Research Anthology of Health-Promoting Building Strategies

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1 INTRODUCTION

Human health is a longstanding value of green building. Green buildings can promote health and well-being in the near term while preserving resources and protecting the environment. By intentionally deploying green building strategies, like those available for use within the LEED rating systems, owners and practitioners can simultaneously promote health and well-being at a variety of population scales.

The real estate industry is well-positioned to improve population health through its direct influence over the design, construction, and operations of our buildings and communities. By making the decision to promote health, green building practitioners are intentionally utilizing public health research to advocate for and contribute to a culture of health within real estate, while maintaining a critical focus on climate change mitigation.

Harnessing LEED's health promotion capacity

While LEED contains a number of health-related strategies, practitioners must be intentional in their use of LEED to maximize its potential health benefit. The majority of credits within the LEED rating systems address the health of the site user and health-related credits are found within every LEED credit category. These credits include guidance on improving indoor air quality, promoting physical activity and healthy nutrition, and designing for mental health and comfort, among many others. Some strategies, however, do not fully state their potential health benefit(s) and/or require practitioners to choose a specific health-related compliance pathway.
With an intentional, needs-based approach to the application of credit requirements, projects can target health goals most relevant to their project's population. Practitioners can also leverage the power of the LEED to achieve sustainability and energy efficiency goals while maintaining a focus on health promotion efforts.

2 BACKGROUND

Last year, the USGBC announced its new vision, Healthy people in healthy places equals a healthy economy, sharing a series of actions and priorities to shape a healthy future for all. While many interpretations of health exist, USGBC, and this anthology, utilize the World Health Organization's definition of health which states that health is "a state of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity." This comprehensive definition of health helps provide a more holistic understanding of the effects of our buildings and communities on the human body and mind.

Determinants of Health

Our buildings and communities have a direct impact on both individual and population health. Health and health behaviors are highly influenced by social and environmental determinants—the physical, social, policy, and economic characteristics of the places that we live, work, and play. The real estate industry is well-positioned to improve population health through its direct influence over the design, construction and operation of the built environment. Green buildings strategies, when used intentionally, can improve health for all, especially vulnerable

populations such as children, seniors and low-income groups. While there are many determinants of health, this anthology focuses on determinants that can be positively influenced by health-promoting building strategies. To capture health most comprehensively, determinants are studied from a physical, social and individual lens.

Table 1. Health determinants affected by building strategies are highlighted in gray.

Health Determinants (KFF, Northridge & Schultz)		
Physical (Environmental)	**Social (Social/Economic)**	**Individual (Behaviors)**
Natural Environment	**Economic Stability**	**Healthy Behaviors**
Topography	Employment	Dietary practices
Climate	Income	Physical health
Water supply	Expenses	Health screening
Built Environment	Debt	Tobacco use
Land use	Medical Bills	
Transportation systems	Support	
Services	**Education**	
Public resources	Literacy	
Zoning regulations	Language	
Buildings	Early childhood education	
Housing	Vocational training	
Safety	Higher education	
Parks	**Food**	
Playgrounds	Hunger	
Walkability	Access to healthy options	
Zip code	**Community/Social Context**	
	Social integration	
	Support Systems	
	Community engagement	
	Discrimination	
	Stress	
	Health Care System	
	Health Coverage	
	Provider availability	
	Provider linguistic/cultural competency	
	Quality of care	

Evolution of Health Within LEED

Health is a longstanding value of the LEED rating system and the U.S. Green Building Council. Green buildings can promote health and well-being in the near term while preserving resources and protecting the environment for human benefit in the long term. Developed by an organization with a people-centric mission, LEED was committed to rewarding spaces that created a healthy environment for occupants. Among these first health-promoting design strategies for green building was the elimination of tobacco smoke in buildings and decreasing occupant exposures to harmful chemicals. As the organization and rating system evolved, the connections between buildings, materials and health became increasingly more clear and LEED adapted and expanded to cover more considerations for health in design. These adaptations, coupled with the massive sustainability and energy efficiency benefits LEED certification provides, contribute to its overall standing as the most widely used green building rating system in the world.

In its current state, over 60% of each LEED rating system is associated with occupant health and health-related credits are found within every LEED credit category. These credits include guidance on improving indoor air quality, promoting physical activity and healthy nutrition, and designing for mental health and comfort, among many others. As LEED was designed to be an adaptable framework, practitioners have a great level of choice regarding which specific LEED strategies to deploy in their projects. While LEED contains a number of health-related strategies, practitioners must be intentional in their use of LEED to maximize its potential health benefit. Pilot credits such as the LEED Integrative Process for Health Promotion can help project teams select and tailor LEED credits based on a project's specific health context. By intentionally applying LEED strategies and credit requirements, project teams can promote health and well-being by creating superior environments for building occupants, while also reducing toxic exposures throughout the supply chain, advancing health of the surrounding communities and mitigating climate change to benefit global populations.

Founded in 2013, the Green Health Partnership (GHP) is an academic research and development group between the University of Virginia School of Medicine and the U.S. Green Building Council with funding from the Robert Wood Johnson Foundation. GHP utilizes the green building movement as a platform and blueprint for creating a self-sustaining, scalable market for health promotion within the real estate industry.

