

BUILDING EVIDENCE

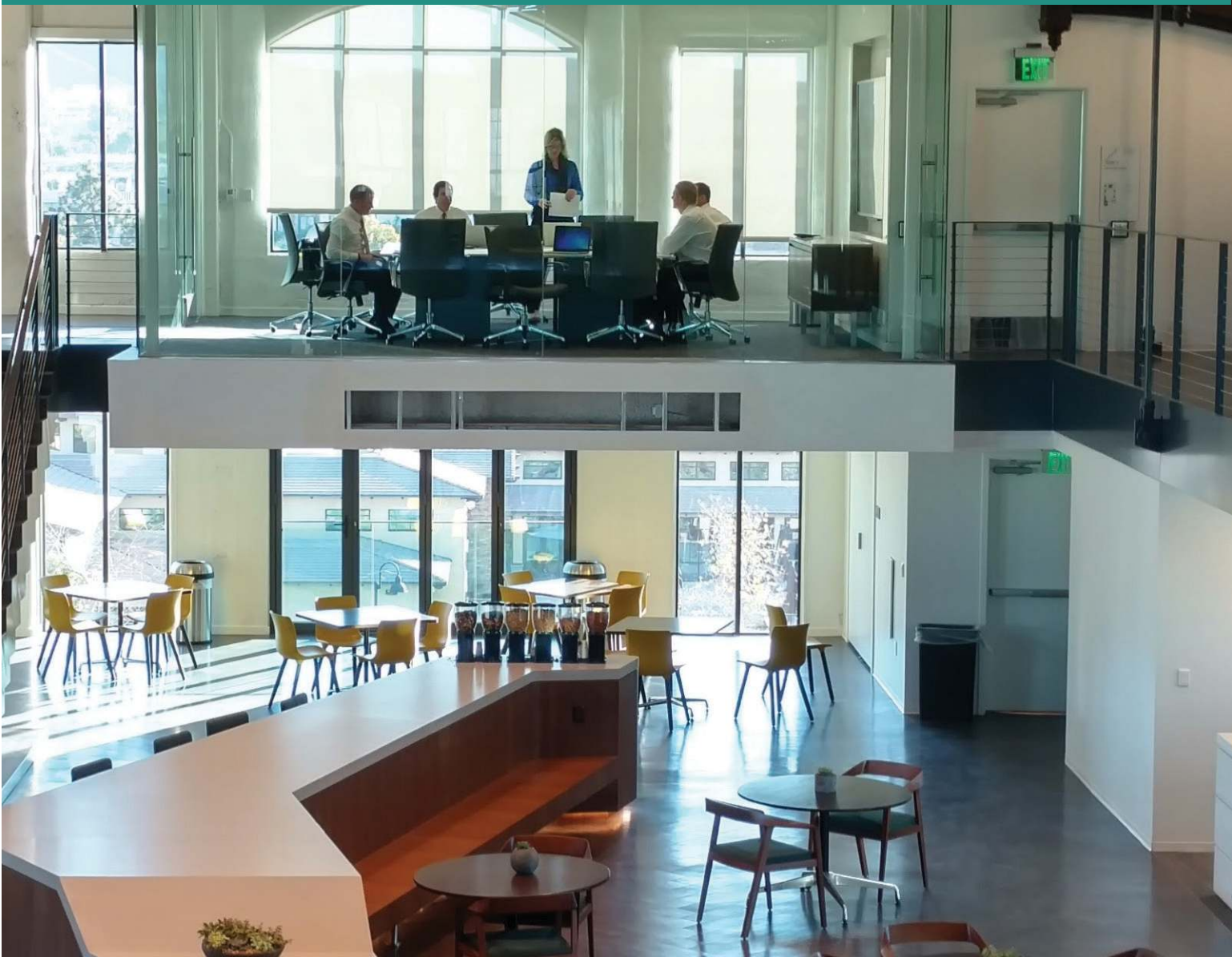


HEALTHY BUILDINGS
FOR HEALTH



HARVARD T.H. CHAN
SCHOOL OF PUBLIC HEALTH

THE 9 FOUNDATIONS OF A HEALTHY BUILDING



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THE 9 FOUNDATIONS OF A HEALTHY BUILDING

The idea for the “The 9 Foundations of a Healthy Building” arose from many interactions over the past several years with real estate professionals, building owners, hospital administrators, facilities directors, homeowners, and academic colleagues. Two things stood out. First, during these discussions, we would often say, “The idea of a healthy building has been made too complicated. We know how to make buildings healthy. There are a few simple foundations.” This of course led to requests to name the foundations of a healthy building. In the ensuing discussion and debate we realized that we, the public health community, have failed to translate our research into actionable information; the richness of the public health literature was invisible to key decision-makers. Second, in these presentations and meetings we would often hear some variation of the refrain, “Your research is very interesting, but I can’t take a scientific paper into my meeting on Monday and convince a building owner or manager to do things differently. I need a short summary.” Thus, the 9 Foundations project was born.

“The 9 Foundations of a Healthy Building” was created by a multidisciplinary team of experts from the Healthy Buildings Program at the Harvard T.H. Chan School of Public Health. You can learn more about the team and our research at www.ForHealth.org. The 9 Foundations curated summaries are designed to be a clear and actionable distillation of the core elements of healthy indoor environments. For each, we created a 2-page summary of the underlying science, fully cited back to the primary literature. These summaries are included in the following pages, along with a short guide for how to achieve each foundation. The 9 Foundations apply universally to all building types, including homes, but the supporting text focuses mainly on commercial office environments.

The 9 Foundations are the beginning of what we are calling “Building Evidence for Health” – a collection of 2-page curations of the scientific literature on key topics related to buildings and health. We began with these 9 Foundations and plan to add to this collection. As always, we are interested in improving and refining this idea, so we welcome feedback. Please write us with your ideas for topics, comments or questions. We will use your feedback and new research to update the Building Evidence for Health summaries periodically.

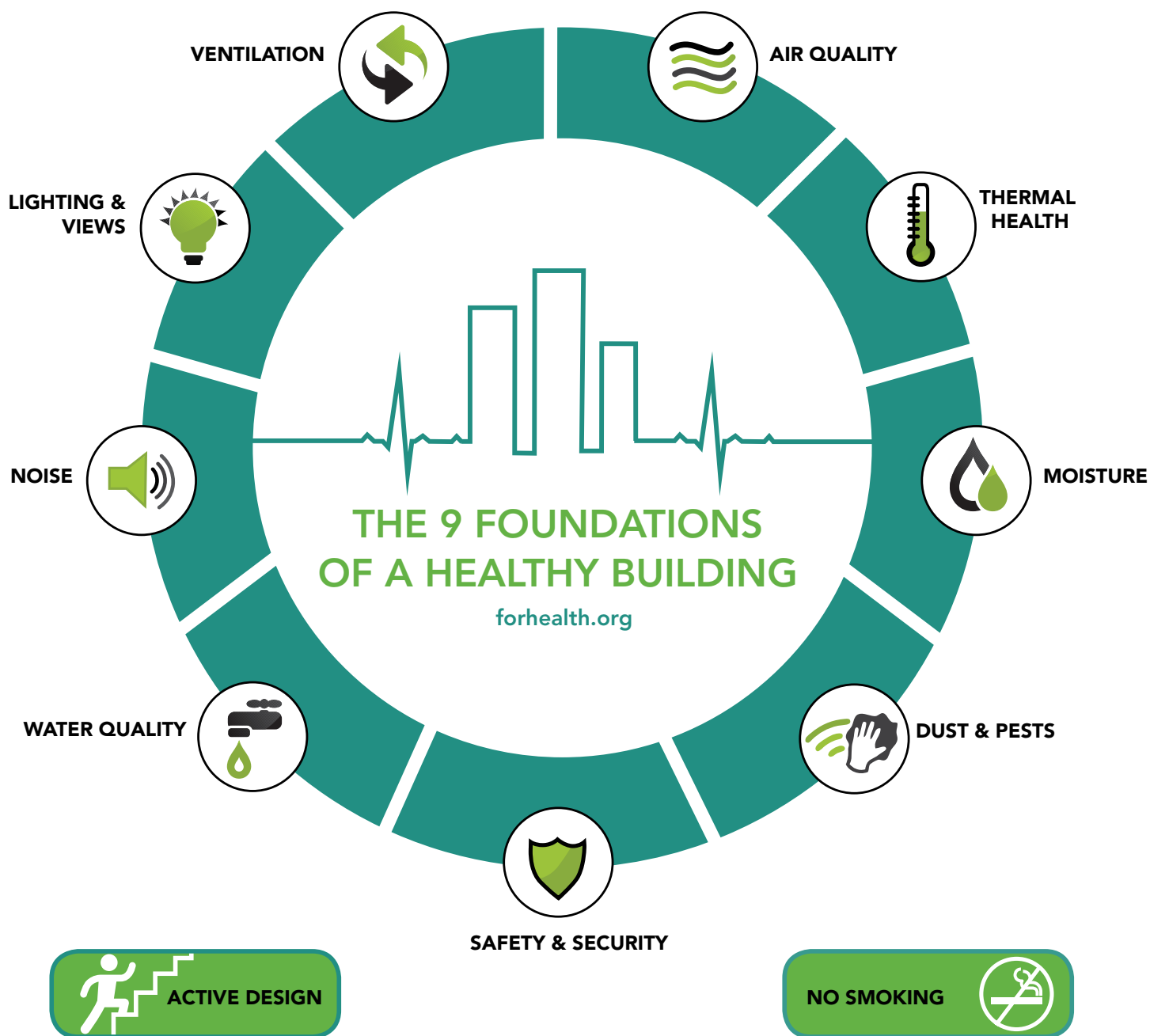
We hope that you find this information helpful. Our goal is to improve the lives of all people, in all buildings, everywhere, every day. We cannot do this if the knowledge generated by our research community does not reach you, the people who control, manage and occupy buildings across the world. The 9 Foundations intends to bridge this gap.

