Environmental Building News™
The Leading Source for Environmentally Responsible Design & Construction
A Publication of BuildingGreen, Inc. www.BuildingGreen.com Volume 25, Number 11 · November 2016
Celebrating Our 25th Year

Clean, Fresh Air: Getting What We Need

Human health probably benefits from more fresh air than current ventilation standards require. But pulling in outdoor air can mean pulling in pollution.

by Candace Pearson

If you're designing an expensive, high-end office tower, you'd better be sure the people inside of it can do their best work. So as Ben Tranel, AIA, principal at Gensler, began working on the Tower at PNC Plaza in Pittsburgh, he thought a lot about air.

"When people are working their hardest, you always hear them say 'Let's go out and get some fresh air,'" Tranel told BuildingGreen. "They say that because they want to get more oxygen—to feel the variability of the breeze. We wanted to see if we could create that feeling."

The firm thus set out to design the 33-story LEED Platinum tower to be completely naturally ventilated for much of the year. But they ran into a problem. Pittsburgh is ranked the eighth-most polluted city in the U.S. for year-round particle pollution by the American Lung Association and is fourteenth for short-term particle pollution.

This conundrum is not unique. Increasingly, the desire to provide more fresh air to our interiors—driven especially by recent research that links fresh air with heightened cognitive performance—is colliding with the realization that there might not always be fresh air to be had.

All of this has given rise to a new market for air quality sensor technologies, which are paving the way for dynamic response natural ventilation systems as well as driving innovations in filtering strategies. Yet surprisingly, we still don't really know how much fresh air is optimal for human health or productivity, or what exactly about that air is beneficial. So while vast quantities of air quality data may soon be available, some answers will likely remain shrouded in haze.

Ventilation Standards Are Based on Odor, Not Health

If there's one thing the experts can agree on about fresh air, it's that we're probably not supplying enough of it. That's because our ventilation standards have a long history, and one that quickly diverged from its original concern for human health.

It all started when doctors during the Crimean War (1853–1855) noticed that diseases spread faster in crowded hospitals with poor ventilation. As a result, the American Society of Heating and Ventilation Engineers (ASHVE) accepted a minimum ventilation rate of 29 cubic feet per minute (cfm) per occupant.

As improvements in hygiene became more effective at controlling contagion, however, researchers began to question the need for such high rates and instead began to talk in terms of comfort and preference. Researchers developed a metric

Photo: Connie Zhou Photography

The Tower at PNC Plaza overcame outdoor air quality issues and found a way to employ natural ventilation with this punctuated façade.

called the "olf"—short for olfactory unit—in the 1920s and 30s to represent the smell generated by a recently showered human of average size wearing clean underwear and clothing while sedentary. Ventilation rates were designed to offset olfs.

Soon after, carbon dioxide (CO_2) became a measurable proxy for the same idea. CO_2 itself was considered benign except at very high concentrations over 5,000 parts per million (ppm), but was found to be a pretty good indicator for the concentrations of *bioeffluents*—the particulates, biological aerosols, and other contaminants that are emitted by human occupants (i.e., body odors). In 1936, a study by C.P. Yaglou suggested that maintaining levels of CO_2 under 1,000 ppm correlated with most people being happy with the air quality. On that basis, ventilation rates were cut in half to 15 cfm per occupant in the American Standards Association code in 1946.

The risk of going too low

The energy crisis of the 1970s hit, and ventilation rates were slashed to just 5 cfm per person just as the industry began to build more airtight, energy-efficient buildings. This time it was too much; without the usual air infiltration providing a source for fresh air, air pollutants began building up indoors and people got sick (see The IAQ Challenge: Protecting the Indoor Environment).

Very quickly, the industry got smarter about things like VOCs, radon, and cleaning techniques to avoid dust and mold. (Though not completely. See VOCs: Why They're Still Here and What You Can Do About It). And ventilation requirements did gradually creep back up. By this time, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62.1 was the industry reference for commercial buildings, and minimum outdoor flow rates increased in 1989 and again in 1999 back up to around 20 cfm per person. On the residential side, ventilation requirements changed significantly in the 2013 standard, jumping from 1 cfm per 100 ft^2 to 3 cfm per 100 ft^2.

Yet the discussion has continued to center on preference levels of bioeffluents. To this day, current ventilation standards are designed so that at least 80% of people don't have complaints about odors in the air. (Practitioners still widely use 1,000 ppm of CO_2 as a general threshold to stay under, although ASHRAE does not include CO_2 recommendations anymore and instead factors in comfort with CO_2 levels when it comes up with its dual metric of cfm per ft^2 and cfm per person). Not only does this methodology not acknowledge CO_2 as a pollutant itself (more on that debate later), but it also arguably does a poor job even at the one thing it's supposed to be handling. Wherever you are right now, the air might be so stale that 20% of you are stuck smelling the body odor of your neighbors and the building would still meet current indoor air quality standards.

No basis in health impacts

That method of ensuring air quality seems to fall short to people like Luke Leung, P.E., the director of sustainable engineering at SOM, who sees the connections between fresh air and human health as integrally tied. Source control measures have been relatively successful at reducing the most obvious signs of sick building syndrome, says Leung, but there still may be a host of problems with our typical air quality that result in impacts that are less immediate.

Florence Nightingale's work was made even more difficult by poor ventilation in the overcrowded hospitals she worked in during the Crimean War. It was during this time that the connection between air flow and the spread of contagious diseases was established.

He points to research linking asthma and other chronic diseases with developed nations. "We are creating a generation of fragile human beings that will live longer, but have chronic diseases because they spend so much time indoors. There is definitely something about people spending more time in the fresh air that is related to health."

In fact, one study found that with every 1,000 ppm increase in CO_2 levels, student absences increased by 10%–20%. Another correlated higher levels of ventilation with reduced sick leave at a large manufacturing plant.

ASHRAE code makers themselves admit that they don't take into account what is optimal for health. "Essentially it is a continuous curve—more ventilation provides more benefits," says Roger Hedrick, P.E., former chair of the ASHRAE 62.1 committee from 2010 to 2015 and principal engineer at NORESCO. "But the nature of a standard is that you have to pick a number. We pick that number based on a set of criteria, and people have to understand that [ASHARE 62.1] is meant to be the minimum—anything less is illegal, and more may be better."

There's simply too much information missing for ASHRAE to try to determine how much ventilation is needed for healthy air, according to Hedrick. "We don't know the health impacts for many contaminants that we see in indoor spaces, and for ones that we

Know The History

- From olfs to CO2, ventilation rates have nearly always been set with the aim of limiting odorous smells
- People get sick when ventilation rates are too low
- Indoor air quality is still audited by measuring CO2 concentrations, which have no officially recognized bearing on health outcomes

know are hazardous, we very rarely know how their emission rates will change over time." Plus, he says, accounting for people's preference for odor is likely a higher bar anyway. "I don't know, but I'm pretty certain that people will find the air objectionable before levels of contaminants are so high that there's a health concern." (Others BuildingGreen spoke with strongly disagreed, citing examples like radon and certain particulates that humans can't smell, as well as particles produced by reactions between ozone and limonene, which could be hazardous but smell pleasant to the human nose.)

Leung recognizes that it is complicated to figure out the amount of ventilation that would be optimal for health, and that ASHRAE might have to "default to using our preference for a certain level of bioeffluents. But if I want to design a building where the air doesn't just not smell but is actually healthy—there's no standard for that, not even a voluntary one. Nobody has a comprehensive understanding of what defines good air."

Agnostic to productivity impacts

A nuance to Leung's point is that the absence of detrimental effects isn't the same as being optimal, and a recent study has suggested that there could be a big difference between the two. In a joint study by Harvard T.H. Chan School of Public Health's Center for Health and the Global Environment, SUNY Upstate Medical University, and Syracuse University released last year, researchers found that adding additional ventilation on top of already low-VOC conditions (increasing from 20 cfm per person to 40 cfm per person) helped people to think better. On a cognitive function test evaluating higher-level thinking like strategy making, crisis response, and information usage, participants' scores were 101% higher with the increased ventilation.