Population Scales of the Built Environment

Green building strategies can be applied at various levels of the built environment: at the building-level, affecting occupants, tenants and visitors; the city-level, shaping interactions in neighborhoods and communities; and at the global-level, through climate change mitigation strategies. While research often associates building level strategies with occupant outcomes and neighborhood or city level strategies with community level outcomes, it becomes interesting to propose building-level strategies that can influence health impacts at the community or even global level. For instance, a green roof on a building can have a positive impact on the surrounding community, while natural ventilation in several buildings of a region may reduce the release of greenhouse gases (GHGs) and air pollutants on a global scale. Figure 1 shows the various population scales in our created environments. Table 2 shows some examples of building strategies applied to larger population scales.

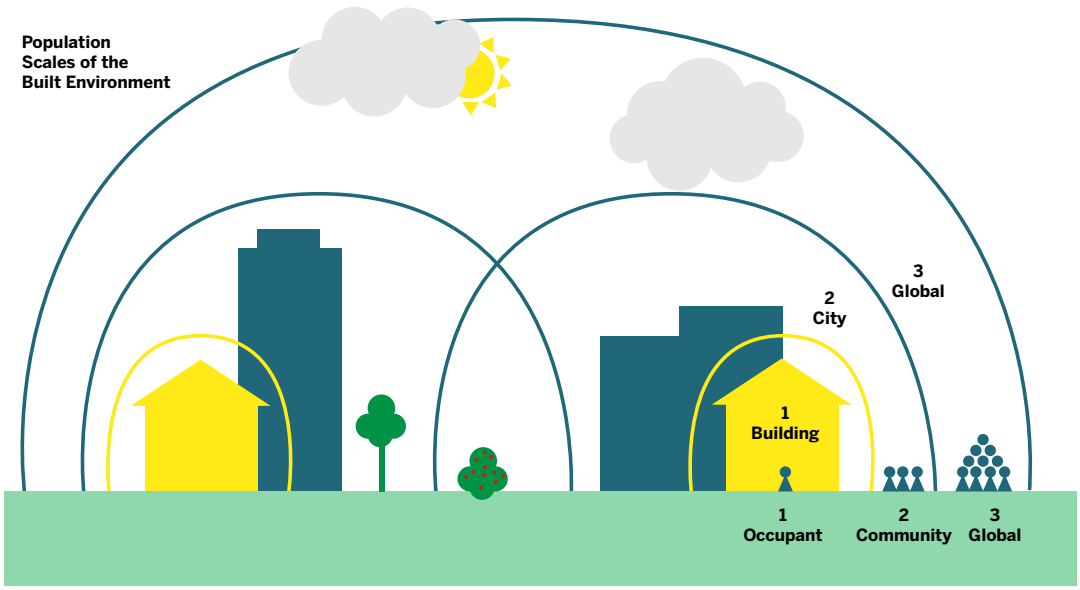

Figure 1. The scales of impact of green building strategies on population health.

Table 2. Green building goals applied to multiple population scales using various strategies.

Green Building Goal	Occupant	Community	Global
Air Quality	Adequate ventilation	Reduce construction pollution	Reduce motor vehicle usage
Water Quality	Water filtration	Groundwater level/ water supply	Clean ocean water
Lighting	Daylighting	Streetlights	Electrical grid
Thermal Comfort	Thermal zoning	Urban vegetation	Reduce global warming
Acoustic Comfort	Sound masking	Noise blocking trees	Reduce industrial noise
Views/Biophilia	Indoor plants	Access to nature	Reforestation
Active Design	Sit/stand desks	Active spaces	Walkability/zoning
Site/Landscape	Roof garden, permeable surfaces	Reduce urban heat island effect, flood risk	Reduce climate change effects

3 HOW TO USE THIS RESOURCE

Design professionals and others can use this resource to identify health impacts of design choices and to justify design decisions based on desired health outcomes. It allows users to search for health outcomes based on building strategies, or alternatively, use the cross-referenced index in Appendix A to search for building strategies based on desired health outcomes. For more information on the research article selection process, please see Appendix C.

Building Health Pathways

The building health pathways relate building strategies to building conditions to downstream health impacts for building occupants (see Figure 2 below). For each building strategy (design, construction, operations), the pathway identifies the anticipated building condition (environmental metric, health determinant, occupant behavior) and the associated health benefit (physical, social, mental) of that improved building condition. Long term health benefits are indicated with an *. This anthology focuses on building strategies at the building level and the associated health impacts at the occupant level. Although the majority of the articles cited in this anthology are based in office settings, the design strategies can be applied to various other building types as well, including residential, school and healthcare buildings.

