
Stephanie Taylor

Bridging Mechanical Engineering and Medicine

Monitoring IAQ And Occupant Health

BY STEPHANIE TAYLOR, M.D.

Mechanical engineers and building managers were suddenly thrust into the very center of protecting public health when infectious disease scientists conclusively showed that SARS-CoV-2 could be airborne for distances greater than 6 ft (2 m). Managing the indoor environment, and specifically indoor air quality, to limit the spread of infectious disease is now relevant to all occupied buildings, not just health-care facilities. This presents an opportunity and a responsibility for building professionals. This column highlights some challenges and opportunities in bridging the silos of mechanical engineering and medicine.

The *2021 ASHRAE Handbook—Fundamentals* states: "Engineers are better able to keep indoor environments safe and productive while protecting and preserving the outdoors." To fulfill the promise to keep indoor environments safe, building professionals must understand not only how to decrease indoor pollutants, but also understand how indoor conditions impact occupant immunity and general health.

Clearly, the human body does not exist in a silo. Our cells, tissues and organs interact with and are impacted by our environment. The task of correlating the indoor environment to health, however, is not easy. Despite the complexity, we must at least not confuse air quality measurements with the more comprehensive health impact of the indoor environment.

IAQ and Health

Many diseases can be prevented or decreased by limiting indoor exposure to particulate matter, organic gases (hydrogen and carbon chains), inorganic gases and low ambient relative humidity. For example, an abundance of data associates fine particulate matter with increased heart disease, strokes and premature birth. Water-soluble gases mix with our respiratory tract mucus to gain access to our tissues, while non-polar gases can diffuse directly through our skin and cause organ damage. When the indoor relative humidity (RH) is low, occupants experience increased symptoms of reactive airway disease (asthma) and upper airway irritation, as well as problems from mild tissue dehydration.

Furthermore, harm from pollutant and adverse thermal conditions does not require days or even hours of exposure. In some cases, damage begins after several minutes.

Creating a Health Impact Score For Indoor Spaces

Engineers with a good understanding of indoor pollutants and acceptable exposure levels are well versed in measuring discrete compounds such as particles and volatile organic compounds (VOC). When IAQ is

Stephanie Taylor, M.D., is president and founder of Building 4 Health, Inc. She is a member of ASHRAE's Epidemic Task Force and the Environmental Health Committee.

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FIGURE 1 Individual indoor exposure metrics vs. occupant health consequences.

AIR QUALITY	MEASUREMENTS	HEALTH IMPACT	MEASUREMENTS
Viral Count	Air Sampling	Infections	Number of Infected People
Particle Levels	Particle Counts	Penetration Into the Body	Infection and/or Inflammation
VOCs	Diffusion Monitors, Photoionization Detectors	Organ Dysfunction	Cognitive Tests, Liver Enzymes
Low Humidity	Resistance Sensors	Skin, Mucus Membrane and Tissue Dehydration	Visual Inspection, Respiratory Mucus Viscosity, Excess Tearing of Eyes
CO_2	Air Monitoring, NDIR Sensors	Brain Impairment	Fatigue, Confusion
Ozone	Air Monitoring, Electrochemical Sensors	Inflammation of Tissues	Pain, Cough, etc.

related to human health, however, the individual exposure levels do not tell the whole story. Occupant health or disease is influenced not only by exposure to individual constituents, but also by the interaction of chemicals, particulate matter, temperature and water vapor levels. Clearly, this dramatically increases the number of variables in an algorithm that connects indoor exposures to health or disease. The benefit to having multiple inputs in a health impact rating is the flexibility this gives to IAQ remediation steps.

Following this logic, adjustments in ventilation and applications of air cleaning strategies should be guided by a holistic health impact view of all of the factors that impact the physiological and immune functioning of occupants (*Figure 1*).

On close inspection of *Figure 1*, monitoring individual indoor constituents is more straightforward than quantifying the health consequences of exposures because an individual's health is a result of many inputs that can be difficult to identify and quantify. These often elusive variables include: occupant age, activity levels, liver function and ability to detoxify chemicals, and other underlying states of health or disease. Furthermore, as already highlighted, indoor compounds can interact and become more impactful than individual chemicals. For example, when indoor RH is less than 40%, inhaled particles can gain deeper entry into lungs and cause greater damage than the same particles in the RH 40% to 60% zone.

What do we need to have a better understanding of the hidden building conditions associated with acute and chronic diseases? Do we have to wait for OSHA to discover a glaring problem after many people have been harmed?

The Economics of Healthy Occupants

COVID-19 has eclipsed debates about the affordability of building interventions to support human health. Assessing the economics of building occupancy and business operations gives us an abundance of reliable data to quantify the financial rewards of health-oriented indoor air management.

Creating a real-time and usable database from measurements of occupant health and productivity would clarify the impact of the design, operation and exposure to building materials. Unfortunately, collecting this data is more complicated than measuring, for example, fuel consumption and energy efficiency because metrics associated with health are more complex. Historically, health outcomes have been considered outside the expertise of the construction industry and have remained largely unmeasured and unregulated, resulting in an economic stalemate.

Without specific health metrics usable in the construction industry, real estate developers cannot demonstrate the "value" of design and maintenance choices associated with improved health and productivity. Meanwhile, the health costs of occupants in poorly designed buildings cannot be accurately assessed by investors and other stakeholders. This obscurity limits incentives to invest in health-based design as a strategy for competitive market differentiation.

With accurate and simultaneous tracking of indoor exposures and concurrent building-related illnesses, we could implement prevention strategies and regulatory codes based on knowledge of specific health-related and financial impacts of IAQ.

Now that the potential severity of COVID-19 and the airborne component of SARS-CoV-2 transmission has been revealed, the cost-benefit model for safe IAQ expands beyond employee productivity and comfort to the very value of a human life. A return-on-investment model that includes occupant health needs not only metrics on energy saved, but also metrics on the short- and long-term costs of medical care for illnesses associated with poor IAQ.

Health insurance companies calculate the cost avoidance of common medical expenditures and conclude that one year of good health is worth $50,000.[1] The Environmental Protection Agency (EPA) takes an even more holistic approach before mandating a new regulation. The EPA asks only one question: Do the benefits outweigh the costs? To answer this, the number of deaths prevented is multiplied by the value of each life saved. They use a calculation called the value of a statistical life (VSL)[2] to calculate the value (although no one wants to use that term) of an entire lifetime. The VSL takes an indirect approach to the question, asking how much money people are willing to pay to reduce the probability of their own death. Using the VSL, the EPA places the value of one life at about $10 million.[3]

If the VSL method is in place to evaluate regulations such as seat belt mandates, why can it not be used to enforce healthy indoor air to prevent health problems? There are at least two reasons why this does not work. Determining even an approximate VSL requires both perception of the risk and an ability to make choices to avert the danger. Often, neither of these variables are present when low levels of pollutants exist in tightly sealed buildings.

In summary, the COVID-19 pandemic has conclusively reminded us that indoor air management is key in protecting us from infectious diseases. Integrating medical knowledge with real-time data on indoor exposures will give us a holistic picture of how buildings impact health. This clarity will allow us to take a huge leap forward in creating indoor environments that truly support our health, boost productivity, decrease job and school absenteeism and alleviate the economic burden of many diseases.

The convergence of health science, building science, and business science is revealing what is perhaps the greatest untapped business and health opportunity of our time.

References

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