"Of the three variables we studied, ventilation had by far the biggest effect [on cognitive function scores]," Joe Allen, Ph.D., told BuildingGreen.

Impact of IAQ on Cognitive Function Performance

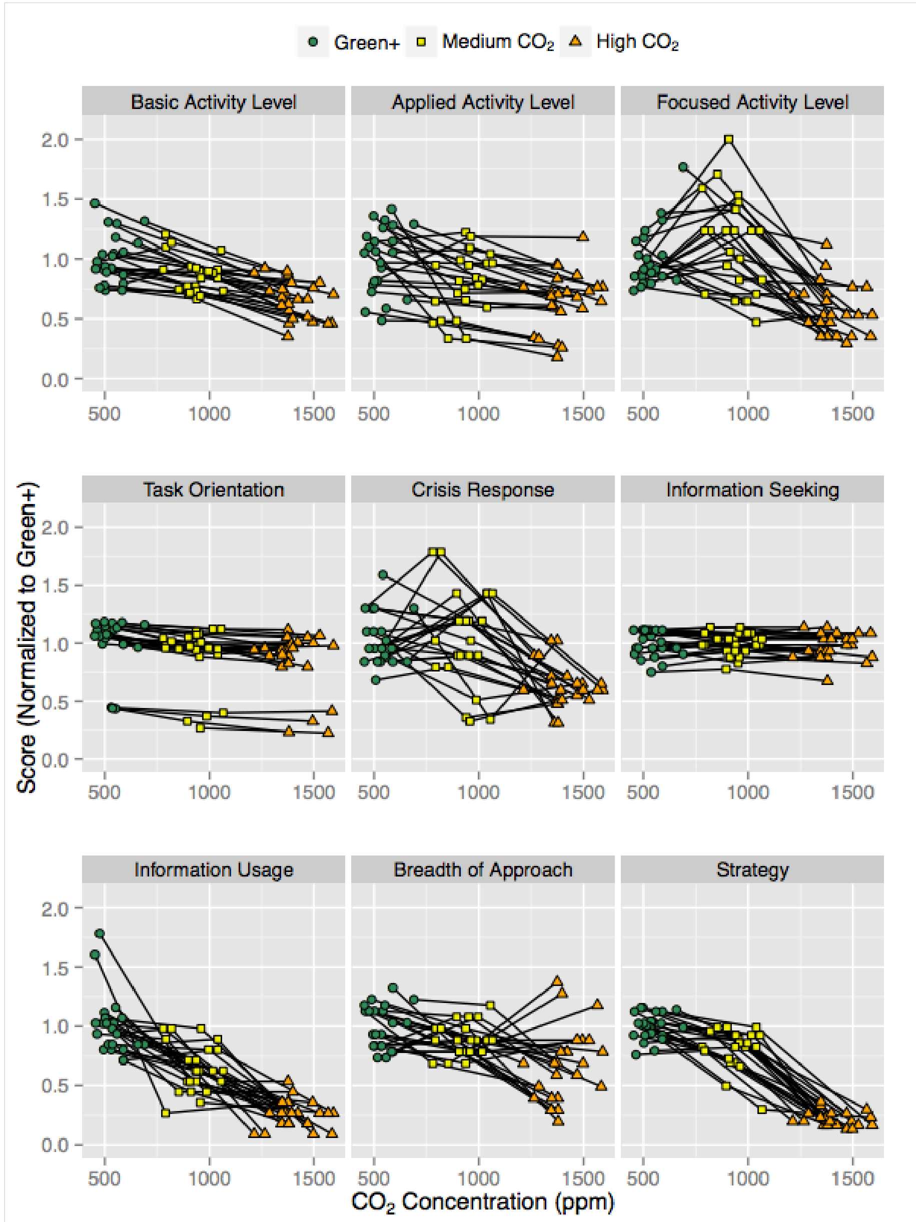

Image: Allen et al.

Harvard research suggests that cognitive function declines as CO_2 levels increase, indicating a direct link between increased ventilation and productivity enhancments.

"We certainly advocate for ventilation rates that exceed ASHRAE 62.1—that should be considered the bare minimum." The adoption rate for the enhanced ventilation credit in LEED is only around 40%, according to Allen. "We recognize that there are perceived barriers to adopting more ventilation, including energy costs, but there really are overwhelming health and productivity benefits," says Allen.

In a follow-up evaluation that attempted to quantify these tradeoffs, Allen and his team estimated that the enhanced ventilation used in the study could be achieved with energy-efficient technologies, resulting in an energy cost of between $1 and $18 per person per year. The associated productivity benefits were estimated to be $6,500 per person per year—a pretty good return on investment (ROI).

Under Ventilating Is Common

Even if you are of the mind that current ventilation standards like ASHRAE 62.1 and 62.2 are sufficient,

The Problem of Controlling Ventilation Through the Thermostat

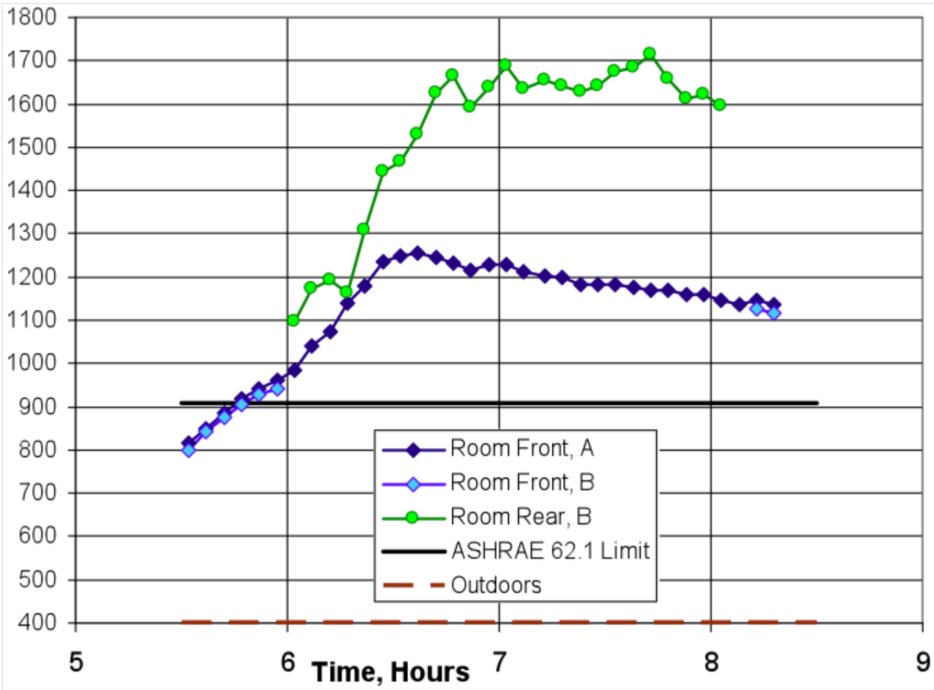

Image: David Bearg

This plot graph shows CO_2 levels in a conference room where a meeting was being held. The trend is typical for a ventilation system that is tied to thermoset set points: there is a delay between the point at which CO_2 reaches undesirable levels and when the temperature rises high enough that the ventilation is triggered to supply more air. Also notice that CO_2 concentrations differ drastically between the front of the room and the back of the room, where there are more people.

there's plenty of evidence to suggest that many buildings don't meet those standards.

While CO_2 levels can't alone be used to determine whether a space is in conformance, levels significantly above 1,000 ppm are still an indication of poor air quality. Surveys taken of around 200 elementary school classrooms in California and Texas found that average CO_2 concentrations were above 1,000 ppm, many exceeded 2,000 ppm, and in 21% of Texas classrooms, peak CO_2 concentration exceeded 3,000 ppm.

Another study conducted in Singapore tracked CO_2 exposure levels by attaching sensors to 16 individuals and observing exposure levels throughout a period of one week. Nearly all participants spent at least an hour of a typical day with CO_2 elevated over 1,100 ppm. In this study, it turned out that a major determinant of more exposure was the mode of bedroom ventilation; people who used air conditioning units in their bedrooms instead of natural ventilation had many more instances of exposures to high CO_2 levels and were also the only group that experienced CO_2 levels over 2,500 ppm. For everyone in the study, the vast majority of significant exposure events—where CO_2 levels fell between 1,000 ppm and 2,500 ppm for 2.5 hours or more—occurred in the home, whereas only 9% of those events occurred in an office.