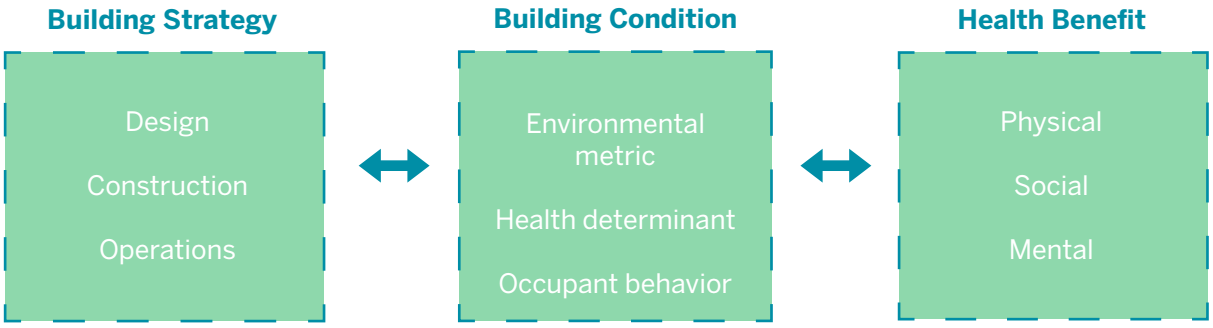

Figure 2. Concept diagram of health impacts of building-level strategies at the occupant level.

4 BUILDING STRATEGIES

There are a number of strategies that can be implemented at the building level to promote occupant health and wellbeing including: indoor air quality, water, lighting, thermal conditions, acoustic conditions, views/biophilia, active design and site/landscape.

A. INDOOR AIR QUALITY

Indoor air quality (IAQ) is a building design feature closely linked to physical health. In the context of created environment design, IAQ is most commonly associated with heating, cooling, ventilation, low-emitting materials, pollution, and cleaning strategies. IAQ is a subset of Indoor Environmental Quality (IEQ), the LEED category which addresses occupant comfort most directly. Several studies show the impacts of IEQ on occupant health, summarized in Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature (2016). This systematic review of recent literature considers the relationship of indoor air quality with thermal, acoustic and visual comfort. Various studies show that improved indoor air quality (measured by levels of CO_2, pollutants (SOx, NOx, PM2.5) and VOCs) are associated with reduced respiratory illnesses, asthma, allergies, headaches, and infectious disease transmission (see Table 3 on the next page).

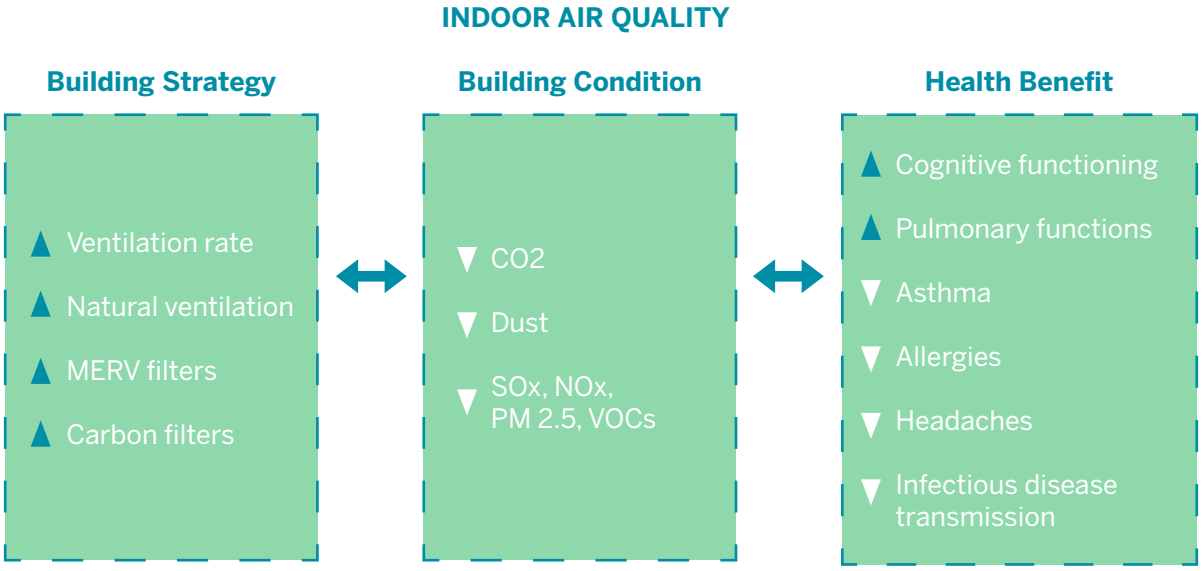

Figure 3. Indoor air quality building health pathway

1. Harvard COGfx Study: Part 1 and 2

1A. Environmental Health Perspectives

Title: Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environment (Joseph G. Allen et al., 2016)

The three-phase COGfx studies by a research group at the Harvard T.H. Chan School of Public Health uses an experimental study design to investigate the impact of IEQ on human health. The first study measured the increase in higher-order cognitive functioning due to improved IEQ. By simulating "Conventional," "Green" and "Green+" buildings in the lab, they found that increased ventilation and reduced CO_2 and VOC levels correlated with significantly higher scores on the SMS test in eight of the nine domains of cognitive functioning. Most significant domains were Crisis Response, Information Usage, and Strategy. "Green" building occupants scored 61% higher, "Green+" scored 101% higher.

