Shaping the Next

Indoor Air Quality

This year's Presidential theme, Shaping the Next, focuses on creating positive change for our world, ourselves, and our work by setting goals, making realistic plans to achieve them, and having the commitment to follow them. Part of that process is imagining the future and the possibilities it holds. To that end, we've invited groups of experts to comment on, and speculate a bit, about the future of several areas of critical importance to ASHRAE, the built environment professions, and society.

This first collection addresses indoor air quality (IAQ), the most important aspect of what I consider to be our fundamental obligation to strive to provide indoor environments that are safe, healthy, productive, and comfortable while conserving resources and the environment.

This diverse group of essays considers a variety of technology issues impacting IAQ and the associated energy use and emissions—use of outdoor air to dilute contaminants, control of unintended airflows in buildings, use of air treatment technologies like filtration and ultraviolet germicidal irradiation to control particulates and bioaerosols, and reduction of indoor contaminant levels through material selection.

Perhaps most importantly, they also discuss a critical shift in thinking from a goal of indoor environments that are acceptable to the occupants to those that are truly healthy and productive. Only if we define the right goals can we use the tools of science and technology to best advantage.

– BY WILLIAM P. BAHNFLETH, 2013–14 ASHRAE PRESIDENT

What is Next?

Indoor Environments, Productivity, and Learning

BY WILLIAM J. FISK, FELLOW ASHRAE

We now have compelling evidence from multiple quality studies indicating that maintaining comfortable indoor air temperatures and providing higher outdoor air ventilation rates often improve work and schoolwork performance. Very limited data indicate that removing sources of pollutants can increase work performance. Higher concentrations of carbon dioxide, with all other factors constant, have decreased performance in decision making, but only two studies have been performed. Higher satisfaction with indoor air quality is correlated with improved work performance, although we do not know if the relationship is causal. Four studies, two from schools, one from offices, and one from a daycare facility now report higher absence rates in buildings with less outdoor air ventilation. Increased absence may be related to worsened work performance and learning.

Many important questions remain. Is it thermal comfort or temperature that affects performance? If comfort is the key parameter, energy-saving measures, such as increased air movement coupled with higher temperatures, can maintain comfort without diminishing performance. Why do higher outdoor air ventilation rates often improve performance? What are the key pollutants?

If we had answers, we might be able to maintain performance through pollutant source control, which is more energy efficient than ventilation. Does ventilation still help to improve performance when the outdoor air is highly polluted? Does the data showing better performance in schoolwork tasks and improved scores in standardized academic performance tests when classrooms have higher outdoor air ventilation rates really indicate better learning by students? We know that sick building syndrome symptoms in offices diminish with more outdoor air ventilation—does the reduction in symptoms increase our work performance?

Answering these and other important questions are keys to production of buildings that maximize performance and learning. In addition, future research should more often assess the relationships of indoor environmental parameters to high level cognitive performance, such as decision making performance, and rely less on task performance, such as typing speed or proof reading accuracy.

Although the list of important unanswered questions is long, the existing findings are more than sufficient to motivate actions to improve aspects of indoor environmental quality. Economic analysis show that the economic benefits of measures that improve performance and decrease absence will far outweigh the implementation costs. However, is imperative that we consider how our actions, designed to improve productivity and learning, affect building energy use and emission rates of greenhouse gases. We are challenged to provide healthy and productive indoor environments while making our buildings even more energy efficient. The challenge is large, but the challenge is one we must meet.

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Tight Building Envelopes—Finally

BY ANDREW PERSILY, PH.D., FELLOW ASHRAE

Sometimes the next best idea has been around for a quite a while. That is the case with building envelope airtightness, the importance of which was recognized in the 1960s by researchers and practitioners in Canada who learned the hard way that a leaky building had a host of problems. Since then the learning curve of the advantages of building tightness has been a slow one, but we are finally getting to the point where more and more people in the building community have learned the importance of airtightness. To summarize, infiltration is a bad way to ventilate a building; its rate and distribution is uncontrolled and unreliable, the incoming air is unfiltered, and it can have serious negative impacts on thermal comfort, indoor air quality and material durability. Oh yeah, and it consumes unnecessary energy 24-7.