Onward!

A handwritten signature in black ink, appearing to read 'Joseph G. Allen'.

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THE 9 FOUNDATIONS OF A HEALTHY BUILDING



The 9 Foundations of Healthy Buildings

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HOW TO ACHIEVE:

The 9 Foundations of Healthy Buildings



VENTILATION

Meet or exceed local outdoor air ventilation rate guidelines to control indoor sources of odors, chemicals and carbon dioxide. Filter outdoor and recirculated air with a minimum removal efficiency of 75% for all particle size fractions including nano. Avoid outdoor air intakes at street level or near other outdoor sources of pollutants. Commission systems, conduct regular maintenance and monitor ventilation in real-time to prevent and resolve ventilation issues promptly.



AIR QUALITY

Choose supplies, office supplies, furnishings and building materials with low chemical emissions to limit sources of volatile and semi-volatile organic compounds. Check for legacy pollutants such as lead, PCBs and asbestos. Limit vapor intrusion by using a vapor barrier. Maintain humidity levels between 30-60% to mitigate odor issues. Conduct annual air quality testing. Respond to and evaluate occupant concerns.



WATER QUALITY

Meet the U.S. National Drinking Water Standards at point-of-use. Test water quality regularly. Install water purification system for removal of contaminants, if necessary. Ensure residual disinfectant levels are sufficient to control microbes, but not in excess. Prevent water stagnation in pipes.



THERMAL HEALTH

Meet minimum thermal comfort standards for temperature and humidity and keep thermal conditions consistent throughout the day. Provide individual level thermal control, where possible. Survey the space and occupants regularly to identify zones that underperform. Respond to and evaluate occupant concerns. Commission systems, conduct regular maintenance and monitor temperature and humidity in real-time to prevent and resolve thermal comfort issues promptly.



DUST AND PESTS

Use high efficiency filter vacuums and clean surfaces regularly to limit dust and dirt accumulation, which are reservoirs for chemicals, allergens, and metals. For homes, take off shoes at the door to limit tracking in dirt. Develop an integrated pest management plan with a focus on preventative measures such as sealing entry points, preventing moisture buildup and removing trash. Avoid pesticide use, if possible. Train building management how to respond to pest problems and complaints.



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LIGHTING AND VIEWS

During the day provide as much daylighting and/or high intensity blue-enriched lighting (480nm) as possible while maintaining visual comfort and avoiding glare. Get regular light breaks outside. Provide blue-enriched task lighting when necessary for comfortable viewing. For as long as possible before sleep, reduce light intensity as much as possible and use blue-depleted light to enhance sleep. Aim to provide direct lines of sight to exterior windows from all workstations. Incorporate nature and nature-inspired design indoors.



NOISE

Protect against outdoor noises such as traffic, aircraft and construction. Control indoor sources of noise such as mechanical equipment, office equipment and machinery. Provide spaces that minimize background noise to 35db for unoccupied work and learning areas, and a maximum reverberation time of 0.7 seconds.



MOISTURE

Conduct regular inspections of roofing, plumbing, ceilings and HVAC equipment to identify sources of moisture and potential condensation spots. When moisture or mold is found, immediately address moisture source and dry or replace contaminated materials. Identify and remediate underlying source of the moisture issue.



SAFETY AND SECURITY

Meet fire safety and carbon monoxide monitoring standards. Provide adequate lighting in common areas, stairwells, emergency egress points, parking lots and building entryways. Manage points of egress and the physical perimeter. Be situationally aware through video monitoring, interactive patrols and incident reporting. Maintain a holistic emergency action plan and mechanism for communication to building occupants.

NO SMOKING



SMOKING POLICY

Establish and enforce a smoke-free policy indoors and within 20 feet of the building.



ACTIVE DESIGN

ACTIVE DESIGN

Incorporate design elements that promote and encourage activity, such as easily accessible staircases and recreational areas. Provide ergonomic furnishings that minimize discomfort and limit the development of chronic physical injuries. Follow applicable occupational safety guidelines to ensure safe work environments.



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VENTILATION



Why is ventilation important?

Ventilation in buildings is required to bring fresh air in from outside and dilute occupant-generated pollutants (e.g., carbon dioxide) and product-generated pollutants (e.g., volatile organic compounds). If mechanically ventilated, a building's mechanical system is designed to bring in outdoor air, filter that air, and deliver it to occupants. Even with proper ventilation, the concentration of pollutants indoors can be higher than concentrations found outdoors.^{2,3} Outdoor pollutants, like PM_{2.5}, can penetrate indoors through several routes, one of which is through the mechanical system if the air stream is not properly filtered. Because people spend so much time indoors (90% or more for many people), most of a person's exposure to outdoor air pollution may occur indoors.⁴

Ventilation systems also influence temperature, humidity, and air pressure.⁷ In an effort to ensure better Indoor Air Quality (IAQ) in building spaces, current ASHRAE standards require a minimum of 20 cubic feet per minute per building occupant (cfm/person).⁸ This standard, by definition, is designed to provide merely "acceptable" indoor air quality despite decades of research showing benefits of higher ventilation rates. In addition to specifying higher ventilation rates, improved maintenance of HVAC is required because substandard ventilation often occurs in buildings where HVAC systems are either neglected or inadequately maintained.⁹

Outdoor pollutants can penetrate indoors. Because people spend so much time indoors (90% or more for many people), most of a person's exposure to outdoor air pollution actually occurs indoors.

How does ventilation affect our health?