1B. Building and Environment

Title: The impact of working in a green certified building on cognitive function and health (Piers McNaughton et al., 2017)

In their follow up study, the authors studied the impact of green building (high IEQ, thermal conditions and lighting) on cognitive functioning through test scores in actual buildings. They measured sleep quality and sick building symptoms. Overall, they found a positive association between green building strategies (high IEQ, thermal conditions and lighting) and increased cognitive functioning and human health.

2. International Journal of Environmental Research and Public Health

Title: Building-Related Symptoms among Office Employees Associated with Indoor Carbon Dioxide and Total Volatile Organic Compounds (Chung-Yen Lu et al., 2015)

This study measured the association between indoor air quality and the incidence of sick building syndrome (SBS) among office workers. Levels of carbon dioxide, temperature, humidity and total volatile organic compounds (VOCs) in 87 office rooms were measured for eight hours of the day, using the difference between indoor and outdoor carbon dioxide concentrations to infer ventilation rates. Using self-report questionnaires, 417 participants rated prevalence of symptoms such as eye syndrome, upper respiratory and non-specific symptoms. Researchers found moderate association between exposure to carbon dioxide and tiredness, difficulty in concentrating, eye dryness, dry throat and dizziness. An increased exposure to VOCs was associated with reported symptoms such as upper respiratory symptoms, dry throat and irritability.

3. International Journal of Environmental Research and Public Health

Title: Respiratory Diseases in University Students Associated with Exposure to Residential Dampness or Mold (Mathieu Lanthier-Veilleux et al., 2016)

In this large-scale observational study, researchers studied the prevalence of respiratory diseases among students living in residential dorms at a university in Canada. Using an online survey, they examined the incidence of self-reported respiratory diseases, residential dampness or mold and covariates (such as student characteristics). They found high rates of allergic rhinitis, asthma-like symptoms and respiratory infections. Using logistic regression analysis, they showed that exposure to residential dampness or mold was associated with allergic rhinitis and asthma-like symptoms. Symptomatic students also faced significant levels of uncontrolled and burdensome symptoms.

Table 3. Studies showing the health impacts of indoor air quality (IAQ) on occupants.

Health Impacts	Studies
Cognitive Function	• The impact of working in a green certified building on cognitive function and health (2017) • Associations of cognitive function scores with carbon dioxide, ventilation, and volatile organic compound exposures in office workers: A controlled exposure study of green and conventional office environments (2016) • Effects of ventilation rate per person and per floor area on perceived air quality, sick building syndrome symptoms, and decision-making (2014) • Association between substandard classroom ventilation rates and students' academic achievement (2010)
Pulmonary Function	• Household Air Pollution Exposure and Influence of Lifestyle on Respiratory Health and Lung Function in Belizean Adults and Children: A Field Study (2016) • Investigation of Acute Pulmonary Deficits Associated with Biomass Fuel Cookstove Emissions in Rural Bangladesh (2017) • Respiratory Diseases in University Students Associated with Exposure to Residential Dampness or Mold (2016) • Volatile Organic Compounds in Anatomical Pathology Wards: Comparative and Qualitative Assessment of Indoor Airborne Pollution (2017) • Building-Related Symptoms among Office Employees Associated with Indoor Carbon Dioxide and Total Volatile Organic Compounds (2015) • Association of Sick Building Syndrome with Indoor Air Parameters (2015) • Outdoor air pollution, meteorological conditions and indoor factors in dwellings in relation to sick building syndrome (SBS) among adults in China (2016) • Endotoxin, ergosterol, muramic acid and fungal DNA in dust from schools in Johor Bahru, Malaysia — Associations with rhinitis and sick building syndrome (SBS) in junior high school students (2016)
Infection Control	• Air pollution and temperature are associated with increased COVID-19 incidence: A time series study (2020) • Airborne transmission of SARS-CoV-2: The world should face the reality (2020) • Evidence for probable aerosol transmission of SARS-CoV-2 in a poorly ventilated restaurant (2020) • Airborne spread of infectious agents in the indoor environment • Role of mechanical ventilation in the airborne transmission of infectious agents in buildings (2016) • HVAC filtration for controlling infectious airborne disease transmission in indoor environments: Predicting risk reductions and operational costs (2013)

B. WATER QUALITY

Water makes up 70% of the human body and is essential for several physiological functions such as maintaining body temperature and transporting nutrients and waste. Contaminated drinking water is a major global health issue, with the WHO reporting that almost one billion people do not have access to safe drinking water. Pathogens in water can cause diseases such as cholera, dysentery, typhoid and polio. Inorganic contaminants such as lead and mercury may induce developmental delays in learning for children as well as high blood pressure and kidney problems in adults, while organic contaminants such as polychlorinated biphenyl have been linked to cancer, immune deficiency and nervous system difficulties. Global Water Pollution and Human Health (2010) provides a comprehensive review of the various hazards in water, their impact on human health and strategies to mitigate pollution of freshwater resources.