So, what's new and where are we going. In recent years we have seen air barrier requirements added to ASHRAE Standards 90.1 and 189.1, as well as a number of state and federal construction programs. Training and awareness have also increased, helping designers and contractors to build tight. But there is more work to be done.

Only some of these standards and programs require actual airtightness testing, which is the only way to know the building is actually achieving its performance goals. Good intentions and applying air sealing membranes or sealants do not alone make a building tight. It takes attention to details, particularly intersections between different wall types, windows and roofs, to get the job done. If we are going to achieve the decades old mantra of "build tight, ventilate right," we need to continue to get serious about airtightness by continuing to increase awareness and training, and by measuring the airtightness of our building as a routine part of the construction process.

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Filtration and Air Cleaning

Where are We and Where are We Going Next?

BY H.E. BARNEY BURROUGHS, PRESIDENTIAL MEMBER/FELLOW ASHRAE

Filtration and air cleaning (FAC) is a relatively mature environmental technology that has a great deal of remaining stamina and potential. But to understand its significance in the future, it is important to appreciate the progress made over recent decades that will set the stage for a launching pad into the future.

When I entered the industry, the HEPA filter (created in World War II as part of the Manhattan Project) was being manufactured under patents and only was applied in nuclear, pharmaceutical, and electronics facilities. The self-supporting, extended high-efficiency pocket filter had just been invented and patented and was

Shaping the Next...

Ultraviolet Germicidal Irradiation for Indoor Environmental Quality

BY STEPHEN B. MARTIN, JR., P.E.

Ultraviolet germicidal irradiation (UVGI) technologies have existed for over a century. Today, UVGI fixtures with low-pressure mercury vapor lamps are commonly installed inside HVAC systems in schools, office buildings, health-care settings, correctional facilities, social-assistance shelters, and homes to improve indoor air quality and reduce disease transmission. With the emergence of new and drug-resistant pathogens, and the continued threat of bioterrorism, it is likely that UVGI systems will be applied even more in the future. However, the effective and efficient implementation of UVGI technologies remains as much an art as a science.

Successful UVGI systems have been installed for a variety of applications, yet no consensus guidelines exist that comprehensively address all aspects of system design to ensure good disinfection. Important tools necessary for establishing design guidance are also lacking. There are currently no standard test methods for rating the performance of typical in-duct UVGI devices. Similarly, critical analyses of real-world systems that evaluate performance and economics are lacking. As a result, UVGI systems are typically oversized to ensure performance, which creates the potential for increased equipment and utility costs, and wasted energy.

ASHRAE's Standards Project Committee 185 has developed two proposed test methods that have each gone through public review and should be published soon. Proposed Standard 185.1P, *Method of Testing UVC Lights for Use in Air Handling Units or Air Ducts to Inactivate Airborne Microorganisms,* was developed to test in-duct UVGI devices for "on-the-fly" disinfection of organisms in the moving airstream. In-duct UVGI devices used to inactivate microorganisms on coils, drain pans, or other surfaces will be addressed by Proposed Standard 185.2, *Method of Testing Ultraviolet Lamps for Use in HVAC&R Units or Air Ducts on Irradiated Surfaces.* Multiple research studies to critically analyze UVGI system performance, energy use, and economics are currently under way or planned to launch soon.

The important information that will result from these test methods and research projects is coming at a critical time. UV light-emitting diodes and amalgam lamps already exist, and research to produce lamps with non-toxic materials continues. Smart ballast systems are being designed to switch lamps on/off and maintain a set disinfection level as variables within HVAC systems change. Closing current gaps in understanding of system design will provide engineers with key tools that can be used as these exciting new technologies are incorporated into future UVGI systems.

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being applied in health care through the requirements of the Hill-Burton Act. The most widely used high-end commercial filtration was performed at that time by elaborate electrostatic precipitation or exotic air washers. Chemisorbant molecular filters had just been patented and introduced to the industrial market. The 2 in. pleated filter had been developed with proprietary fabrication technology. And, the 21st century was a career lifetime away.