In buildings with lower ventilation rates, air quality is often reported as stuffy and unpleasant. Not only does this make the indoor environment uncomfortable to work in, but the increased pollutants can cause an array of harms. Poorly ventilated spaces promote symptoms such as headache, fatigue, shortness of breath, sinus congestion, cough, sneezing, eye, nose, throat, and skin irritation, dizziness, and nausea.^{6,10} This collection of symptoms stemming from extended exposure to poorly ventilated spaces has been called the sick building syndrome (SBS).¹¹ As defined by the World Health Organization in 1984, SBS refers to the nonspecific set of health

The current ventilation standard, by definition, is a minimum standard designed to provide merely "acceptable" indoor air quality despite decades of research showing benefits of higher outdoor air ventilation rates.

effects associated with time spent in a particular building.¹²

A growing body of research has found that employees or students who work in buildings where fresh air is adequately circulated and distributed are more productive and healthy than those who work in poorly ventilated spaces.^{5,6} In schools, one study conducted in California found students had longer attention



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spans, and felt calmer in highly ventilated classrooms.²⁴ Poor ventilation has further been associated with increased absences, decreased productivity, and higher operational costs.^{7,25} In offices, studies have demonstrated relationships between lowered ventilation rates and higher instances of short-term sick leave, asthma, and respiratory infection among building occupants (Table 1).¹⁷

Table 1. Health impacts of ventilation rate in medium office prototype building[#]

Reference	Outcome	Ventilation Rate (cfm/person)		Relative Risk
		Low	High	
Milton et al. 2000 ¹⁹	Short term sick leave	12.9	25.8	1.5
Brundage et al. 1988 ²⁰	Illness all years	4.5	30	1.5
Brundage et al. 1988 ²⁰	Illness 1983 data	4.5	30	1.9
Drinka et al. 1996 ²¹	Illness	48	120	2.2
Drinka et al. 1996 ²¹	Influenza	48	120	4.7
Knibbs et al. 2011 ²²	Influenza	15	45	3.1
Knibbs et al. 2011 ²²	Rhinovirus	15	45	2.1
Knibbs et al. 2011 ²²	TB	15	45	3.3
Hoge et al. 1994 ¹⁵	Pneumonia	20.4	30	2.0
Stenberg et al. 1994 ²³	SBS symptoms	8.5	42.4	5.0

[#]adapted and updated from Fisk et al, 2003¹⁸

What is the relationship between ventilation and performance?

Several studies have shown that substandard ventilation rates negatively impact cognitive function. For example, research conducted at the Harvard T.H. Chan School of Public Health used a real-life simulation tool to test the higher order cognitive function of office workers at the standard-specified minimum outdoor air ventilation rate of 20 cfm/person compared to 40 cfm/person.²⁶ Participants shifted upward from the 62nd to 70th percentile in terms of cognitive performance when compared to normative data of 70,000 people who had taken the cognitive tests in the past. This change in performance is equivalent to a \$6,500 increase in salary per person per year, while the energy costs of achieving the same change in ventilation were less than \$40 per person per year, and down to \$1 per person per year when energy efficient systems are used.²⁷ When combined with the comorbidity in terms of sick building symptoms and absenteeism as presented in Table 1, the benefits of higher ventilation rates far outweigh the costs in terms of energy by several orders of magnitude. Investing in advanced ventilation systems can further mitigate both energy costs and environmental damages; in fact, in some cases these systems supply twice the outdoor air that conventional strategies can while simultaneously consuming less energy.



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AIR QUALITY



What is indoor air quality (IAQ)?

Indoor air quality (IAQ) depends on the presence and abundance of pollutants in the indoor environment that may cause harm. It includes chemical and biological pollutants in gas, liquid or solid states that we are exposed to indoors. When IAQ is poor, occupants can experience building-related illnesses such as asthma, fatigue, irritation, and headache. Because humans spend up to 90% of their time in offices, schools, and residences, and inhalation exposure is continuous, our largest exposure to pollutants (of both indoor and outdoor origins) occurs indoors.^{1,2}

Which types of indoor air pollutants concern us?

Air pollutants can be found in all indoor spaces throughout the world. We absorb them into our bodies through breathing, swallowing them and some enter through our skin. While the effects of outdoor pollutants have been researched extensively, a growing body of research has demonstrated indoor air pollutants to be just as harmful.^{2,3} The U.S. Environmental Protection Agency states that indoor pollutants pose higher human health risks than those outdoors, as outdoor sources are more tightly regulated to control the formation of photochemical smog and particulate matter. Common indoor pollutants that pose risks to human health include nitrogen oxides, carbon monoxide, ozone, particulate matter (PM), and volatile organic compounds (VOCs) such as formaldehyde, limonene, and benzene.⁴ In offices, schools, and residences alike, these pollutants may come from printer emissions, pest and rodenticides, cleaning supplies, personal care products, paint, pollen, and fungal spores.^{5,6} Radiological hazards such as radon, a gas that naturally emanates from soil and rock and can enter buildings through cracks and fissures in the foundation, are carcinogens. Radon is considered the second leading cause of lung cancer, behind smoking.⁷ And while we know a lot about exposure and risk associated with many indoor air pollutants, there are 82,000 chemicals in commercial use, 85% of which do not have any available health data.

Of the 82,000 chemicals that we find in commercial use, 85% do not have any available health data.

How does poor indoor air quality affect human health?

Volatile organic compounds (VOCs) are a class of chemicals that are commonly associated with IAQ issues. VOCs are chemicals with a high vapor pressure that emit gas into the air and can come from building materials, consumer products, paints, personal care products, furniture, and many other products. Exposure to VOCs has been associated with everything from minor irritation of the eyes to certain forms of cancer. While extensive evidence has documented adverse respiratory health effects of outdoor air pollutants, more recent studies have shown that indoor air pollutants can have similar consequences. For example, the substantial presence of indoor ozone has been linked to irregular heartbeats and poor lung function as well as irritation to the eyes, skin, nose, and throat.^{4,8} Concentrations of pollutants indoors, in some instances have been shown to be twice as high as those outside (EPA).

Exposure to indoor air pollutants have been repeatedly linked to asthma, allergies, bronchitis, and chronic obstructive pulmonary disease.^{4,9,10} Research examining indoor pollutants in the food service sector observed a positive correlation between kitchen PM, VOCs, polycyclic aromatic hydrocarbons (air pollutants produced in the process of broiling meat and burning fuel) and kidney inflammation.¹¹ Allergic



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reactions are also commonly associated with exposure to indoor air pollutants, among both sensitive and non-sensitive individuals.¹²

“Health effects from indoor air pollutants may be experienced soon after exposure or, possibly, years later.”²

Poor IAQ disproportionately effects vulnerable individuals (WHO 2010),³ with the elderly particularly impacted, given their limited time spent outdoors. A comprehensive geriatric study in Europe (GERIE) observed a correlative relationship between exposure to indoor particulate matter and reports of wheezing and asthma-related symptoms among occupants.¹³ Substantial evidence has also been collected indicating the sensitivity of children to poor air quality due to their smaller airways and higher ventilation rates of air relative to body size as compared to adults.¹⁴ Research conducted on school populations found that VOCs in

carpet cleaner (toluene), cleaning supplies (limonene is commonly used to provide citrus scent), and pest control mechanisms can harm children’s lungs.^{14,15}

What is the cost of poor air quality?

Not only does poor IAQ harm occupant health and well-being, it also negatively impacts productivity. The buildup of indoor pollutants contributes to absenteeism through the increased prevalence of sick building symptoms.^{16,17} Exposure to indoor pollutants such as VOCs and carbon dioxide can also have direct impacts on cognitive function.^{1,18} A 2009 meta-analysis evaluated the monetary and societal costs of indoor air pollutant-related damages, and observed a range of reported damages associated with poor IAQ including productivity loss, healthcare costs, and building damages (from moist air and mold development). Each study estimated upwards of \$10 million in annual “air pollution costs”.¹⁹ There are also significant economic benefits from cleaner indoor environments. In the U.S. alone the savings and productivity gains from improved indoor environments have been estimated at \$25 to \$150 billion per year.²⁰

In the U.S. alone the savings and productivity gains from improved indoor environments are estimated at \$25 to \$150 billion per year.

What are “chemicals of concern”?

Increasing attention is being paid to “chemicals of concern” that are used in some building materials and consumer products and which can adversely impact human health. Many of these chemicals are called “semi-volatile” compounds, meaning that they can reside in both air and dust. We opted to include them in this section on IAQ, but they fit equally well in the section on dust, as well.