"We have to understand the places where these exposure events occur," Elliott Gall, Ph.D., lead author on the paper, told BuildingGreen. "Most studies are focusing on mimicking office environments, when what we found was that residences can be much worse." While that was just one small study done in Singapore, other studies corroborate that offices tend to not have as much trouble with elevated CO_2 levels (though problems are common in meeting or conference rooms with high occupancy levels); in a 2008 survey of 100 U.S. offices, only 5% of the measured peak indoor CO_2 concentrations exceeded 1,000 ppm.

Even so, offices don't get a get-out-of-jail-free card. Remember that the 1,000 ppm threshold is based on research conducted in the 1930s. A recent study, conducted by Carnegie Mellon University (CMU) for the U.S. General Services suggests that level may be too high. In this analysis of 64 buildings, occupant satisfaction with indoor air quality significantly increased when CO_2 levels were below *600 ppm*. If 600 ppm is really the maximum threshold we should be shooting for, then many more office buildings would likely register as problem cases.

Why our ventilation strategies fail

There are several reasons that CO_2 levels might reach such high levels. The vast majority of homes don't have mechanical ventilation installed. Historically, air infiltration supplied the needed fresh air, but as home upgrades and improvements have occurred over the decades, it is possible that envelopes have gotten more airtight without ventilation systems being installed.

Ventilation systems are more common in commercial and institutional buildings, but the way they operate isn't always tuned towards people.

"A lot of mechanical systems do a very poor job of getting fresh air to the nose," says Vivien Loftness, FAIA, architecture professor at Carnegie Mellon.

Most are conventional mixing systems that aim to uniformly dilute the concentrations of pollutants in a space. So fresh air may be brought in, but

Ventilation Priorities

- Correct under-ventilation in existing building stock
- Design ventilation systems to benefit people—not just cooling or heating cycles
- Figure out how to get more fresh air into every building, while minimizing the energy penalty. The benefits of fresh air are a "continuous curve"—so more is always better.

the air that people actually breath is mixed with the polluted indoor air, and thus never quite as fresh. Displacement ventilation systems do a better job of providing the freshest air at breathing height, but are less common.

The majority of systems are also tied to the heating or cooling, so that "when the thermometer says to stop conditioning the air, your breathing air stops," says Loftness. Demand-controlled systems help to decouple ventilation from thermal conditioning needs using CO_2 sensors to better align ventilation set points with actual occupancy levels, but because they only kick in when CO_2 levels have gotten too high, "in some senses they are like a Band-Aid after the fact," says Loftness.

Opening Up for Fresh Air and Facing Outdoor Air Pollution

Given the absence of clear guidelines for ensuring healthy air, the most one can currently do is to provide as much fresh air as makes sense. "Ultimately, the longer we can run outside air, the better off we are," argues Loftness.

Loftness believes that economizers should be more widespread. These rooftop devices bring in outside air whenever the HVAC system is calling for cooling and the temperature outside is cool enough. That allows buildings to save energy on conditioning while maximizing of the amount of fresh air that enters the building. She's also a firm believer in buildings having operable windows. In temperate climates, she thinks they should be mandatory.

Others are clearly on that path too (see Natural Ventilation: The Nine Biggest Obstacles and How Project Teams Are Beating Them)—but a certain pesky issue is getting in the way: outdoor air pollution.

Health hazards from outdoor air pollution

Increasing ventilation will only benefit occupants if the air is actually fresh. If it's not, then it will most certainly negatively affect indoor air quality. This was recently demonstrated by an indoor air quality assessment performed in Pittsburgh, Pennsylvania as a part of a 2030 District pilot. (This research was not connected to the Tower at PNC Plaza discussed earlier.)

"We clearly saw a spike in PM2.5 concentrations when the building's windows were open," Aurora Sharrard, Ph.D., executive director of the Green Building Alliance, which founded Pittsburgh's 2030 District, told BuildingGreen. PM2.5 is just one, though particularly nasty, outdoor air pollutant of concern (see a full list in the accompanying table). These particles form as gaseous pollutants emitted from traffic and factories react with each other. Long-term exposure is associated with heart attacks and lung cancer.

"We don't want to discourage natural ventilation or more ventilation in general, but we have to start accounting for the quality of our outdoor air," says Sharrard.

Outdoor air quality problems are not unique to Pittsburgh, and they are certainly not isolated to China or India. The 2016 State of the Air Report from the American Lung Association found that more than half of all Americans—more than 166 million people—live in counties where they have been exposed to harmful levels of either ozone, short-term particle pollution, or long-term particle pollution for at least one day in the three year period of 2012–2014. Worldwide, the World Health Organization estimates that air pollution caused around 7 million premature deaths in 2012, and those aren't limited to unregulated industrial hotspots: nearly 500,000 of them were in Europe.

Furthermore, experts have predicted that most of our current outdoor air quality problems will be exacerbated by climate change: our atmosphere

Image: SOM

The Suzhou Center tower planned for Wujiang, China incorporates an atrium that is designed to bring fresh air source into the building's lobbies and public spaces.

will be more conducive to forming ozone, increasing wildfires and droughts will add more dust to the air, and rising temperature will mean longer allergy seasons.

There's a social justice component, too, which can't be ignored. If indoor air quality problems seem more immediate in your buildings, "that's because you probably deal with wealthy communities where the outdoor air is clean," says Sara Grineski, Ph.D., associate professor of sociology at the University of Texas at El Paso. Grineski has done extensive research in the Southwest and along the U.S.-Mexico border where she has found strong correlations between poor air quality and disadvantaged populations (see Air Pollution Near Kids' Homes Linked to Lower Grades at School). "Air pollution is one of the strongest examples of environmental injustices that we have," says Grinieski. And it is not just industrial pollutants—poorer communities often are more prone to highway pollution, ozone, and even dust in the air, Grineski has found. Missing a chance to correct for these issues in a low-income housing project, for example, because designers are not used to dealing with air quality issues, "just piles onto the multitude of factors that keep people marginalized," says Grineski. "These populations are likely already more vulnerable—whether from food insecurity, poor health care, or low-quality housing. Another stressor is just one more thing."

The Rise of Air Quality Sensors

So how can building professionals increase the amount of fresh air for occupants, without exposing occupants to outdoor pollutants? Generally, the industry is putting its chips on better data. "For the longest time, air quality has been viewed as this very static thing," Chris Pyke, Ph.D., who recently joined the environmental sensor network company Aclima as the company's chief strategy officer, told BuildingGreen.

Until very recently, there have been few ways to understand site-specific outdoor air quality risks. The U.S. Environmental Protection Agency lists "non-attainment zones," which are areas that don't meet the department's criteria for good air quality, but only entire counties are listed. Yet scientists know that outdoor air quality can differ drastically by neighborhood or even by block given geography and wind patterns, as well as the location of point source polluters, such as industry or highways. Even at the building level, you've probably been in a building at some point where you experienced diesel exhaust in the indoor air because of an idling truck near a major air intake.

The Pittsburgh metro area is listed by EPA as one of those non-attainment zones. Speaking about initial research for the Tower at PNC Plaza, Ben Tranel told BuildingGreen, "It would have been incredibly easy to dismiss [a natural ventilation strategy] at the beginning based on generalizations about the air quality."

But as Pyke describes, more localized data is proving such generalizations wrong. "We are entering a world where distributed sensors can give us finer data, and they are showing that conditions within a building and on the outside of the building are much more variable than they first appeared." In the end, the Gensler team used air quality sensors to enable PNC's final design—more on that later.

City-wide mapping

Aclima has been measuring and mapping air quality in various cities by placing its air quality sensor technology on Google Street View cars. This has helped paint a more detailed picture of how air quality morphs and changes throughout a day, as well as how it is informed by geography. For example, when Aclima mapped the Denver metro area, it found that three key pollutants—nitrogen dioxide (NO_2), ozone (O_3) and nitrogen oxide (NO)—predictably became more or less present throughout the day, primarily due to atmosphere dynamics.