Here we are in the 21st century and, of course, those original restrictive patents and cumbersome products are long gone, allowing proliferation and maturing of products, companies, and markets. However, the latter period of the 20th century, including the last decade, contributed significant factors that impact FAC application and technology.

The 1989 version of ASHRAE Standard 62 incorporated the Indoor Air Quality Procedure, which allowed the use of FAC as an alternative to increased use of treated outdoor ventilation air for internal contamination control.

The development of the "mini-pleat" fabrication technology enabled high-efficiency and high capacity particulate filtration with lowered pressure drop.

The development of new synthetic polymer-based fibers yielded filter media with electrostatic properties that enabled enhanced extraction efficiencies with lower pressure drop.

The development of ASHRAE Standard 52.2 facilitated more authentic particulate efficiency performance data and replaced 70 year-old test methodology. Likewise, *Advertisement formerly in this space.*

Ventilation Trends

BY DENNIS STANKE, FELLOW/LIFE MEMBER ASHRAE

Indoor pollution impacts occupant comfort, health and productivity. An old adage holds that "the solution to pollution is dilution" and that's true. But this question remains: What minimum outdoor airflow (OA) rate provides adequate dilution? Of course, the answer depends on the rate of indoor-source pollution and the type of ventilation system used.

Since 1973, Standard 62 has been the primary ventilation resource document with requirements to: 1) reduce indoor contaminant sources and 2) prescribe minimum outdoor airflow rates for listed occupancy categories.

Indoor Sources

The standard addresses indoor contaminant sources with requirements that, for example, reduce the potential for microbial growth, reduce the intake of contaminants from outdoors, and reduce the potential for dirt accumulation within the air-distribution system. In the future, architects will probably select lower-emitting materials, designers will probably include better dehumidification features, and they may specify better air-cleaning devices to remove both indoor- and outdoor-source contaminants.

Minimum OA Rates

The standard allows three alternative ventilation approaches. For mechanical ventilation systems, the Ventilation Rate Procedure (VRP) prescribes rates and calculations necessary to determine minimum zone and system OA rates; and the Indoor Air Quality Procedure (IAQP) provides a method to find minimum zone OA rates based on a performance analysis of contaminant levels, which requires considerable design-team judgment. For natural ventilation systems, the Natural Ventilation Procedure (NVP) prescribes geometry-related parameters to provide at least adequate OA rates under the right conditions. When conditions are wrong (too cold, too hot, too windy, too polluted, and so on) a properly designed mechanical ventilation system must be used, so most NV systems require mixed-mode operation.

Designers continue to use the VRP; it's low risk and it forms the basis for ventilation requirements in building codes, labeling programs and rating systems. Use of the IAQP may increase as more information about contaminants of concern, emission rates, and gaseous air-cleaning efficiency becomes available, but some key design-team risks will continue to limit its use. The NVP (with mixed-mode mechanical ventilation) may see increased use, too, especially in those climates with many economizer-cooling hours.

Future Mechanical Ventilation Systems

The VRP defines three mechanical ventilation systems: single-zone, 100% outdoor air, and multiple-zone. In recent years, use of 100% OA systems has grown, since they often deliver minimum OA rates while reducing energy use. But when properly designed to meet standards and codes, these systems don't always deliver significant energy or IAQ advantages over other, well-designed systems, and may be more expensive. For instance, Standard 189.1 requires demand-control ventilation (DCV) in classrooms, which means variable OA rates; the 100% OA unit must be designed without population diversity credit and it must be a VAV system with all the associated ducts, dampers and controls. A 100% OA system in a school might be more expensive to install and operate than a VAV-reheat multiple-zone system.

Who can say what the future holds? But it wouldn't be surprising to see more VAV single-zone systems, more VAV 100% OA systems with VAV boxes and DCV, more VAV multiple-zone systems with a long list of energy-saving controls. Now we wait.

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the development of the ASHRAE Standard 145 series test methods provides meaningful gas phase filter performance data.