Three classes of chemicals of concern, in particular, warrant mention: chemicals that are used as flame retardants, as stain repellents, and as plasticizers. Flame retardant chemicals can be found in many common furnishings and building materials used in schools. The majority of these chemicals don’t stay in their products – they migrate out of products into the air and dust over time and they accumulate in our bodies. Many flame retardant chemicals are endocrine disrupting chemicals that interfere with the reproductive system and are associated with thyroid disease.^{21,22} Stain repellent chemicals are widely used in many products because they confer resistance to water, oil and greases. These classes of chemicals, called polyfluorinated alkyl substances (PFASs) or polyfluorinated chemicals (PFCs), are used in furnishings, carpets, clothing, non-stick cookware and paints, among others. People are exposed to these chemicals through air, dust and drinking water.²³ In fact, a study published in 2016 found that over 6 million U.S. residents have PFASs in their drinking water above limits set by EPA.²⁴ Phthalates are a class of chemicals that are used as plasticizers to make products soft and flexible. They can be found in many products in schools such as vinyl tile, PVC, school supplies, and artificial leather, to name a few (phthalates are also commonly found in personal care products like nail polish, hair spray and skin lotions).²⁵ And, like flame retardant and stain repellent chemicals, phthalates can leach out of their original product and enter air and dust in our homes, offices, and schools. Future versions of “Building Evidence for Health” will include more details about these “chemicals of concern” and other specific IAQ topics.



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HEALTHY BUILDINGS

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THERMAL HEALTH



What is thermal health and why does it matter?

Thermal health is a term proposed by the ForHealth team to replace the more commonly used and narrow term “thermal comfort”. The term thermal health encompasses all of the impacts of thermal conditions on health, including mortality, that go beyond just “comfort”. Traditionally, the focus in the built environment has been on thermal comfort, which is defined as “the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation”.¹ Thermal comfort is influenced by objective factors like air temperature, mean radiant temperature, air speed, and humidity, as well as personal factors like metabolic activity level and thermal insulation from clothing.² A model developed in the 1970s by Ole Fanger, and still used today, provides a means of predicting if an occupant in a space will be satisfied in terms of thermal comfort based on these parameters.³ This model is the basis for the current standard that governs thermal comfort in buildings, and its stated goal is to provide an environment where at least 80% of people will be satisfied.¹ Many studies have shown that when thermal comfort parameters fall outside of these acceptable ranges there is a significant impact on performance in offices, schools, and homes. But the impacts of thermal conditions extend beyond comfort. Temperature and humidity can also have a drastic effect on health, as evidenced by the heat wave in France in 2003, which claimed nearly 15,000 lives.⁴ In the face of rising global temperatures, these events will become more frequent. As such, we propose the use of the term “thermal health” to highlight all the health effects of thermal conditions.

The impacts of thermal conditions extend beyond comfort. Temperature and humidity can also have a drastic effect on health, as evidenced by the heat wave in France in 2003, which claimed nearly 15,000 lives.... As such, we propose the use of the term “thermal health” to highlight all the health effects of thermal conditions.

What is the role of the mechanical system in a building?

The invention of the first modern air conditioning system by Willis Carrier in 1902 created the ability to have a fully controllable thermally-stable environment in buildings. For the first time in history we could regulate temperature and humidity conditions indoors within a narrowly defined and acceptable range, thus forever altering where and also when people could work. Indoor temperatures are influenced by a number of factors including the building design, building geography and orientation, occupant density, ventilation strategies, building structure, and mode of ventilation.^{5,6} In most buildings today, the ventilation system is responsible for governing indoor temperature and humidity. However, there are efforts to separate the dual role of the mechanical system in controlling both ventilation and heating/cooling by providing dedicated systems for heating/cooling that are not dependent on ventilation.

How do thermal conditions impact the body?

Thermoregulation of the body is controlled by a homeostatic system that responds to external thermal cues and internal hormonal cues to maintain core body temperature at approximately 37° Celsius. This is primarily accomplished by dilating or constricting blood vessels, which can change how fast heat dissipates from the body through convection and conduction, and by other thermoeffectors like sweating and shivering. Humidity influences the evaporative cooling mechanisms of our physiology. That is, if the humidity is too high, and the air more saturated, our body has a reduced capacity to cool itself through sweating.



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How can thermal conditions impact human health?

It is well documented that thermal conditions are integral to the occupant experience. In a study conducted in office buildings across Europe, the foremost complaint reported by employees was the thermal comfort of their workspaces. Many reported that ventilation, temperature control, and humidity were all factors

Humidity influences the evaporative cooling mechanisms of our physiology. That is, if the humidity is too high because the air more saturated, our body has a reduced capacity to cool itself through sweating.

that contributed significantly to workplace experience and task capabilities.⁷ Importantly, in addition to thermal comfort, there is increased evidence around the potential for health impacts related to thermal conditions indoors. A study on workplace thermal conditions and health impacts observed that workers experienced itchy, watery eyes, headaches, and throat irritation when thermal

factors such as ventilation, humidity, and heat were unfavorable.⁸ When indoor environments are too warm, there is evidence of increases in sick building syndrome symptoms, negative moods, heart rate, respiratory symptoms, and feelings of fatigue.⁹ Temperature and humidity may also influence disease transmission.¹⁰ Cold and dry environments have been found to facilitate the spread of the influenza virus because low humidity levels permit virus particles to stay in the air longer and low temperatures prolong the virus shedding period. On the other end of the spectrum, warm humid environments are conducive to mold and fungal growth.¹¹

Can thermal conditions impact performance and learning?

Thermal conditions play a role in learning and performance of schoolchildren. In a survey of more than 4,000 sixth grade students, those who reported that they had never experienced high indoor temperatures achieved 4 percent more correct answers on a national mathematics test compared to students who experienced high temperatures daily.¹² Another study of more than 3,000 schoolchildren in 140 fifth grade classrooms found that each 1°C decrease in temperature within the range of 20-25° Celsius (68 – 77 degrees Fahrenheit) was associated with an increase in students' average test scores in mathematics.¹³ And a recent study of performance of New York City high school students on the NY State Regents exam has shown that test performance is significantly impaired when tests are taken on hot days. Students were 6.2% less likely to pass the exam when taken on a 90° day relative to a 72° day, and the authors conclude that this can have economically meaningful impacts on short and long-term student outcomes.¹⁴

Thermal comfort has been suggested to be more important to office workers' performance than job stress or job satisfaction.

What are the risks associated with extreme heat events?

Heat waves are a major cause of mortality globally, causing thousands of deaths each year. A high-profile heat wave in 2003 killed nearly 15,000 people in France alone.⁴ Buildings have the potential to mitigate this heat exposure or exacerbate it. Risk factors for death from heat waves include age, socioeconomic status, urbanicity, and air conditioning. Air conditioned spaces can protect against heat-related mortality by providing a thermally stable place of refuge. If a building is not air conditioned, indoor temperatures can actually exceed the outdoor temperatures due to internal heat loads. Further, the temperatures indoors can remain elevated at night or after the heat wave has ended due to the thermal mass of the building. The frequency and severity of heat events is rising significantly due to global climate change, increasing the likelihood of heat-related mortality and making control of thermal parameters in buildings a critical public health issue going forward.



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MOISTURE



Why does building moisture matter?

The scope of water damage and subsequent exposures is quite extensive; studies conducted across Europe, Canada, and the United States have observed mold, mildew, or water damage in up to 36% of homes.¹ A nationwide survey conducted by the Environmental Protection Agency found that 85% of office buildings across the United States had been damaged by water, and 45% had active leaks at the time of the survey.² In a review of indoor exposure publications between 2000-2013, researchers identified that dampness and moisture-related indoor exposures are of primary concern for preventing asthma and other respiratory conditions among both sensitized and unsensitized individuals alike.³ Prior to being sensitized an individual can be exposed to elevated levels of the allergen without experiencing an allergic response, but once a person becomes sensitized, even low levels of the allergen may initiate a reaction.

How does moisture impact the indoor environment?

Entrance of water into damaged, poorly designed, and improperly maintained buildings has been identified as the main source of building-related illness from mold exposure in an Occupational Safety & Health Administration (OSHA) review of over 120,000 indoor air quality documents published between 1994 and 2001.⁴ Common sources of moisture in buildings can include: leaks from plumbing, roofs, and windows; flooding; condensation on cold surfaces (e.g., poorly insulated walls and windows, non-insulated cold water pipes, toilets); poorly maintained drain pans; or wet foundations from landscaping or gutters that direct water into and around a building. Secondary sources of moisture include water vapor from inadequately vented kitchens, showers, or combustion appliances.⁵ Excessive moisture collection in buildings creates favorable conditions for mold growth, which, if left unchecked, can destroy the surfaces they grow on.⁴ Moisture and mold growth can accumulate in materials such as wallboard and carpeting without being noticed even in buildings with good housekeeping and maintenance.