The boundary of our atmosphere rises throughout the day as the ground heats up and causes air to rise and mix with the cooler air above. So in Denver, the days usually progresses like this:

- NO and NO_2 are greatest in the morning, as they are contained in a smaller volume of air.
- As the day continues, those concentrations decrease as the atmosphere boundary rises, but O_3 begins to form by photochemistry (chemical reactions catalyzed by sunlight)
- Around 4 p.m., O_3 concentrations reach their peak. NO emissions might increase with afternoon rush hour, some of which might be converted to NO_2 by interacting with O_3.
- At night, O_3 drops and NO_2 increases to a higher nighttime concentration.

This type of more granular data is expected to inform some general guidelines that designers and operators can implement manually. Pyke makes an analogy to how our understanding of sunlight enables designers to spec a window with a different solar heat gain coefficient for different sides of a building. "We need to better understand how ambient pollution changes throughout the day and what are the typical episodic emission sources. If you know that your ambient pollution is mostly coming from a nearby highway then you can change where you place your air intake, or adapt your controls so that you're not bringing in air during rush hour."

Outdoor Air Pollutants

Air Pollutant	Source	Health Impacts
Ozone (O_3)	Formed when pollutants emitted by cars, power plants, and other industrial processes chemically react in the presence of sunlight.	Can trigger chest pain, coughing, throat irritation, and airway inflammation. It also can reduce lung function and harm lung tissue.
Nitrogen Dioxide (NO_2)	Formed by the burning of fossil fuels.	Can cause respiratory harm, may contribute to the development of asthma, reacts with other chemicals to form particulate pollution.
Sulfur Dioxide (SO_2)	Released by industrial processes, power plants, and emissions from vehicles that burn fuel with high sulfur content.	Can cause respiratory harm and react with other chemicals to form particulate pollution.
Particulate Matter	Emitted from site sources such as construction sites or fires, and formed when sulfur dioxides and nitrogen oxides emitted from vehicles, factories, and power plants react.	Smaller particles (PM1.0) can directly enter the bloodstream via the lungs. Bigger particles (PM2.5) cause haze and longterm exposure is associated with cardiopulmonary mortality.

Source: U.S. Environmental Protection Agency

We are moving towards having the kind of guidance that people can "operationalize," says Pyke. In fact, developing a new credit for LEED is one of the goals of a new partnership announced between Aclima and USGBC.

Building-level tracking

Some projects aren't waiting for their city to be mapped or a LEED credit to be developed. They're monitoring indoor and outdoor air quality themselves at the building level and tweaking their systems to see what works.

In fact, an entire standard was recently developed based on that idea. "The price of sensors has dropped dramatically, even from just six months ago," Raefer Wallis, founder of GIGA and the developer of the RESET standard, told BuildingGreen. As a result "a business tower might be able to install eight monitors at a relatively miniscule cost, and use that data for communication and marketing."

It's an idea that more projects are willing to entertain, especially in China where pollution is severe. The first project that RESET certified was an office building built by the American developer, Tishman Speyer, in Shanghai. "Their project was seven miles away from the nearest outdoor monitoring station," said Wallis. "A lot can happen in that space." Demonstrating that the building offered fresh, filtered air was a high priority—and a strong competitive advantage for top rental space in China—but there have been problems with the filtration companies installing monitors in places that would positively skew results. RESET sets out a standard for which monitors to use, how to install them, and how to report results, so that there is more standardization and transparency in the market. Then they certify buildings that meet their actual performance benchmarks. Air quality is the first of four individual modules that a project can certify in, similar to Living Building Challenge petals. (The remaining three are Comfort, Materials, and Energy.)

Tower Height and PM2.5 Concentrations

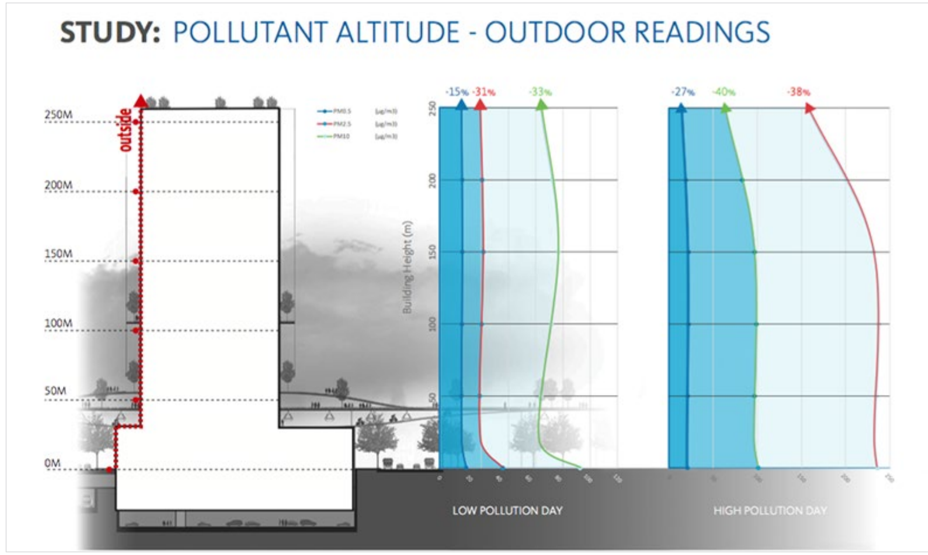

Image: Kyle Mertensmeyer

PM2.5 concentrations lessen at higher elevations, so Gensler is exploring how mechanical systems might be re-worked to take advantage of such variations.

The standard is purposefully performance driven. "We need engineers to become heroes again," says Wallis. "These challenges are big. I don't care if you achieve fresh air through a mechanical system, with a mixed mode building, or entirely through indoor plants. It is the results that matter, so we need to be encouraging innovation."

Multiple projects have now successfully met RESET's air quality benchmarks, and the organization is not shying away from translating those results into expected health outcomes. Five buildings tracked PM2.5 levels throughout 2015, and GIGA recently reported that as a result, employees in those offices gained an average of 5.6 days of life expectancy than if they were exposed to the level of pollution outdoors. Over the span of a 35-year career, that would amount to nearly half a year of more life for each employee. Health impacts were calculated using an algorithm based on medical research conducted in Beijing (which typically has higher pollution levels than Shanghai). Wallis says those estimations may be conservative because no other pollutant source was evaluated, though it is unclear whether outdoor air quality is really an appropriate benchmark. Most people spend their time indoors during the day, where even in a conventional building, PM2.5 is not likely to be as high as outdoor levels.

Enabling research and development

Gensler is one firm that has seriously invested in research involving air quality. In highly polluted environments like China, the ultimate solution can't just be mechanical filtration. Gensler has found that filtration installed in its LEED Platinum buildings there comes with an energy penalty of 7%, according to Kyle Mertensmeyer, AIA, the founder and research director for Gensler's "Design for Polluted and Toxic Environments" program. As a result, the indoor air might be better, but in places where electricity is supplied by fossil fuels, the added energy demand causes the outdoor air to get worse as power plants work to supply it.