The development of dual filtration media having both particulate and gaseous control capabilities.

The focus on the indoor environment and related human health effects started with UFI (urea formaldehyde insulation) and then grew to include respirable particulates, VOCs (volatile organic compounds) and "toxic" mold. This yielded litigation, media focus, regulation ("no smoking"), and awareness by building owners and homeowners and occupants alike, becoming the "IAQ" issue.

9/11 left lasting societal impact. One aspect was the

Natural Ventilation

BY YUGUO LI, FELLOW ASHRAE

Natural forces such as winds and buoyancy force due to indoor and outdoor air density difference drives natural ventilation through purpose-built envelope openings. These include windows, doors, solar chimneys, wind catchers, trickle ventilators, etc. For our discussion, we do not consider uncontrolled air infiltration through unintended envelope leakage as a natural ventilation system as its expected performance will be poor.

Before the invention of mechanical fans, natural ventilation had been the only available system for providing outdoor air in buildings. Addington[1] gave an interesting account of the debate as to whether mechanical ventilation or open windows provided the best building ventilation in the early 20th century. At the time, engineers and manufacturers believed that only mechanical systems were capable of providing buildings with reliable ventilation. The revitalization of natural ventilation and the development of mixed-mode ventilation in the last 20 years confirms the wisdom of Charles-Edward Amory Winslow and Dr. Leonard Hill, who led the failed effort in promoting open windows in early 20th century.

Natural ventilation can help solve a number of problems typically connected to mechanical systems. Generally, natural ventilation can provide a high ventilation rate more economically than mechanical ventilation and can be more energy efficient. The relatively low first costs and maintenance costs are other advantages.

The natural ventilation performance depends on climate, building design, human behavior and other requirements such as security, mosquito control, fire smoke control etc. The major drawbacks of a natural ventilation system are:

- Without proper design and control, ventilation rates can be greatly variable and dependent on outside climatic conditions. The two driving forces that generate the airflow rate—wind and temperature difference—vary stochastically as a function of outdoor climate conditions and of occupant behavior (opening and closing windows and doors and varying the indoor air temperature). Ventilation may be difficult to control, with airflow being uncomfortably high in some location and stagnant in others. There is a possibility of having a low air change rate during certain unfavorable climate conditions.
- There can be difficulty in controlling the direction of airflow, which can be significant in some hospital environment, toilets, etc.
- The relative small driving natural force often precludes the use of particulate filters.
- Energy and comfort criteria usually dictate that windows and vents remain closed in winter, when outside temperatures are low, or in hot and humid climate.

As with mechanical ventilation, natural ventilation of buildings has its own design and operation challenges.

Modern natural ventilation is also a technology-dependent solution similar to mechanical systems. Unlike traditional natural ventilation systems, natural ventilation today depends on computer control systems, smart sensors and controls, and modern design of ventilation openings, etc. If properly designed, natural ventilation also can be reliable, particularly when combined with a mechanical system using the hybrid ventilation principle. In hybrid ventilation, natural and mechanical forces either co-exist or can be switched between each other.[2] Natural ventilation is now recommended as a design solution for infection control by WHO.[3]

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emergence of high-efficiency particulate and gas phase filtration (FAC) as the last bastion of survivability protection of occupants exposed to airborne weapons of mass destruction.

With that understanding, here is what I believe is next with FAC and contamination control in the indoor built environment.

The drivers of “net-zero” and “sustainability” will

Materials Selection

BY BOB MAGEE

The "*solution to pollution is dilution" or "build tight ventilate right*" approaches can be ineffective/costly ways to achieve "healthy" indoor environments if other factors are ignored. A careful systematic approach to the design and operation of buildings is essential to proactively avoid IAQ problems and minimize true operational costs (including those related to occupant productivity). These concepts, while not new, are increasingly threatened by resurgent pressures to build energy-efficient buildings.