85% of office buildings across the United States have been damaged by water and 45% have active leaks, according to a nationwide survey conducted by the EPA.

In buildings, molds reproduce through the accumulation of spores, tiny cells that float continuously through indoor and outdoor air.⁶ When mold spores encounter a moist surface indoors, they can begin to grow on and digest their host surface. Areas typically exposed to mold in buildings are on carpets, ceiling tiles, insulation materials, wood, areas behind wallpaper, or in HVAC systems.⁴ These fungi can produce a number of irritating substances, including spores and volatile organic compounds (VOCs). The latter substances are responsible for musty odor, and can contribute to adverse health effects of individuals exposed.⁷ The most common indoor molds are *cladosporium*, *penicillium*, *alternaria*, and *aspergillus*.⁵

How does indoor moisture impact human health?

Among those most vulnerable to mold-related health effects are infants, children, the elderly, and people with compromised immune systems. The most prevalent health effect associated with moisture is mold-related asthma. In partnership with the Lawrence Berkeley National Laboratory, the EPA estimated that



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exposure to residential dampness and mold contributed to 21% of 21.8 million cases of asthma each year.³ Several studies have found high concentrations of residential mold presence to increase asthma severity among children with both allergic and nonallergic asthma.^{8,9,10} Far graver effects such as asthma morbidity have been observed in populations with congenital severe asthma.⁶ For individuals without preexisting respiratory conditions or allergies, exposure to mold contamination can trigger a host of allergy-related symptoms, such as sneezing, runny nose, eye irritation, coughing, congestion, and skin rash.⁵ Mold exposure has been positively associated with hypersensitivity pneumonitis, allergic rhinitis, eczema, toxic mold syndrome, bronchitis, and lung tumor development.^{2,7,11}

How does indoor moisture impact productivity and learning?

As mentioned in the preceding section, large shared spaces such as schools and office buildings can expose occupants to a host of building-related illnesses associated with water damage and mold presence. The health effects of this exposure can interrupt workplace productivity, impact job performance, and create an unpleasant work environment. A study conducted in Sweden in 2000 found that self-reported moisture-related problems in office buildings were positively associated with asthma, allergic symptoms,

Exposure to residential dampness and mold contributed to 21% of 21.8 million cases of asthma each year.

and airway infections. Older buildings that used natural ventilation indicated a high frequency of interior dampness, and an increased frequency of employee complaints.¹² Studies conducted in the United States observed 21% of new-onset adult asthma diagnoses could be connected to occupational exposures.¹³

In schools, both children and teachers run a high risk of suffering from health effects of mold exposures. In fact, recent studies have determined that teachers have a greater prevalence of asthma than other non-industrial occupational workers, and have a similar

prevalence to that of blue-collar workers.¹⁴ This study also suggested that these increased asthma-like symptoms among teachers may reduce quality of life, decrease productivity, and disrupt classroom learning. In water-damaged buildings, teachers have seen significantly higher rates of vocal cord dysfunction, as well as cough, chest tightness, wheezing, and hoarseness.¹⁵ Among students, who spend up to 12,000 hours in school buildings each year,¹⁶ rates of absenteeism and productivity are directly affected by toxicants present in classrooms. An investigation into the frequency of respiratory symptoms in moisture-damaged schools observed a significant reduction in symptoms such as runny nose, dry cough, phlegm, hoarseness, swollen or itchy eyes, headache, and less fatigue during weekends and holidays compared to the school week.¹⁷



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DUST & PESTS



What is the significance of dust to human health?

Many contaminants reside in dust and lead to exposure in three different ways: 1) inhalation of resuspended dust, 2) direct dermal absorption, or 3) ingestion from hand-to-mouth behaviors. For the first pathway, dust (also called particles) on a person's clothes, furniture, and other upholstered materials is continuously suspended and resuspended through normal activities like walking through the house, vacuuming, or folding laundry.¹ In fact, people have a personal "cloud" of resuspended dust around them as they go about daily activities, not unlike the famous "Pigpen" character in the Charlie Brown cartoon.² When the particles are resuspended, exposure can occur through inhalation. For the second pathway, chemicals in air and dust can partition out of the air and dust onto the skin and enter our bodies via dermal absorption. The third pathway, sometimes referred to as "incidental dust ingestion," occurs when dirt and dust accumulate on our hands and are transferred to food or are ingested directly through hand to mouth contact. It is estimated that adults ingest up to 100 mg of house dust per day and children up to 200 mg per day.³ Higher ingestion rates in children are due to the greater amount of time they spend in contact with the floor and other surfaces, and higher frequency of hand to mouth behavior.

An adult ingests up to 100 mg of house dust per day and a child ingests up to 200 mg per day.

This mass of dust that enters our body every day is relevant to human health because dust acts as a reservoir or sink for a variety of potentially harmful agents – outdoor particles that penetrate indoors, viruses, bacteria, chemicals, allergens (pets, mites, mold spores, pollen), building materials, dander, fabric fibers, and paint flakes that contain lead. Some of these agents (such as viruses) may only exist in dust for a few hours, while others may remain in the dust for decades. Indoor dust is the primary route of exposure for lead from lead-based paint, which can accumulate in dust from flaked paint or dirt tracked in from outdoors. Unlike chemicals in the air, chemicals in dust can continue to

expose occupants long after the sources have been removed. This is of particular concern for Persistent Organic Pollutant (POPs), a name given to chemicals that are resistant to breakdown in the environment, and thus they can persist in the dust for many years.⁴ For example, flame retardant chemicals that are used in consumer products migrate out of those products into air and dust.⁵ Studies have documented that the amount of chemical that is present in indoor dust can be directly correlated with amount of chemical found in the blood of people living and working in those environments, providing quantitative evidence of the significant role of indoor dust in overall chemical exposure.⁶

What is the significance of pests to human health?

The primary concern from pests and domestic animals is that they introduce allergens to the indoor environment which can cause an immune response in adults and children. The most relevant sources for most indoor locations are: dust mites, cockroaches, mice, rats, cats and dogs.



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Dust mites are microscopic pests that feed on shed human and animal skin cells, typically burrowing in bedding, mattresses, and furniture upholstery. While dust mites do not bite or sting, their feces and body parts create a harmful allergen (Der p1) that can dramatically impact human health.⁷ Mites have been associated with asthma,⁸ immune responses such as allergic rhinitis (hay fever), and allergic reactions ranging from mild symptoms like runny nose and watery eyes, to more severe responses such as asthma attacks. Among asthmatic children, the rate of dust mite allergen sensitivity can range from 48-63%,^{9,10} and high allergen exposure among these individuals increases their risk of hospital admission.¹¹ In a study conducted across the United States, four out of every five homes had detectable dust mite allergens in at least one bed.¹² Insects, like cockroaches, can also introduce allergens (Bla g1 and Bla g2) into the indoor environment and people can become sensitized after exposure.¹³ In one study of children with asthma, exposure to cockroach allergen was identified as a risk factor for hospitalization.¹⁴ Pests like mice and rats release allergens in their urine (Mus m1 and Rat n1). When the urine dries, the dust can become resuspended and inhaled, causing an allergic reaction. Domestic animals like dogs and cats also produce allergens (Fel d1 and Can d1).¹³ Cat allergen, in particular, is well-known to cause reactions in people who are sensitive. Cat allergen is “sticky”, meaning it adheres to surfaces like clothing, walls, furniture and carpets.¹³ In studies of homes with and without cats, the levels of cat allergen in homes with cats are higher, but surprisingly, cat allergens are regularly detected in homes without cats, and in schools, offices and airplanes, due to the ‘sticky’ nature of this allergen.¹⁵

Dust acts as a reservoir for a variety of harmful agents – outdoor particles that penetrate indoors, viruses, bacteria, chemicals, allergens (pets, mites, mold spores, pollen), building materials, dander, fabric fibers, and flakes of paint with lead.

Pesticides – Part of the solution or part of the problem?