There's also a limit to what filtration can do, explains Raefer Wallis. RESET sets a general threshold of having less than 15 µg/m^3 (micrograms per cubic meter) of PM 2.5. However, "over a certain pollution level, you can filter all you want, but 20%–30% of the outdoor pollutants will make their way back into the building through the elevator shaft or through the

The Impact of a Green Wall on CO_2 Concentrations

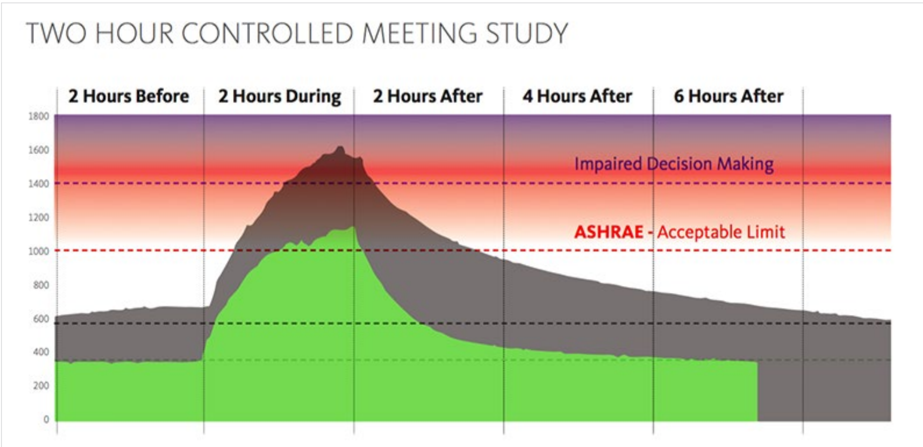

Image: Kyle Mertensmeyer

In this Gensler experiment, the presence of a vegetated wall kept CO_2 concentrations lower than the control condition.

envelope." For that reason, RESET has an allowance: if outdoor PM2.5 levels exceed 60 µg/m³, the filtration unit need only be sized to remove 75% of the outdoor levels because the remainder can be expected to infiltrate the building anyway.

China's air quality certainly surpasses these levels regularly. During the "airpocalypse" of 2015, PM 2.5 readings were over 1,400 µg/m³, a level 50 times what's considered safe by the World Health Organization. On that day, *indoor* levels were around 50 µg/m³, according to Mertensmeyer. But places in the U.S. pass this threshold too. On December 9, 2012, Los Angeles had a PM2.5 reading of 79 µg/m³.

"At that point, you have to rely on individual filtration units within offices to capture [what's not filtered out]," explains Wallis. In China, these individual air filters have had a 400% increase in sales in the last year, according to Mertensmeyer. But

Time to get creative

- The answer is not always filtration. We have to find less energy-intensive solutions to obtaining clean air.
- Air quality sensors are less expensive than ever! Start testing what you've done on past projects to see what worked and what didn't.
- Use natural variations to your advantage. Time of day, elevation, and proximity to plant life can all influence air quality.

these devices have the same problem as whole-building filtration systems: their operating energy consumption causes more pollution to be emitted from power plants than they remove. Mertensmeyer has calculated one of these units might remove 62 grams of PM2.5 in an hour operating indoors, while the typical 215-watt device would simultaneously cause 3,440 grams of PM2.5 to be emitted to the public air (assuming the typical utility fuel mix for China, 64% of which is coal).

Consequently, Gensler has been researching how to get cleaner air without mechanical filtration. One idea has been to use typical office tower height as an advantage. Pollution is usually held within a certain atmospheric boundary that rises and falls throughout the day. By placing air quality sensors on two office towers, Gensler found that at 32 stories, particulate matter is reduced, and 60 stories seems to rise over the atmospheric boundary in Shanghai. That has led Mertensmeyer to ask, "why not bring in your air at the top of the tower, so you can spend less energy filtering it?" Though such a system hasn't yet been implemented, he's worked on some conceptual schemes.

"It seems contradictory to traditional methods, but if we don't think of this as only a filtration method but also as a multi-model system for heating and cooling the air passively, and even possibly incorporating energy generation, suddenly we begin to look at this as an entirely new building system. Building design needs a back-to-the drawing board approach if we want to bring ingenuity and innovation into the design process," says Mertensmeyer.

He has also been experimenting with plants as a non-energy-intensive filtration medium. In one experiment, he tested how a green wall in a small conference room affected indoor air quality before, during, and after a two-hour meeting as compared to a control room without a green wall. The biggest impact was with CO_2: the green wall kept CO_2 levels around 1,000 ppm while the control room rose to 1,400 ppm. The plants also helped keep PM2.5 levels down compared to the control. How? Mertensmeyer hypothesizes that the particulate matter sticks to the tiny hairs on the leaves.

Pairing with natural ventilation

Another low-energy approach has been to capitalize on natural ventilation and use sensors to trigger a response when outdoor air quality is poor.

That's the direction that the Tower at PNC Plaza ultimately went with. The design team's research showed that air quality issues in Pittsburgh are typically worse in the summer, when the building would have to be air-conditioned anyway. When the season is ideal for natural ventilation—during the fall and spring—outdoor air quality problems aren't typically that bad, Ben Tranel told BuildingGreen. So the team went forward with a natural ventilation strategy, but decided to incorporate monitoring and controls.

The building has a double-skin façade and a solar chimney to aid in passive heating and cooling. Sensors on the outside of the building measure PM2.5, ozone, and pollen count. When the air quality is good and the thermal conditions are right, the building automation system triggers natural ventilation mode and the exterior

Photo: Connie Zhou Photography

On good air quality days when the Tower at PNC Plaza is in natural ventilation mode, occupants can open the windows on the interior of the double-skin façade if they want a more direct breeze.

walls and interior vents open up. Then, indicator lights along each floor turn green, notifying the occupants that they can open the doors of the interior façade if they want direct air flow into their workspace.

"We came to a point where we realized that if we sensored and monitored the building, we could make [natural ventilation] work. And that would be make it a healthier place with reduced energy consumption," says Tranel.

The designers also put a contingency plan in place for an "extreme air quality event" like a fire or an explosion. While it typically takes the envelope a couple of minutes to close up from natural ventilation mode, there is a setting that can make it close in ten seconds.

It's a similar story with a mixed-use tower in Wujiang, China. Rather than dismissing natural ventilation out of hand, the design team from Skidmore, Owings & Merrill looked at outdoor air pollution data, and found air quality was best during the shoulder seasons when natural ventilation was most likely to be used. The design team went forward with a natural ventilation strategy—incorporating a 42-story atrium on the top of the tower with operable windows to the exterior. When outdoor air quality sensors show that conditions are good, the windows open and the atrium acts as a lung, according to Luke Leung. When conditions are bad, the atrium closes and the building relies on mechanical filtration.

"Natural ventilation is one of the best ways to restore peoples' connection with the outdoors," says Leung. "These buildings are meant to last 100 or more years. If we do manage to move towards a cleaner environment, I want the people in my building to have the option to choose that."

Limitations

Despite all the opportunity that affordable air quality sensors currently enable, there are weaknesses too.

Raefer Wallis points out that accuracy and availability are both still very much real limitations. There are currently no ozone or nitrogen dioxide monitors that meet RESET standards, for example. "The monitors coming out of the U.S. are tested and used at lower concentrations than we see in China," says Wallis. "A 20% variation is not a big deal at lower concentrations, but here those monitors can be off by a factor of 10." Sometimes, there's the opposite problem: a sensor might be extremely accurate—perhaps designed for an industrial or laboratory setting—but be far too expensive to use in a building monitoring system. "For years, we've only had two ends of the spectrum: really expensive instruments for labs and basically consumer toys," says Wallis. "Really good building-grade monitors didn't exist up until 18 months ago. But the market is catching up, and it will catch up fast."

In the U.S., Aclima has a strong reputation for its building-level systems, in addition to its city-wide mapping. USGBC currently has Aclima sensors installed at its Washington headquarters and is testing how they might feed into the LEED Dynamic Plaque, the real-time monitoring software that generates a LEED performance score, according to Chris Pyke (see Dynamic Plaque Piloted as LEED Performance Path).

But perhaps the biggest limitation is that while these sensors might help people make better decisions about avoiding pollution as they try to bring in more outdoor air into a building, they do not yet answer the question of whether our indoor air is healthy—even if they seem to purport to. First, research has suggested that "healthy" air is not merely the absence of pollutants. Different studies point to a plethora of constituents in the air that might be beneficial to human health, from negative ions, to phytoncide, to beneficial bacteria. The science about these agents is still emerging, and we're far from incorporating those measures into sensor-based monitoring systems.

Second, it turns out there's not even consensus on what should be considered a pollutant. In addition to disagreement about whether total VOCs (TVOCs) and semi-volatile organic compounds (SVOCs) have identifiable health effects, researchers are currently debating whether CO_2 could be acting as a direct pollutant, rather than just an indicator for bothersome bioeffluents (see sidebar).

