hours.

The air samples contained trace amounts of five hydrocarbons. These included toluene, benzene, 1,2,4-trimethylbenzene, tetrachloroethane, and m,p-xylene. All concentrations were well below threshold limits set by the American Conference of Government Industrial Hygienists. Table 6 shows the results of the air sampling.

Table 6 — Air Sampling Results

Location	Compound	Test Results (ppb)	ACGIH TWA (ppm)
Room 220/221	Toluene	18.0	50.0
Room 173/180	Toluene	30.0	50.0
	1,2,4-Trimethylbenzene	1.3	25.0
Room 215	Benzene	2.2	10.0
	Toluene	93.0	50.0
	Tetrachloroethane	2.8	1.0
	m,p-Xylene	2.6	100.0
Room 265	Benzene	2.6	10.0
	Toluene	160.0	50.0
	m,p-Xylene	1.1	100.0
	1,2,4-Trimethylbenzene	1.4	25.0
Room156	Toluene	46.0	50.0
	m,p-Xylene	1.0	100.0
Room 265	None detected	—	—
Lab Blank	None detected	—	—

Source: David Hiipakka

Conclusions

As a result of the sampling and visual inspection, the investigators came to several conclusions:

- The building was suffering from poor air supply, due in large part to the modifications without concern for upgrading HVAC systems;
- The systems were in great disrepair due to the lack of an adequate preventive maintenance program; and
- Microbial contamination was most likely responsible for increased respiratory distress among the building occupants.

They made several recommendations, among them:

- Initiate immediate HVAC repairs;
- Hire a dedicated HVAC mechanic to run a preventive maintenance program;
- Bring the HVAC system into line with current building needs, including major AHU replacements and capacity upgrades.

The investigators reported that the recommendations are currently being implemented. The facility hired an HVAC mechanic who is now maintaining the system. Follow-up testing shows that airborne fungal counts have dropped by up to 97% in some areas. The building average is now less than 300 cfu/in^2.

For More Information

David Hiipakka, CIH, of the US Naval Hospital, Rota, Spain, who conducted the study, reported on the case at the American Industrial Hygiene Conference and Exposition last May in Dallas. He also provided additional information for this report. For further information, contact Hiipakka at PSC 819, Box 18-226, FPO AE 09645; +34 56 82-2783, Fax: +34 56 82-3506, E-mail: rth1dwh@rth10.med.navy.mil.

News & Analysis

Building Owners May Soon Be Able to Buy IAQ Insurance Policy

Building owners and managers may soon be able to insure themselves against losses and expenses involved in IAQ problems. Weeks away from coming on the market, the policy will cover such things as bodily injury claims, property damage, loss of rent, and the cost of mitigation. Stu Samuels of the Clair Odell Group (Plymouth Meeting, Pennsylvania) tells ***IEQS*** that brokers at his group developed the policy language at the behest of the Building Air Quality Alliance (BAQA) and that they have been working with underwriters to craft the final version of the proposed policy. "I wouldn't be surprised to see this on the market in the next 60 days," Samuels tells ***IEQS***. If the policy becomes available as Samuels describes it, this will be the first such policy on the market. Traditional thinking has been that current liability policies often don't cover IAQ