When discussing pest control in the built environment, a point of primary concern is the use of chemical pesticides. Pesticides are used to kill insects (insecticides), weeds (herbicides), rodents (rodenticides), and to control the growth of molds and fungi (fungicides and biocides). Although these compounds may offer potential benefits if used properly, their function as a potentially toxic agent has garnered concern from agencies such as the EPA and CDC.^{16,17,18,19} In a 2014 survey, the EPA reported 75% of households use pesticides in their homes, usually in the form of insecticides or disinfectants. The survey also found 80% of most people’s exposure to pesticides was indoors, and that significant levels of over a dozen pesticides had been measured in the air inside homes.²⁰ Pest control chemicals such as pyrethroids and organophosphates (OPs) are toxic substances that have the potential to cause long-lasting effects, even in low doses. Several studies have documented the carcinogenic effects of pyrethroid exposure.²¹ A childhood health meta-analysis observed links between indoor pesticide contaminants and urinary tract infections, inner ear infections, acute lymphoblastic leukemia, acute myeloid leukemia, and non-Hodgkin’s lymphoma.²² Exposure to OPs has been linked to adverse reproductive health effects and thyroid disease.²³ Rodenticides are highly toxic if ingested or inhaled because they contain anticoagulants, putting those exposed at risk of internal bleeding.²⁴



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SAFETY AND SECURITY



Why is 'Safety and Security' part of the 9 Foundations of a Healthy Building?

Maslow's Hierarchy of Needs tells us that Safety and Security are fundamental to our ability to thrive, coming only after the basic needs of food and water. We understand this in society and as individuals we see the role of security in our everyday lives through interactions with police, security lines, security cameras, and locking and unlocking the doors to our cars, homes and offices. We recognize the importance of these acts in keeping us safe from acute security events like robberies and crimes. What we may not recognize as clearly is that these feelings of safety and security directly influence our health, and buildings play a critical role in keeping us safe and secure.

The desire to protect ourselves and seek safety is so important that we carry within our genetic heritage a 'wall-hugging' behavioral trait, thigmotaxis, which describes our tendency to cling to perimeters since we can never quite predict what may be coming around the corner.³ Neurobiologists suspect that our brain's 'security motivation system' evolved as an adaptive response to dealing with rare, extreme threats by keeping us on high alert as we surveil our environment, and in the absence of satisfactory cues, this state of alarm may only be de-activated by engaging in security-related behaviors.⁴

Even in the absence of personal victimization, there are many ways by which living in a world with crime can impact upon health.

How does feeling unsafe impact health?

When our sense of security is threatened, it can trigger a cascade of biological "fight or flight" responses that alter our physical and psychological functioning.⁵ Perceived threats to safety flood our bodies with stress-induced hormones like adrenaline and cortisol that elevate heart rate and increase blood pressure.⁵ While individuals vary in their response, psychological stress can negatively affect immune function with onset of immune changes occurring in as little as five minutes.⁶ Chronically elevated stress hormones suppress immunity which can exacerbate autoimmune diseases and other inflammatory conditions, while elevated blood pressure levels can eventually lead to damaged arteries and plaque formation, putting stressed individuals at greater risk of hypertension and cardiovascular disease.⁵ Over time, these responses place wear and tear on the body that increases disease susceptibility.⁷

Damage to property and loss of resources, along with perceived life threat, are associated with the onset of Post-Traumatic Stress Disorder and other mental health disorders.⁵ Yet even without actually being a victim, anticipating possible victimization can induce stress, depression, sleeping difficulties, and constrained use of public spaces.⁹ It can also contribute to withdrawal from social activities¹⁰ which may indirectly harm health since lower levels of social support have been implicated in increased risk of cardiovascular illness.⁷ Ultimately, the preventative actions and behavioral changes stemming from fear of crime can adversely impact psychological and physical health and lessen a person's quality of life.^{9,10} Feeling unsafe at school has even been shown to negatively affect students' academic performance.²⁰ Sample populations from numerous studies investigating the link between fear of crime and health have found that:

- victims and non-victims report suffering negative psychological effects from the fear of crime. For non-victims, fear of crime contributes to feelings of anxiety and stress (65.1%), sleeping difficulties (27.4%), depression (10%), and panic attacks (8%).¹¹



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- individuals with greater crime worry participate in fewer social activities, exercise less, are about 1.5 times as likely to have a common mental disorder, and nearly twice as likely to have depression compared to those reporting low fear of crime.⁸
- being 'very worried' about crime has been significantly associated with higher levels of psychological distress.¹²
- perceptions of community violence have been found to significantly predict fear of walking outdoors, and higher levels of fear are associated with lower scores on self-reported measures of physical health.¹³
- perception of neighborhood safety has been significantly associated with body mass index, and individuals perceiving their neighborhood as safer from crime had a lower BMI.¹⁴

In addition to these examples drawn from research in adults, there is evidence that fear of crime can also affect children. Students' perceived sense of security within the school environment can impact their mental health, engagement in school activities, and academic achievement. Exposure to school neighborhood violence has been associated with lower test scores in English and math among elementary and middle school students.²⁴ Inner-city children in unsafe neighborhoods have higher likelihoods of having poorly controlled asthma, increased dyspnea and rescue medication use, more limitation in activity, and higher night-time asthma symptoms.²⁵

"Worry about crime is implicated in a cycle of decreased health, increased vulnerability, and further insecurities about crime."¹⁵

The relationship between fear of crime and health may be reciprocal because fear of crime can negatively impact health and poorer health can heighten anxiety about an individual's increased vulnerability to victimization. People with long-term depressive symptoms, poorer physical functioning, or poorer mental functioning are more likely to report subsequent fear of crime.¹⁵ There is growing evidence that particularly for women and older adults, physical inactivity is higher among people who perceive their neighborhood to be unsafe from crime⁹ and because some groups are disproportionately victimized based on their age, ethnicity, or disability, fear of crime may exacerbate existing health inequalities.¹⁶

What is the role of the built environment on security and health?

Indoor security threats are continuously evolving as we progress into the 21st century. Building managers must consider and address a complex variety of existing and emerging risks that may arise from unauthorized entry, occupants armed with guns or explosive devices, cyber security attacks, and the threat of chemical, biological or radiological weapons of mass destruction. We may take for granted the fire and life safety systems are continually operating in buildings, only noticing when inadequate systems or failures lead to catastrophic consequences. Research on the efficacy of closed-circuit television (CCTV) remains limited,¹⁹ however, the presence of city street security cameras has been shown to positively influence feelings of safety.²² Feelings of safety may be influenced by the presence of uniformed security guards, but there is some research that suggests that if a place is already perceived as safe then feelings of safety may not be enhanced.²¹

There is evidence that well-designed security measures like fences, locks, or secure entry systems have the potential to reduce fear of crime.¹⁷ After enhanced security measures were introduced into Liverpool, U.K. tower block buildings, fear of domestic crime was much lower among residents relative to the greater population of Britain. Residents who also reported less fear of victimization on neighborhood streets at night scored significantly better on a composite indicator of mental health.¹⁸ These initial findings reveal that security may positively influence health in ways not previously considered. The emerging evidence that fear of crime impinges on our physical and psychological health suggests promising potential for strategically aligning security measures with public health goals to both protect and enhance our well-being in the built environment.



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WATER QUALITY



Why does water quality matter?

We all know that water is an essential nutrient for life¹ as it is necessary to maintain a normal body temperature, lubricate joints, protect sensitive tissues, and promote healthy waste removal through urination, perspiration, and bowel movements.² What is less well known is that contaminated drinking water is one of the leading causes of disease globally, responsible for transmitting pathogens (i.e. cholera, dysentery, typhoid, polio), causing nearly 850,000 deaths due to diarrheal diseases, affecting 240 million people with the water parasite schistosomiasis, exposing millions to unsafe levels of neurotoxic heavy metals such as lead, and requiring considerable time and effort just to acquire safe drinking water.⁴ According to the World Health Organization, in 2015, 4.2 billion people obtained their water through a piped connection and 2.4 billion use improved sources such as public taps, protected wells, and boreholes.⁴ Microbial contamination is by far the largest contributor to the global burden of waterborne disease, and although the United States has one of the safest public drinking water supplies in the world,⁵ outbreaks of waterborne illnesses continue to occur. Surveillance data from the CDC revealed that in 2011-2012, thirty-two drinking water related outbreaks were reported across the nation, contributing to 431 cases of illness, 102 hospitalizations, and 14 deaths.⁶ More than 78% of these outbreaks were associated with community water systems.