Research suggests CO_2 is a direct pollutant

CO_2 has been considered an indicator for other pollutants for more than a century; nearly every ventilation standard devotes a paragraph to describing that it's not a pollutant itself at levels usually seen in indoor environments. Now there's research suggesting otherwise.

Two studies, a 2012 Lawrence Berkeley National Lab (LBNL) and the previously mentioned 2015 Harvard study, prompted this new line of research by injecting ultrapure CO_2 (i.e., CO_2 with no naturally accumulated bioeffluents) into test chambers and measuring the decision-making and cognitive performance of test subjects. Both studies found diminished cognitive performance at CO_2 levels commonly seen in indoor environments. The LBNL study saw overall reduced performance at levels at 1,000 ppm compared to 600 ppm, and the Syracuse study found reduced performance at 950 ppm compared to 500 ppm (lower thresholds weren't tested).

Both experiments used a test called the Strategic Management Simulation tool, which is designed to test the effectiveness of management-level employees in higher-order decision-making (as opposed to other tests often used to measure productivity like proofreading text or adding numbers). In both studies, most decision-making variables showed a decline with higher concentrations of CO_2, but measures of focused activity improved. In the LBNL study, the authors surmise that although focused activity is important for overall productivity, here better focus at high levels of CO_2 might indicate a state of "overconcentration," similar to how people who are drunk or have head injuries tend to become highly focused on small details at the expense of the big picture.

In a counterpoint to these studies, researchers out of Shanghai Jiao Tong University and the Technical University of Denmark conducted a similar experiment in 2016 using a different test to measure cognitive performance. They found no impacts of cognitive performance when pure CO_2 concentrations were increased from 500 ppm to 1,000 or 3,000 ppm. When the researchers allowed bioeffluents to build up with increasing CO_2 levels, however, subjects reported headaches, fatigue, sleepiness, and difficulty thinking clearly proportionally as CO_2 levels increased. As a result, the authors suggest that "moderate concentrations of bioeffluents, but not pure CO_2, will result in deleterious effects on occupants during typical indoor exposures," according to the study.

"There are important differences between the two tests," Allen told BuildingGreen. "The tool used in the Denmark study to measure cognitive function measured more simple tasks, like memory and addition. Our test is designed to measure how effectively people make complex decisions. I see both studies as being important findings, and all of us researchers as working together to get at the heart of these impacts."

If CO_2 is found to have a direct effect on cognitive performance, the implications would be huge. Common stances on how much ventilation is needed would likely increase. And as others have noted, including Joe Romm, of Think Progress, intersections with what's happening with climate change should be considered. Romm's fear is that outdoor levels of CO_2 could rise to levels detrimental for human cognition and there will be no way to bring down CO_2 to safe levels indoors. Even if we are able to curb levels before they reach that threshold, *any* increase in CO_2 ppm outdoors means that we'll have to pour more outdoor air into our buildings to bring down indoor CO_2 levels. With less of a differential between indoors and out, we would need more ventilation to keep levels as low as possible.

That is, unless technologies are adopted to remove CO_2 from indoor air. Most people BuildingGreen spoke with thought it was premature to be talking about actively scrubbing CO_2 from indoor air. "We still have competing studies showing slightly different conclusions," says Elliott Gall. "I think what this shows is that cognitive function can be difficult to measure. I'd say we have to wait for more data." Yet Gall himself has worked on developing a sorbent technology to remove CO_2, and other products—such as the enVerid system, a recent BuildingGreen Top Ten award winner—that are market-ready. Raefer Wallis told BuildingGreen that he has specified and worked with the enVerid system, but as with other air filters, is concerned about added energy use. EnVerid claims the system actually enables 20% energy savings on average, by recirculating indoor air and saving on temperature conditioning, but BuildingGreen was not able to verify performance with any installed projects.

Given that CO_2 is our primary way to determine air quality, a system to remove CO_2 would seemingly reduce or eliminate the need to bring in outdoor air at all. At least it might look that way if you considered current sensor metrics comprehensive. And therein lies the problem; such data tracking can make new engineered approaches feel justified, when—if you take a step back—it becomes clear that we haven't come very far from measuring air quality in olfs. It would be ludicrous to completely cut our buildings off from outside air before having a comprehensive health-based standard for fresh air.

Measuring More Than Olfs

Luckily, the way air quality sensors are currently being used is to aid in bringing in *more* outdoor air when it is safe, and to test the effectiveness of strategies for removing known pollutants. That's encouraging, as increased outdoor air ventilation is associated with better human health and productivity outcomes. And we certainly owe it to disadvantaged communities to pay closer attention—both at a building and a city scale.

However, sometimes with better and more data, it can feel like we know more than we do, and given that a strong understanding of what's beneficial and harmful in our air is still emerging, it's important to recognize that we still have a lot to learn.

NEWSBRIEFS

U.N.: Walking and Cycling Infrastructure Is Urgent Health Priority

A report calls for countries to invest 20% of transportation budgets in infrastructure improvements to promote safety and mitigate climate change

by Sarah Lozanova

Every year, 1.3 million people die in road accidents, and nearly half of the fatalities are pedestrians, cyclists, and motorcyclists, according to the United

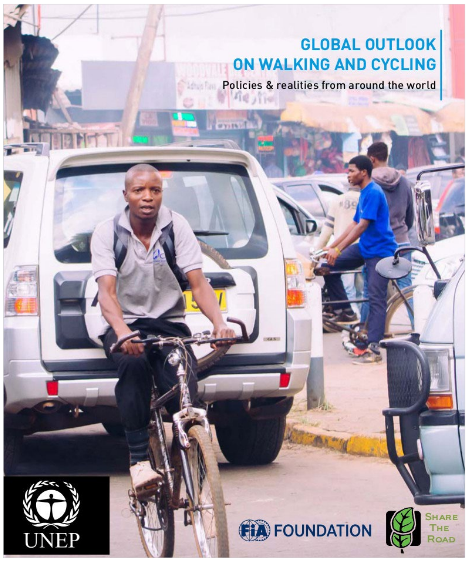

Image: UN Environment

Nations Environment Programme (UNEP) report Global Outlook on Walking and Cycling. Deaths are likely to increase in coming years given that the world's fleet of private cars is expected to triple by 2050, with most of this growth occurring in developing countries.

UNEP is now calling for countries to create and implement local and national policies for non-motorized transport, and to invest 20% of their transportation budgets into infrastructure improvements for pedestrians and cyclists. Such investments can prevent fatalities and promote sustainable forms of transportation.

For the report, UNEP examined 20 low- to moderate-income countries across Africa, Asia, and Latin America and found that proportionately twice as many people die in road traffic accidents in these countries compared to rich countries. The existence of safe pedestrian infrastructure is a key factor in reducing pedestrian fatalities and decreasing air pollution.

"People are risking their lives every time they leave their homes," says Erik Solheim, executive director of UNEP. "But it isn't just about accidents. Designing transport systems around cars puts more vehicles on the road, increasing both greenhouse gas emissions and deadly air pollution. We must put people, not cars, first in transport systems."

Given that motorized transportation accounts for more than one-quarter of total global carbon dioxide emissions, encouraging non-motorized forms of transportation is essential for mitigating climate change. Walking and cycling also offer economic and social benefits as some of the least expensive and most widely available forms of transportation to low- and moderate-income people.

In many developing countries in particular, however, pedestrians and cyclists are at an extreme disadvantage on the road they must share with high-speed traffic. This makes it harder for such people to safely get to work or school and disproportionately impacts disadvantaged populations.

"Unless we act to make our roads safe, in ten years an estimated 13 million more people will have died on our roads—that is more than the entire population of Belgium," says Solheim. "The human impact is horrific, but the impact on all of our survival must not be ignored."

Stone Certification Recognized in LEED v4, Living Buildings

Natural stone is one of the oldest green building materials, but it's the newest to have a rigorous multi-attribute certification recognized by USGBC

by Tristan Roberts

Stone is one of our most durable, timeless, and beautiful building materials, but is it sustainable? Yes, if best practices are employed in stone quarrying, processing, and transportation (see Stone, The Original Green Building Material). To improve the sustainability of stone production and help projects find greener products, the Natural Stone Council (NSC) released ANSI/NSC 373 Sustainable Production of Natural Dimension Stone in 2014. That certification has now gotten a boost with approval by the U.S. Green Building Council (USGBC) for recognition in LEED v4.