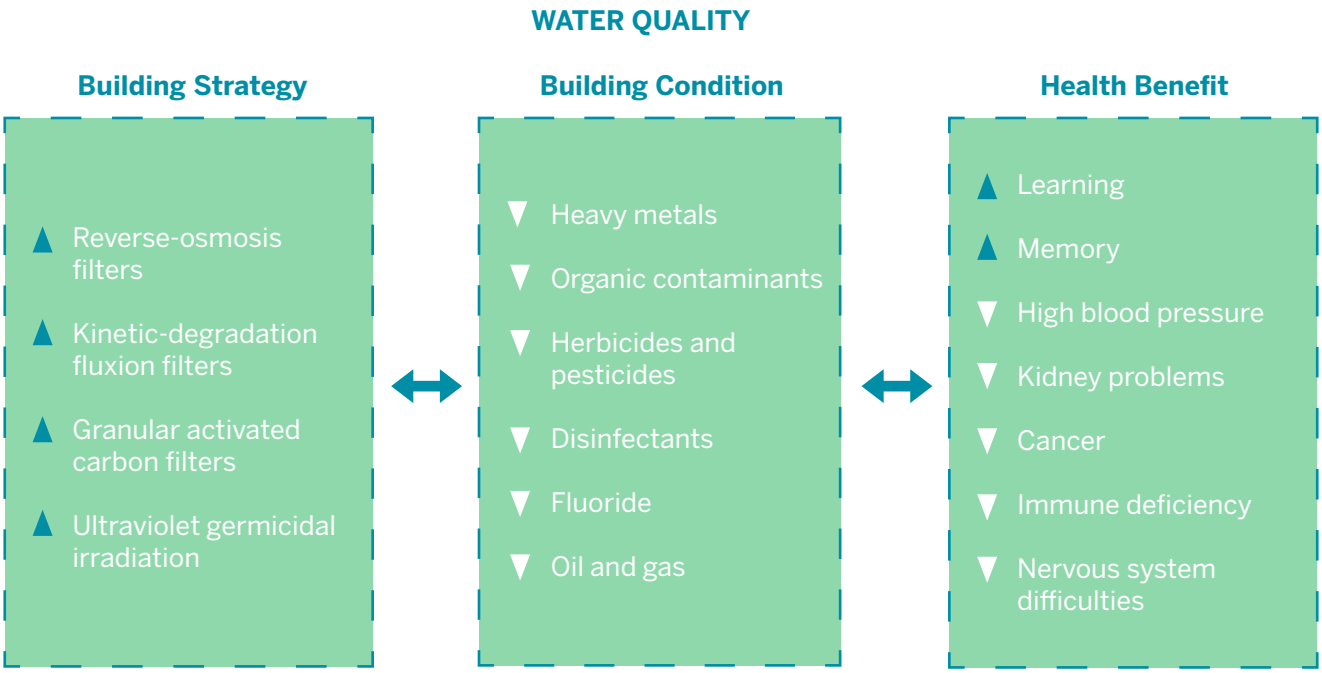

Figure 4. Water quality building health pathway

1. Science Total Environment

Title: A discussion about public health, lead and Legionella pneumophila in drinking water supplies in the United States (Michael B Rosen et al., 2017)

The Flint water crisis that occurred in 2014 in Flint, Michigan provides a rich example to study the public health effects of contaminated water. This article uses Flint as a case study to summarize the impacts of elevated levels of lead and legionella on public health. It addresses the policy regulations and responses that contributed to the crises, barriers associated with measuring and reducing lead levels in tap water and factors influencing legionella growth. The paper analyzes the relationship between changes in water chemistry and public health effects, while offering a discussion on future water quality research to inform and guide public health decision-making.

2. Environmental Research

Title: A community-based evaluation of proximity to unconventional oil and gas wells, drinking water contaminants, and health symptoms in Ohio (Elise G Elliott et al., 2018)

In this exploratory study, researchers examined the environmental health impacts from water contamination in residents living close to an unconventional oil and gas (UO&G) well. They analyzed levels of contaminants such as volatile organic compounds (VOCs), gasoline-range organics (GROs) and diesel-range organics. Through interviews and self-report assessments, they found a relationship between distance to UG&O wells, water contamination and health. They found that proximity to UG&O wells likely to result in elevated levels of contaminants and health symptoms such as stress or fatigue.

3. Journal of Cellular Biochemistry

Title: Prevalence of exposure of heavy metals and their impact on health consequences (Kanwal Rehman et al., 2018)

This article reviews the global contamination of drinking water with heavy metals and the associated health impacts of consuming metal-contaminated water. The article describes health hazards ranging from cardiovascular disorders, neuronal damage, renal injuries and risk of cancer and diabetes. It also delves into the growing rise in morbidity and mortality rates worldwide due to heavy-metal contaminated water. Discussions about exposure limits and physiological responses, major organs affected and acute vs chronic poisoning symptoms are included as well.