Microbial contamination is by far the largest contributor to the global burden of waterborne disease, and although the United States has one of the safest public drinking water supplies in the world, outbreaks of waterborne illnesses continue to occur.

How can water quality be compromised in a building?

Approximately, 61% of total plain drinking water intake in the United States comes from the tap.⁵ Yet our nation's water infrastructure is significantly deteriorated and approaching the end of its useful life as many water pipes and mains are more than 100 years old.⁷ A 2013 assessment by the American Civil Society of Engineers found America's water infrastructure to be in "poor to fair condition and mostly below standard" with "strong risk of failure", brought to national attention by the Flint water crisis in Michigan, which exposed thousands of children to unsafe levels of lead.⁸ There are several key ways water quality may be compromised. First, wear and tear on service pipes can exacerbate corrosion, dissolving metals due to chemical reactions between water and plumbing fixtures, influencing the extent to which lead, copper and other metals can contaminate drinking water.⁹ For example, lead may be present in service pipes due to lead piping and solder, particularly in water with high acidity, low mineral content, and hot water systems.⁸ Second, drinking water may be contaminated by improper treatment; poor maintenance of distribution systems; malfunctioning wastewater treatment systems; accidental sewage releases; pesticides, fertilizers, and livestock waste from agricultural runoff; and heavy metals from manufacturing processes.¹⁰ Third, the

The U.S. Environmental Protection Agency controls the National Primary Drinking Water Regulations (NPDWR) which sets water testing schedules and legal limits for more than 90 contaminants in drinking water.


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duration of time that water is stored within a system before being used may affect its quality. Storage for long periods of time can damage plumbing materials and compromise the safety of drinking water by diminishing the efficacy of disinfecting agents (such as chlorine) and contributing to the growth of microorganisms that pose a risk to human health.¹¹ Changes in disinfection practices in lead service lines can also increase levels of lead in drinking water.^{12,13,14}

How does poor water quality impact human health?

The U.S. Environmental Protection Agency controls the National Primary Drinking Water Regulations (NPDWR) which sets water testing schedules and legal limits for more than 90 contaminants in drinking water.¹⁵ Limits are set for the following classes of potential contaminants: microorganisms, disinfectants, disinfection byproducts, inorganic chemicals, organic chemicals and radionuclides. For each, EPA sets a Maximum Contaminant Level Goal (MCLG) and a Maximum Contaminant Level (MCL), of which the latter is the legally enforceable limit. Occasionally these limits are not met. An investigation and analysis of over 20 million tap water quality test results from 2004-2009¹⁶ found that even among regulated contaminants, 87 chemicals were detected at least once at levels above recommended guidelines. Water quality is a broad topic that cannot be fully covered in two-pages, so we have provided a few specific examples that relate to water quality and health, covering three categories: inorganic chemicals (lead), organics (polyfluorinated chemicals), and microorganisms (Legionella).

Example 1 – Inorganic Chemicals - Lead

An estimated 40-45 million Americans get their drinking water from smaller, private systems that are not regulated under the Safe Drinking Water Act's Lead and Copper Rule, nor are they routinely tested for lead.¹⁷ Lead bioaccumulates in the body and numerous research studies have long established that lead can affect cognitive development in children,¹⁸ even at low levels¹⁹ (copper, in high doses, can cause symptoms such as irritation of the eyes, mouth and nose; nausea, vomiting, stomach cramps, and diarrhea).²⁰ Lead service lines and higher levels of lead in water have been significantly associated with elevated blood lead levels in young children.^{14,21} In 2016, elevated lead levels have been detected in the drinking water of many U.S. public schools across the country,^{22,23,24,25} due to an aging school building infrastructure that predates the Lead and Copper Rule. Due to developing children's' increased vulnerability to lead exposures, the U.S. Environmental Protection Agency, in concurrence with the general scientific community, has stated that there is "no known safe level of lead in a child's blood".¹⁵ Lead in drinking water not only poses a health hazard to children; it can also harm adults. Elevated blood lead levels in adults have also been associated with systolic blood pressure variability, a risk factor for cardiovascular disease,²⁶ as well as hypertension, nerve disorders, decreased kidney function, reproductive problems, and reduced fetal growth in pregnant women.²⁷

Example 2 – Organic Chemicals - Polyfluorinated Chemicals

Highly fluorinated chemicals, also called polyfluorinated chemicals and more recently polyfluoroalkyl substances (PFASs), are a class of compounds that are used to confer stain resistance and non-stick properties to consumer products like cookware, couches, carpets and clothing. They are also used in firefighting foam. These chemicals are extremely persistent and do not break down in the environment. Once they are released from consumer products, or directly from industrial facilities, they can migrate into water sources. A recent study found PFASs were detected at levels above the EPA's lifetime health advisory in drinking water supplies in 33 states, affecting an estimated 6 million Americans. Exposure to PFASs has been associated with cancer, elevated cholesterol, obesity, endocrine disruption²⁸ and immune suppression, which may reduce the efficacy of vaccines in children.²⁹

Example 3 – Microorganisms - Legionella

Legionella bacteria in building water systems accounted for two-thirds of waterborne illness outbreaks in the U.S., 26% of reported illnesses, and all 14 reported deaths – 12 of which were associated with health care facilities.⁶ Legionella thrive in building plumbing systems with stagnating water (plumbing system "dead legs" or areas with infrequent water use), warm water, and when residual disinfectant concentrations are low. Exposure occurs after the water is aerosolized from a faucet or shower and the *Legionella* is inhaled. Legionella causes two types of disease – Pontiac Fever, a self-resolving flu-like illness, and Legionnaire's disease, a severe type of pneumonia.³⁰



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NOISE



What is 'noise'?

Noise is defined as “unwanted or disturbing sound” that interferes with normal activities such as work, sleeping and conversation.¹ Noise enters building interiors from outside sources such as aircraft, road traffic, trains, lawn mowers, snow blowers, and the operation of heavy equipment at construction sites. Indoors, noise can be generated from a building’s mechanical and HVAC systems, office equipment, vacuum cleaners, industrial machinery, or conversations among occupants. Most people are familiar with the potential for direct auditory effects of noise exposure, namely noise-induced hearing loss. Noise-induced hearing loss can lead to a cascade of other downstream effects including creating communication barriers, limiting concentration and attention, and increasing stress and fatigue due to strain. However, there are also non-auditory health concerns from noise exposure. For example, estimates from 2013 suggest that as many as 145.5 million people in the United States may be chronically exposed to levels of noise (55-60 dBA) that can increase risk of hypertension.²

Each year, around 30 million Americans are occupationally exposed to hazardous noise levels and another 26 million Americans ages 20-69 have hearing loss that may have been induced by noise exposure in the workplace or leisure activities.

How does noise impact human health?

Each year, around 30 million Americans are occupationally exposed to hazardous noise levels³ and another 26 million Americans ages 20-69 have hearing loss that may have been induced by noise exposure in the workplace or leisure activities.⁴ The presence of background noise can also be disruptive and interfere with an individual’s ability to communicate and clearly perceive speech at a normal speaking volume. Thus, a building occupant may need to raise their voice to compensate. High noise levels outside schools and self-reported poor acoustics in the workplace have been significantly associated with teachers’ voice symptoms such as vocal fatigue, dry throat, hoarseness, and voice loss.⁵

Noise exposure can alter the function of many of the body’s internal organs and systems.⁶ Multiple studies on the non-auditory effects of noise exposure have observed that increased noise levels are associated with higher systolic and diastolic blood pressure, changes in heart rate,⁷ and hypertension.⁸ In children, environmental noise exposure has been associated with fatigue, irritability,⁹ emotional symptoms, behavioral conduct problems, increased hyperactivity,^{10,11,12} higher blood pressure,^{13,14,15} increased levels of stress hormones such as adrenaline and noradrenaline, poorer well-being,¹⁶ and noise annoyance among students.^{17,18} Noise annoyance, which is a form of psychological stress, encompasses feelings of irritation, discomfort, distress, or frustration.¹⁸ In adults, long-term transportation noise annoyance has been associated with lower levels of physical activity.¹⁹

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Although research on the effects of noise exposure on children's sleep quality is limited, preliminary findings suggest that nighttime road traffic noise may be associated with daytime sleepiness¹⁶ and sleep disturbance.⁷ In adults, substantial epidemiological evidence has revealed that nocturnal noise exposures have been associated with sleep disturbance and that environmental noise exposures can exacerbate the risk of cardiovascular disease.^{6,20} Daytime road traffic noise has been associated with increased mortality from hypertension among women,²¹ with hospital admissions for stroke among elderly adults, and with all-cause mortality in adults in areas exposed to noise levels greater than 60 dB.²² Long-term residential road traffic noise exposure has also been associated with increased risk for diabetes,²³ higher waist circumference and Body Mass Index, and obesity.^{24,25,26}

How does noise impact human performance?