Appropriate selection of building products, finishes and furnishings is a key aspect in the proactive control of indoor sources of health-relevant organic contaminants given the fact that emissions (or "off-gassing") from products (including paints, adhesives, engineered wood materials, flooring, etc.) can easily vary by orders of magnitude. Long-term durability is another key consideration (reducing the frequency of replacement and associated higher emissions from new materials) as is selection of materials that can be cleaned using relatively inert (low emission) cleaning agents.

So how does the building design/renovation/operation team make effective material selection choices?

Product labeling systems based on content of volatile organic compounds (VOC), typically expressed as mass per unit volume, provide some indication of potential source strength, but are limited in terms of prediction of the true impact on indoor air levels of contaminants of concern. More comprehensive evaluation is provided by emissions chamber testing of products or through validated mass transfer-based modelling of emissions. These approaches can lead to reasonable prediction of indoor levels of a broad spectrum of organic (and possibly particulate) contaminants resulting from the installation of a specific amount of a given material indoors. The resulting ability to estimate acute exposures (critical to determination of risk for workers involved in installation of new materials as well as for establishing safe re-occupancy times following renovation activities) may be equally important in certain cases to the long-term, chronic exposure levels that are key to building occupants.

Harmonization of the methodologies used in the evaluation of product emissions, the estimation of indoor levels based on emissions data, and on the identities and levels of concern for specific indoor contaminants (including semi-volatile organic compounds, or SVOCs, such as phthalates, flame retardants; as well as reactive compounds such as isocyanates) are all key elements under consideration in North America, Europe and globally. These challenging tasks will have enormous impact on the effective identification of low-emission materials suitable for use in truly "sustainable" buildings.

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re-ignite the "Disney-like" dream of the "bubble" building. Walter dreamed in 1960 that Epcot and Celebration and Disneyland would all be under a bubble…a totally environmentally controlled community for live, work, and play. I believe that the totally enclosed, minimally pressurized building is possible and practical through the use of FAC for contaminant control. This eliminates the dependency on the energy cost and availability of clean and dry outdoor air for contaminant control by dilution and provides increased cleanliness efficiencies providing an indoor environment that will approach clean-room conditions.

The trend for high capacity, high efficiency, and lower pressure-drop FAC systems will continue through tactics like mini-pleating, over-sizing, product development, and combination particulate and gas phase control products.

The awareness of the impact of PM 2.5 particulates on respiratory effects and the increasing knowledge about the role of environmental toxins are hinting at the exposure influence on health issues like arthritis, allergies, diabetes, heart disease, weak immunity, fatigue, dementia, and even obesity. This indicates the need for improved control of the particulate and chemical contaminant burden in the indoor environment and may bode for regulatory coverage.

The importance of indoor contamination control will drive energy, ventilation, and sustainability Standards, like 62, 90, and 189 to more fully exploit the potential of applied FAC technology. Likewise, building performance protocols, like LEED, will more strongly support enhanced FAC tactics as being both cost effective and energy effective.

The need for low energy usage, high performance, and low maintenance requirements will drive the research, development, and field verification of performance of new or emerging technologies, including UVGI and other irradiation approaches; various catalyst/reactive approaches for both particulate and molecular control; and unique combinations of tactics.

The prevalence of ozone as a specific reactive contaminant of concern and its role in the creation of adverse contaminants, both particulate and gas phase, will drive specific research, product development, and performance verification of control technologies and products.

Much of the original research linking FAC with health-related application is lost or obsolete. This will drive new research employing FAC as an intervention mechanism of exposure in the etiology of airborne disease. This will reestablish the role of FAC in health care and disease prevention in light of current environmental and mechanical conditions.

The importance and critical nature of the indoor chemical environment and the need for accurate system maintenance will drive the development of sensor technology to accurately monitor the indoor environment to signal quality excursions and indicate the need for system maintenance.

Implicit in the sensor development is the need for target exposure levels which will drive the development of meaningful and science-based concentration targets of acceptability from both a comfort, but also health effects basis.

Yes, FAC is a mature 70+ year old technology from the prior century, but the technology has unique established advantages and proven potential to offer as the HVAC industry faces the challenges of the second decade of the 21st century.

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