Table 4. Studies showing the health impacts of water quality on occupants

Health Impacts	Studies
Cognitive Performance	• Prevalence of exposure of heavy metals and their impact on health consequences (2018) • Public Health Consequences of Lead in Drinking Water (2018) • Mercury, lead and arsenic: impact on environment and human health (2016) • Lead (Pb) in Tap Water and in Blood: Implications for Lead Exposure in the United States (2011)
Healthy Eating and Water Quality	• Effects of a large-scale distribution of water filters and natural draft rocket-style cookstoves on diarrhea and acute respiratory infection: A cluster-randomized controlled trial in Western Province, Rwanda (2019) • A post-implementation evaluation of ceramic water filters distributed to tsunami-affected communities in Sri Lanka (2012) • Climate and Health Co-Benefits in Low-Income Countries: A Case Study of Carbon Financed Water Filters in Kenya and a Call for Independent Monitoring (2017) • Antibiotic resistance in drinking water systems: Occurrence, removal, and human health risks (2019) • WHO water quality standards Vs Synergic effect(s) of fluoride, heavy metals and hardness in drinking water on kidney tissues (2017) • A discussion about public health, lead and Legionella pneumophila in drinking water supplies in the United States (2017) • A community-based evaluation of proximity to unconventional oil and gas wells, drinking water contaminants, and health symptoms in Ohio (2018)

C. LIGHTING

A growing body of evidence shows the numerous benefits of daylighting not only for building energy-efficiency, but also for the health and wellbeing of the occupants. Lighting can be measured by quantity (lumens, lux), quality, glare, daylight, and task type. Direct health impacts of daylighting include physical health effects such as increased productivity, but also mental health effects such as increased positive feelings and reduction in depression and seasonal affective disorder. The Benefits of Natural Light: Research supports day lighting's positive effect on building performance and human health (2014) provides a review of several research studies that explore the positive effects of daylit spaces on efficiency, productivity and the circadian rhythm. The article also includes several external resources to guide designers through the design-making process for daylighting design.

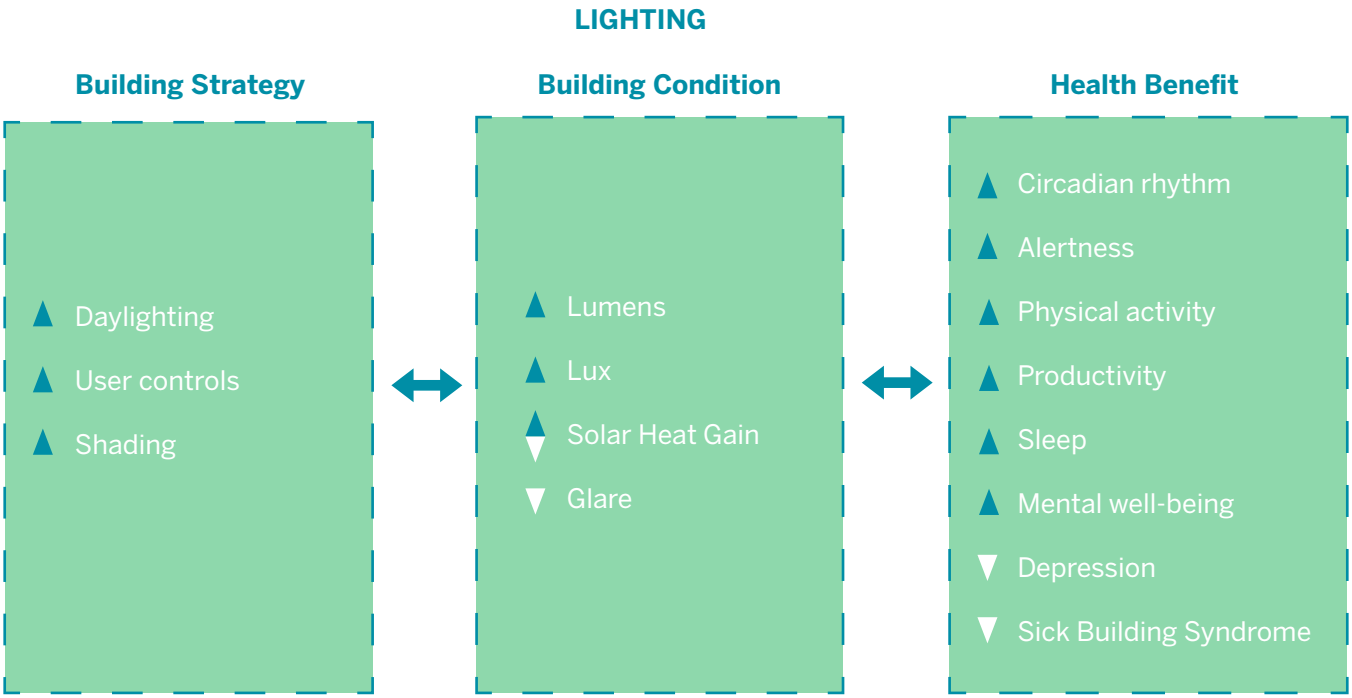

Figure 5. Lighting building health pathway

1. International Journal of Environmental Research and Public Health (View Inc.)

Title: The Impact of Optimized Daylight and Views on the Sleep Duration and Cognitive Performance of Office Workers (Mohamed Boubekri et al., 2020)

In this experimental study, researchers studied the impact of daylight and views on sleep duration and cognitive performance. Thirty knowledge workers were put in two identical office environments, however one had electrochromic glass (optimized condition), the other had traditional blinds (control). Participants in the optimized condition slept for 37 minutes longer on average and scored 42% higher on a cognitive simulation used to test higher-order decision making. Results could be seen after just one day; however, results were more significant after a week of being exposed to the condition.