Children under age 15 are more sensitive to inappropriate listening conditions because they are still developing mature language skills.²⁷ Noise interference in the classroom from outdoor sources (like aircrafts) can impair children's speech and listening comprehension²⁸ as well as their concentration, understanding of verbal information,⁹ reading comprehension,^{29,30,17,9} and memory.^{16,31} Research has shown that non-auditory higher cognitive processes such as memory and attention, which are critical elements of reading comprehension, develop slowly³¹ and thus children may be especially sensitive to chronic noise exposures.⁹ Noise has also been found to adversely impact reading and writing, and research suggests that chronic exposure to noise may impact children's cognitive development.²⁸ As of 2014, more than 20 studies have shown environmental noise exposures to be negatively correlated with children's learning outcomes and cognitive performance.^{32,7} In the workplace, environmental noise exposure can increase accidents³ and impair employee performance and productivity, especially during difficult and complex tasks.³³ With approximately 70% of U.S. offices having an open floor plan,³⁴ more workers are susceptible to distractions from noise while working. A recent survey of more than 1,200 senior executives and non-executive employees found that 53% of employees report that ambient noise reduces their work satisfaction and productivity.³⁵

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LIGHTING AND VIEWS



Why do lighting and views matter?

The eye has dual roles: It detects light to allow us to see but also detects light to tell the brain what time of day it is. These visual and 'non-visual' effects of light have different sensitivities to light intensity, spectrum, timing, pattern and light history and are served by different light detectors (photoreceptors) in the eye. Both of these roles are important considerations when assessing the quality of a built environment. In today's increasingly urban societies, views to natural landscapes are often obstructed and indoor spaces are typically illuminated with electric light sources that differ in intensity, spectrum, and exposure timing from outdoor daylight. The average person spends about 90% of their time indoors¹ which has important implications for the wellbeing of building occupants. Any electric lighting used should optimize both the visual and non-visual responses to light.

Non-visual responses to light

Like most other organisms on the planet, we have evolved biological rhythms synchronized to the fluctuations of night and day. These rhythms are controlled by a circadian clock in the brain that needs to be synchronized each and every day by a 24-hour light-dark exposure.² Without appropriate light exposure, our internal clock can become disrupted or even drift on its own time, leading to sleep disorders³. In addition to its circadian

Like most other organisms on the planet, we have evolved biological rhythms synchronized to the fluctuations of night and day. These rhythms are controlled by a circadian clock in the brain that needs to be synchronized each and every day by a 24-hour light.

resetting properties, light is also a stimulant and can directly enhance alertness and performance, or, at the wrong time, disrupt sleep.⁴

While there are other factors such as the pattern, timing and history of exposure, light intensity and light spectrum are two important factors in mediating the effects of light. In general, increasing the intensity of indoor light will increase the magnitude of non-visual effects. Similarly, increasing the short-wavelength (blue) content of indoor light will also increase its effectiveness. This is because the non-

visual effects of light are mediated primarily by a novel photoreceptor in eye that is most sensitive to short-wavelength blue light (peak 480 nm). Manipulating the light intensity and spectrum can therefore change the impact of indoor lighting on human physiology.

How can electric lighting impact our health and wellbeing?

Light levels typically experienced indoors (tens to hundreds of lux) are capable of inducing non-visual responses. We therefore need to consider the type of lighting we expose ourselves to through during the day and night to ensure that we optimize exposure to the right light at the right time, and avoid the wrong light at the wrong time.

The first principle is to ensure that we are exposed to a distinct and stable 24-hour light-dark cycle each day, with bright days and dark nights, to ensure proper synchronization of circadian rhythms. The circadian system plays a key role in regulating many aspects of our physiology, metabolism and behavior including hormone regulation, sleep-wake cycles, alertness, mood and performance patterns, immune function and



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reproductive function. Disruption of circadian rhythms, for example in shiftworkers, has been associated with multiple negative health outcomes ranging from an increased risk in accidents, chronic diseases such as diabetes and heart disease, and some types of cancer.^{5,6,7} Maintaining exposure to a strong light-dark cycle will ensure that the circadian system, and the rhythms it controls, will be properly aligned to the 24-hour day.

Students in classrooms with access to green views through their windows have been observed to experience significantly faster recovery from stress and mental fatigue and performed significantly higher on tests of attentional functioning, compared to students in classrooms with no windows or windows looking out onto other buildings facades.

How can light influence cognitive function and performance?

Light has acute effects on our cognitive function and sleep. Keeping the circadian sleep-wake cycle in proper alignment to obtain adequate levels of sleep is essential to maintaining good cognitive function. Circadian rhythms influence basic cognitive processes like attention, working memory and executive functions^{8,9} and learning and memory can be impaired when the sleep-wake cycle is disrupted.^{7,9,10}

We can also use light to proactively increase our alertness by using light with a higher intensity and greater short-wavelength content, for example after we wake up in the morning or throughout the school or working day. For example, exposure to blue-enriched white light (300 lux, 5500K) in the early morning during winter was associated with faster cognitive processing speed and better concentration performance compared to standard lighting conditions (300 lux, 3000-3500K) conditions.⁸ A laboratory controlled study of 47 university students found that participants reported significantly higher levels of alertness, performed significantly better on a computerized test, and made fewer typing errors when under artificial daylight (correlated color temperature = 6500K) compared to when they were under cool white light (4000K) or warm white light (3000K).¹¹ Similarly, office workers exposure to blue-enriched fluorescent light reported greater alertness, mood, concentration and sleep compared to when working in standard office lighting,¹² and care home occupants given better lighting demonstrate better cognition, better sleep and less depression.¹³

There are times in the day, for example in the hours before sleep, where we would want to reduce the alerting effects of light and calm the brain in preparation for sleep. Reducing the light intensity and short-wavelength content has these effects, reducing evening alertness, making it easier to fall asleep and increasing the amount of deep sleep.^{14,15}

How can daylight and views enhance occupant health and wellbeing?

Many studies on the health impacts of daylight have reported evidence for potential benefits including improvement to vision and sleep quality and reduced symptoms of myopia, eye strain, headache, and depression. Low levels of light indoors, coupled with less time spent outdoors, have been associated with increased risk for nearsightedness,¹⁶ whereas high levels of daylight can benefit individuals who require more light to perform well visually.¹⁷ Daylight exposure and access to windows at work has been linked to improved sleep duration and mood, reduced sleepiness, lower blood pressure and increased physical activity, whereas lack of natural light has been associated with physiological, sleep, and depressive symptoms.^{17,18,19,20} Office workers exposed to electric and natural lighting conditions have reported experiencing less glare and less sleepiness earlier in the day under natural lighting compared to when they were under electric lighting.^{20,21} Moreover, not only intensity but also the timing of daytime light exposure has been found to influence BMI in adults, with lower BMI in those who receive the majority of their bright light exposure earlier rather than later in the day.²²



Views to natural landscapes are often obstructed. Researchers in the field of environmental psychology have become increasingly interested in the restorative effects of visual access to natural environments. Students in classrooms with access to green views through their windows have been observed to experience significantly faster recovery from stress and mental fatigue and performed significantly higher on tests of attentional functioning, compared to students in classrooms with no windows or windows looking out onto other buildings facades.²³ This research supports the biophilia hypothesis posited by E.O. Wilson – that there is an innate connection between humans and nature.²⁴ Buildings can bring nature in through biophilic design, which aims at improving indoor environments by incorporating natural elements into the design of the building.²⁵

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