USGBC-approved certification

LEED Interpretation #10455, released in October 2016, recognizes ANSI/NSC-373 as a USGBC-approved certification under the Materials & Resources (MR) credit Sourcing of Raw Materials, with products carrying third-party certification to the standard counting toward full credit under Option 1 of that credit. In addition to earning the certification (at any level: Bronze, Silver, Gold, or Platinum), the stone facility has to make its scorecard publicly available and earn one of two optional credits in the system: either 7.2.1 (Ecosystem Boundaries) or 7.2.2 (Environmental Impact Assessment).

In addition, the standard was incorporated into the recent v3.1 release of the Living Building Challenge. In that standard, projects are required to advocate to manufacturers of all dimension stone products used within the project to pursue certification.

Finding certified products should become easier

Products carrying the certification aren't common yet, but they're on the way, according to Kathy Spanier, NSC sustainability committee chair and director of marketing at Coldspring, a Minnesota-based stone industry producer. Spanier told BuildingGreen that four companies carry certifications, with another five on

Image: Natural Stone Council

TexaStone Quarries, Coldspring, Northern Stone Supply, and Stony Creek Quarry are the first four companies to be certified under ANSI/NSC 373, which is now recognized in LEED and the Living Building Challenge.

the way. Companies can certify either quarries or processing facilities. For a finished product to reach a construction project with the NSC certification, however, "the stone would have to be certified at a quarry and then transported to a certified processing facility to maintain chain of custody," says Spanier.

Pursuing the certification has benefited Coldspring and its environmental practices, according to Spanier, noting that it instigated some consolidation in its operations, which in turn reduced its environmental footprint. She also noted that although stone processing doesn't use many chemicals except to operate and maintain equipment, a required chemicals inventory has raised awareness of potential problems and often leads to unneeded chemicals being removed from facilities.

PRODUCT NEWS & REVIEWS

A Tour of Cool Products from Greenbuild 2016

These products from Greenbuild 2016 expo floor save water, use wood in innovative ways, and protect buildings and materials from the elements

by Brent Ehrlich

The annual Greenbuild Expo is one of the best places to discover exciting product innovations and the 2016 convention in Los Angeles was no exception. We're going to present in two parts the standouts that we saw. This article will cover water-saving products, drywall, weather barriers, and select wood products. Stay tuned next month when we'll look at innovative energy recovery systems, photovoltaic panels, insulation, and more.

Water Savings

There were the usual wide selection of designer toilets, faucets, and showerheads at Greenbuild this year, but were there any true water-saving advances or new devices that could influence our habits? We found some, as well as graywater systems that may finally be ready for prime time.

Niagara Conservation: New products for commercial applications

Niagara's Stealth toilet was a BuildingGreen 2010 Top 10 winner with innovative (and quiet) technology that results in an impressive 0.8 gallons per flush (gpf). The Stealth toilet has had more traction in residential applications due to concern from some professionals that the flush volume was *too* low and would not adequately remove waste where there is a long section of pipe or low slope. Now, Niagara is moving into commercial applications with new ADA-compliant side flush handle (the original Stealth models have a push button) and easy to clean models, and is working with architects and builders pre-construction to ensure pipe runs are sloped to handle the low flow.

Niagara also showcased its Hot Start showerhead system that shuts off water flow when temps reach 95°F so those who wander off to brush teeth or grab clothing don't waste water and the energy used to heat it. You push a button when you get in to resume the flow. These WaterSense-labeled products are available in 1.5 and 2.0 gallons per minute (gpm) flow models and use a mechanical spring thermostat shut-off valve system.

Kohler and Toto: New 1.0 gpf products

Performance of Kohler and Toto toilets now approach the Niagara Stealth with WaterSense-labeled products at 1.0 gpf. Both companies offer a range of products that meet Maximum Performance (MaP) requirements for removing solids. For Kohler, its Class Five 1.0 gpf products include the Wellworth and Highline lines; for Toto, it's the Carlyle II and Drake II lines, but Toto also offers a Neorest dual flush model at 0.8 or 1.0 gpf.

Evolve Technologies: Hot-water shut-off valves

Evolve also offers several water-saving systems that incorporate thermostat shut off valves when water temperatures reach 95°F. Evolve says that its systems are a response to "behavioral waste," the 38–56 seconds of time, on average, that hot water runs in a shower before people actually get in, as found by researchers at Lawrence Berkeley National Lab (LBNL). Evolve uses a proven wax-based system, including the Showerstart TSV (thermostatic shut-off valve) that is installed between the shower pipe and showerhead, with Watersense-labeled 1.5, 1.75, and 2.0 gpm showerheads. The company also now offers a system that shuts off water at the tub spout (normal spouts can flow up to 5 gallons per minute) and diverts it to the Showerstart showerhead.

Grayworks: Rainwater management solutions

With droughts throughout the world, reservoirs down, aquifers running dry, and water costs increasing across the board, expect graywater treatment and reuse to become more relevant in the coming decade. At Greenbuild, the Grayworks modular plug-and-play commercial graywater reuse system was on display. Grayworks units are available to handle flows from 1,200 –10,000 gallons per day, according to the company, using these steps:

Image: Rainwater Management Solutions

Grayworks is a modular plug-and-play commercial graywater reuse system for flow rates from 1,200 to 10,000 gallons per day.

- A prefilter removes hair, lint, and other debris from the water. Worried about maintenance? A high-pressure spray automatically keeps the stainless steel screen clean.

- Bacteria on the company's proprietary media break down contaminants.

- A self-cleaning filter (that lasts 2–3 years) removes the remaining solids and sends debris to the sewer, before an ultraviolet light disinfects the water.

- The components for a chlorine and dye system (to mark treated water as as graywater) are also integrated into the unit and can be used where codes require further sanitation.

The system is monitored for performance and integrates into building management systems. Information can be accessed via a web-based dashboard.

Protecting Drywall and Sheathing from Moisture Damage

Some exciting new products protect drywall and sheathing from moisture damage caused by leaks and weather.

VersaDry: Simple protection from nuisance moisture

Sometimes simple systems change the industry and the VersaDry Drywall Track System has the potential to do just that. This steel rail system elevates drywall onto a shelf two inches above floor level, protecting it against water that gets into a building during construction or via nuisance leaks. With standard construction, water can wick into drywall from the floor, which damages the drywall and can lead to mold, remediation, and removal. Water-damaged drywall is a significant source of material waste in the construction industry, and replacing finished drywall in occupied buildings is expensive and inconvenient.

The VersaDry system installs into the floor and studs, and can be used for wall systems using 2″–12″ studs. The system leaves no void at the floor so there is no need for caulking, which can save considerable labor, time, and material costs, and it is available with one- or two-hour fire ratings. The flat surface also simplifies installation of base materials, a bonus for trades.

DensElement: A labor-saving weather barrier system

For anyone interested in Georgia-Pacific's DensElement system (see A Manufactured Solution for Continuous Air and Water Barriers) in person, Greenbuild offered a full mockup. This system uses a factory-applied air- and weather-barrier applied beneath the fiberglass of DensGlass exterior sheathing to manage air and water leakage (a similar system is Securock 430—a BuildingGreen 2017 Top 10 winner). Georgia Pacific uses Prosoco's silyl terminated polyether (STPE) chemistry R-Guard FastFlash (another former BuildingGreen Top 10 winner) at screw heads, joints, and transitions.

Vaproshield: First Red-List-free peel-and-stick

Vaproshield's peel-and-stick air and weather resistive barrier emits no VOCs and requires no primer in most applications, yet it is UV resistant and can be exposed to the elements before cladding installation. Used in Living Building Challenge (LBC) projects such as the Brock Environmental Center, it is the first weather resistive barrier self-adhered sheet to earn a Declare label signifying that it contains no LBC Red-List chemicals.