2. Journal of Clinical Sleep Medicine

Title: Impact of windows and daylight exposure on overall health and sleep quality of office workers: A case-control pilot study (Mohamed Boubekri et al., 2014)

Researchers conducted an observational study to assess the effects of daylighting on the physical and mental health of office workers. They administered tests to two groups: workers in offices with windows and in windowless environments. The results revealed that workers in windowless environments suffered from less or poorer sleep, while workers in offices with windows were exposed to more light and trended towards more physical activity and better quality and quantity of sleep. While these results are significant, the limitations of this study includes the small sample size of participants, a potential convenience sample bias, unaccounted confounding factors such as caffeine, errors in their measurement tools and obscuring of natural light versus views versus daylighting.

3. U.S. Green Building Council (USGBC)

Title: Daylighting-Bias and Biophilia: Quantifying the Impact of Daylighting on Occupants Health (Ihab M.K. Elzeyadi, 2011)

This study conducted an observational study to investigate the relationship between lighting quality, views from windows and occupant health in office spaces. Split over three phases, the study involved both qualitative and quantitative methods of data collection, through observation, interviews, online surveys and health data records. The researchers recorded the quantity and quality of daylight and biophilic views in 120 office spaces and compared it to the number of days of sick leave and Sick Building Syndrome (SBS) symptoms of 175 office workers. They also investigated mental health effects, such as stress levels and hypersensitivity to biophilic features in the environment and their impact on sick leave and health of office workers. Using statistical analysis tests, they showed that access to daylighting and biophilic environments improves physical and mental health of office workers.

Table 5. Studies showing the health impacts of lighting on occupants

Health Impacts	Studies
Cognitive Performance	• The Impact of Optimized Daylight and Views on the Sleep Duration and Cognitive Performance of Office Workers (2020)
Productivity	• Blinded by the light: Occupant perceptions and visual comfort assessments of three dynamic daylight control systems and shading strategies (2019)
Balanced Circadian Rhythm **Sleep**	• Impact of windows and daylight exposure on overall health and sleep quality of office workers: A case-control pilot study (2014) • The Impact of Optimized Daylight and Views on the Sleep Duration and Cognitive Performance of Office Workers (2020)
Alertness	• Natural Light and Productivity: Analyzing the Impacts of Daylighting on Students' and Workers' Health and Alertness (2016)
Reduced Sick Building Syndrome	• Daylighting-Bias and Biophilia: Quantifying the Impact of Daylighting on Occupants Health (2011)
Reduced Depression	• Increased daylight availability reduces length of hospitalisation in depressive patients (2016) • Pilot study to examine the effects of indoor daylight exposure on depression and other neuropsychiatric symptoms in people living with dementia in long-term care communities (2018)

D. THERMAL HEALTH

Thermal comfort is the term used to describe occupant satisfaction with building conditions such as indoor air temperature, air speed and humidity levels. However, thermal conditions can affect more than just comfort, thus the ForHealth team at Harvard has proposed the more holistic term Thermal Health to include health impacts such as productivity, stress and even mortality. The metric for measuring thermal conditions include operative temperature (ºF), operative relative humidity % (RH%), indoor air flow speed (CFM) and mean radiant temperature (MRT). Other measurements used to describe thermal health are personal factors such as clothing insulation (clo) and metabolic rate (BMR).