Unique Wood Products

There has been a resurgence in the use of wood timbers for structural use because of its purported lifecycle and carbon advantages over steel and concrete (see Engineering a Wood Revolution). WholeTrees displayed a new take on this concept, but there was an intriguing interior product at Greenbuild as well.

WholeTrees: Structural elements from trees

WholeTrees uses unmilled round timber from invasive black locust to create fully engineered structural architectural systems that directly replace conventional structural systems but instead look like, well, whole trees. They create a distinctive look that provides an attractive connection to nature, but they also have real performance and environmental credentials.

WholeTrees products are available with FSC-certifications, have a Declare Red List Free Label, and have an HPD v1.0 with residuals revealed down to 100 parts per million. To protect against insects and decay, the wood is treated with borates. WholeTrees uses a natural finish made from tung and linseed oils, pine resin, beeswax, and D-Limonene (which unfortunately is an aquatic toxicant).

Though WholeTrees structures look rustic, the engineering that goes into these systems is sophisticated. The company takes advantage of unmilled timber's strength, and assists in the design and engineering to create systems that are as code-compliant as heavy timber structures.

Photo: Heartland Photography

In this Festival Foods store, WholeTrees used 30,000 ft² of structural supports sourced from regional forest cullings. Each column is capable of supporting 200,000 lbs.

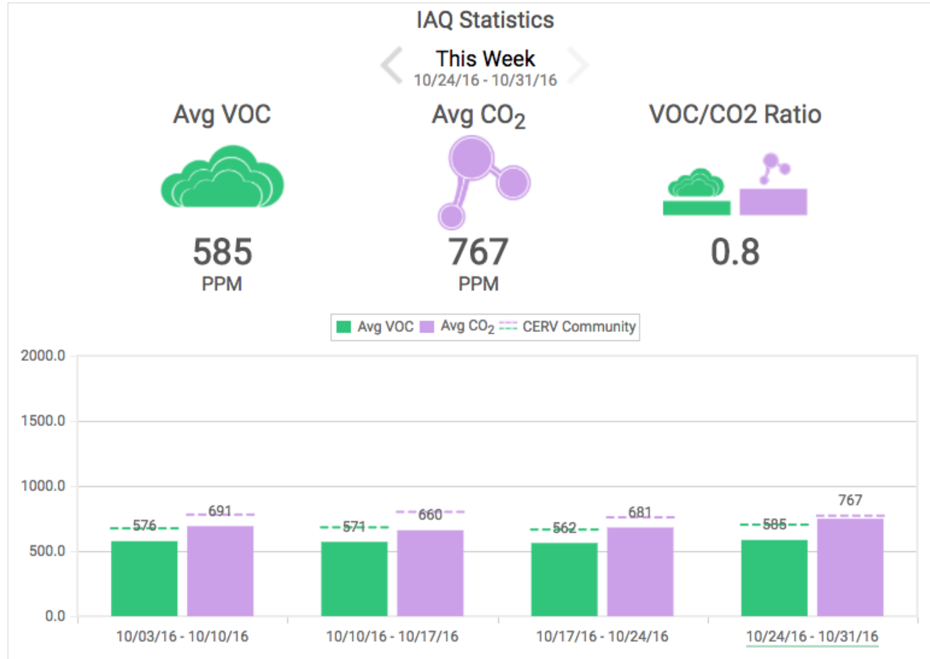

Image: Build Equinox and CERV

Demand-controlled ventilation systems monitor air quality indicators—such as CO_2 and VOC concentrations—in real time, and adjust ventilation rates based on the actual need for fresh air. This can help ensure that the air quality stays within target parameters, as demonstrated by this dashboard from a CERV system installed in a home in Urbana, Illinois.

WoodTique: Ultrathin veneer

The opposite of strong, unmilled lumber might just be WoodTique, an ultrathin wood veneer (0.2 mm or 0.0008″ thick) from Japan. WoodTique is flexible and has a paper backing that gives it the performance of wallpaper. It comes in 2′ x 8′ sheets and can be used for accents or wallcovering, or can be wrapped around columns. Using WoodTique could reduce the amount of wood required for these applications and save on labor, and though the company does not currently have FSC certification, the company claims its logs are carefully selected from sustainable sources.

It is applied like wallpaper. Over drywall, use wallpaper paste, smooth it out, and trim the corners with a utility knife. Metal or other substrates would require contact cement or another appropriate adhesive. WoodTique is currently available in maple, mahogany, oak, cedar, and walnut.

What Did You See?

As mentioned, this great mix of products is just Part 1. We have many more to come next month and several of them could potentially change how we design our buildings. In the meantime, if you saw anything new at Greenbuild, please let us know in the comments online.

PRIMER

Demand-Controlled Ventilation: Fresh Air Only When You Need It

Balancing the need for fresh air with minimizing energy use is difficult. Demand-controlled ventilation is the responsive solution.

by Candace Pearson

People often talk about the "energy penalty" associated with more fresh air ventilation. Some level of fresh air is needed for human health and comfort, but pulling in and conditioning fresh air negates hard-earned efficiency measures.

Demand-controlled ventilation is a way to reduce that energy penalty by pulling in fresh air only when it is needed, and shutting off when it is not.

Originally driven by occupancy

Ventilation's main purpose is to dilute or expel two types of indoor air pollution: odors and pollutants generated by people, and volatile organic compounds that are offgassed from building components and furniture.

Demand-controlled ventilation was initially conceived because the first source of pollution—people—is variable; a different number of people may be in a room at any given time. Certain kinds of spaces—like classrooms, theaters, or conference rooms—can have very high peak occupancies, but are vacant or have lower occupancy for much of the time. For ventilation to serve peak levels 100% of the time is wasteful.

A variety of strategies have been developed to account for occupancy fluctuations. Ventilation systems can be programmed to run on certain schedules. If you knew the school gym was only used from 3:30–6:30 p.m., for example, ventilation rates for that space could be dialed back the remainder of the time.

Ventilation schedules, however, seldom match up with the true specifics of occupancy. Sensors can provide much more accurate triggers for ventilation. Occupancy sensors, like the ones that activate lighting when you walk into a room, can also be used in to trigger ventilation. Carbon dioxide (CO_2) sensors are now an even less expensive option and more precise. CO_2 levels are a good indicator for concentrations of people-related pollutants, as CO_2 levels proportionally increase with added occupancy. (This is because CO_2 is a natural product of human respiration, which occurs at a relatively predictable rate.)

In a recent study of demand-controlled ventilation systems installed in Minnesota, researchers found that these kinds of systems brought a median energy savings of 34%, which equated to $0.09 per square foot annually.

Becoming more precise with added sensors

However, occupancy is only part of what determines that more fresh air is needed. As sensor technologies are evolving, demand-controlled ventilation systems are getting smarter about analyzing other sources as well, thus finding further efficiencies.

Levels of volatile organic compounds (VOCs), for example, shift over time. A piece of furniture will typically offgas less with age, while cleaning compounds used to deep clean bathrooms might clause levels to spike. At least one residential ventilation system, the Conditioning Energy Recovery Ventilator (CERV), now utilizes VOC sensors to respond to these changes, according to CERV founder Ty Newell Ph.D. In retail settings, formaldehyde and other VOCs that offgas from clothing and other retail goods could turn out to be much more relevant indicators for ventilation needs.

Responsive only to what you can measure

Demand-controlled ventilation promises to save energy by providing fresh air only when you need it, but there is some debate about whether its application produces outcomes that are actually optimal for human health. For example, demand-controlled ventilation systems have a slight lag because it takes CO_2 levels time to build up in a space. As a result, the system kicks on only once levels are already high, and it may take a while to bring them down.

Furthermore, some question whether current metrics are sufficient for determining when fresh air is needed (see Clean, Fresh Air: Getting What We Need). CO_2 is currently recognized as merely an indicator for other pollutants—rarely are pollutants like formaldehyde measured directly. And other issues, like what kinds of substances we want *in* our air, are still questions for research.

Yet demand-controlled ventilation systems have been on the market for over a decade, and some research—such as the Minnesota study—suggests that occupants are happier with indoor air quality where such systems are utilized. And with evolving technology, we can expect that such systems will become ever more responsive, adapting to whatever actual conditions we're able to measure.