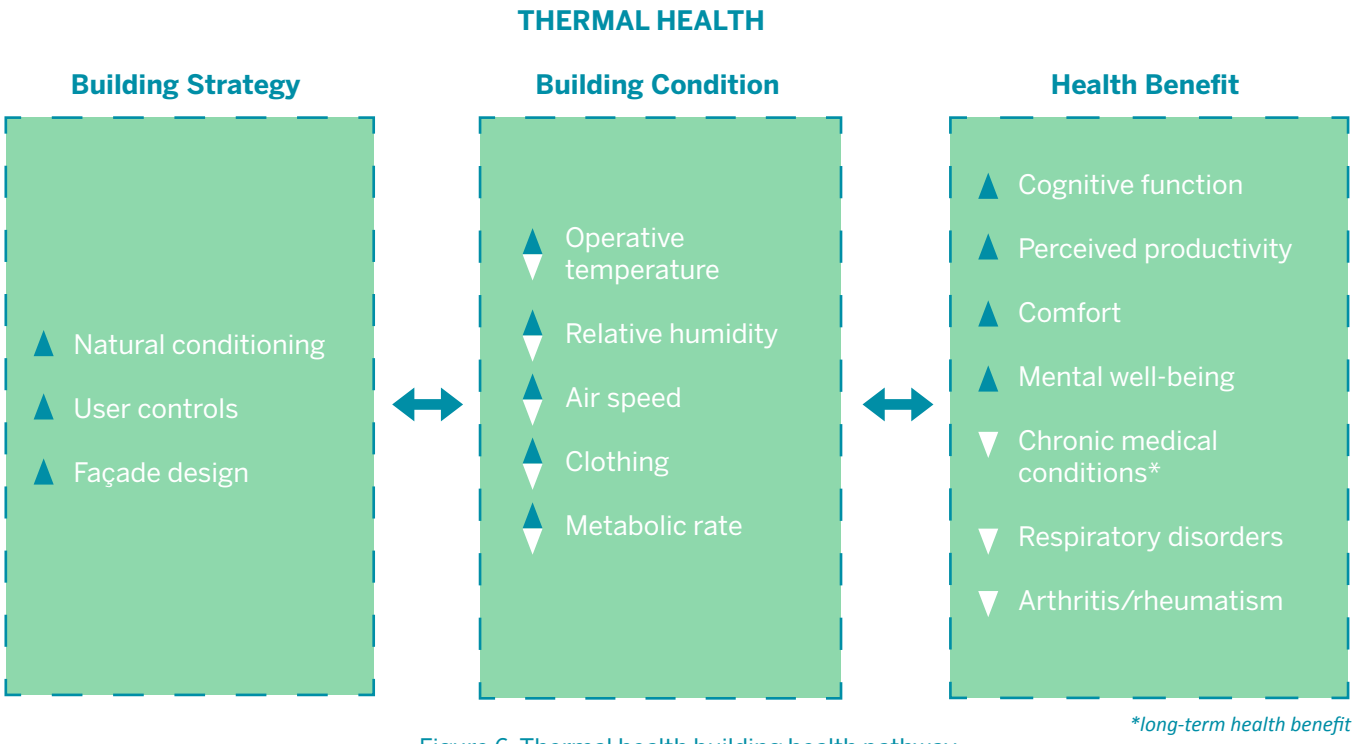

Figure 6. Thermal health building health pathway

1. International Journal of Indoor Environment and Air

Title: Wellbuilt for wellbeing: Controlling relative humidity in the workplace matters for our health (Javad Razjouyan et al., 2019)

This research study measured the impact of relative humidity and objectively measured stress response, physical activity and sleep quality on 134 participants in 4 federal office buildings. Chest-mounted heart-variability monitors were used to measure stress levels and relative humidity and temperature was measured in the workspaces. The research team found that participants in a room with 30-60% relative humidity experiences 25% less stress than those in drier conditions. There was also an indirect effect of poorer sleep quality as mediated by stress responses for those participants outside this range.

2. Harvard Kennedy School Research Faculty Working Paper Series

Title: Heat and Learning (Joshua Goodman et al., 2018)

New studies also show the impact of poor thermal health on cognitive functioning. An observational study in school settings showed that cumulative heat exposure affects student cognitive performance. Increased temperatures before an exam negatively impacted students' scores due to reduced learning in the days leading

up to the exam. Socio-economic levels of students add compounding effects, further driving down learning levels. A financial assessment calculated that the health benefits of installing air conditioning in school buildings likely outweighs the costs. The strengths of this study include using a large sample size, quantifying the benefit of air conditioning and documenting the effect of socioeconomic level. However, it was limited in its solution, considering if air-conditioning really is the best method for cooling if it does not help in climate change mitigation. Perhaps classrooms can also look into passive techniques for cooling and ventilation as well. The study also excluded some of the poorer areas of the country, where their results on change in academic performance could potentially be more significant.

3. Journal of Green Building

Title: The relationship between comfort perceptions and academic performance in university classroom buildings (Simi Hoque et al., 2016)

Another recent finding on the effect of thermal health on cognitive performance studied 409 university students in 9 classrooms over 3 seasons. Students were given thermal comfort questions as an extension to their class exams; scores on these exams were used as a measure of academic performance. The researchers found that the perception of thermal discomfort negatively affected academic performance. Higher thermal discomfort was associated with a more significant difference in academic performance. Although the study quantifies the relationship between thermal comfort parameters, psychological comfort and academic performance, it is still weak because the researchers did not control the room thermal conditions or educational material for students. Since this is only an association study, the researchers cannot deduce causation.

Table 6. Studies showing the health impacts of thermal conditions on occupants.

Health Impacts	Studies
Cognitive Function	• Heat and Learning (2018)
Perceived Productivity	• The relationship between comfort perceptions and academic performance in university classroom buildings (2016) • The impact of thermal environment on occupant IEQ perception and productivity (2017)
Comfort	• The underlying linkage between personal control and thermal comfort: Psychological or physical effects? (2016) • Potential indicators for the effect of temperature steps on human health and thermal comfort (2016)
Stress	• Living in a cold and damp home: frameworks for understanding impacts on mental well-being (2015) • Wellbuilt for wellbeing: Controlling relative humidity in the workplace matters for our health (2019)

E. ACOUSTIC COMFORT

Another feature often considered within IEQ is acoustic comfort. It can be measured in decibels (dB) indoors, as well as through levels of outdoor noise, traffic noise or occupational noise. Some of the main physical and mental health impacts of acoustic comfort include increased attention span and productivity. The feature article, Acoustics is instrumental in creating spaces that support employee wellbeing, engagement and productivity (2020) details some of the challenges in achieving acoustic comfort in open offices, along with building conditions that can help mitigate the adverse health impacts of noise.

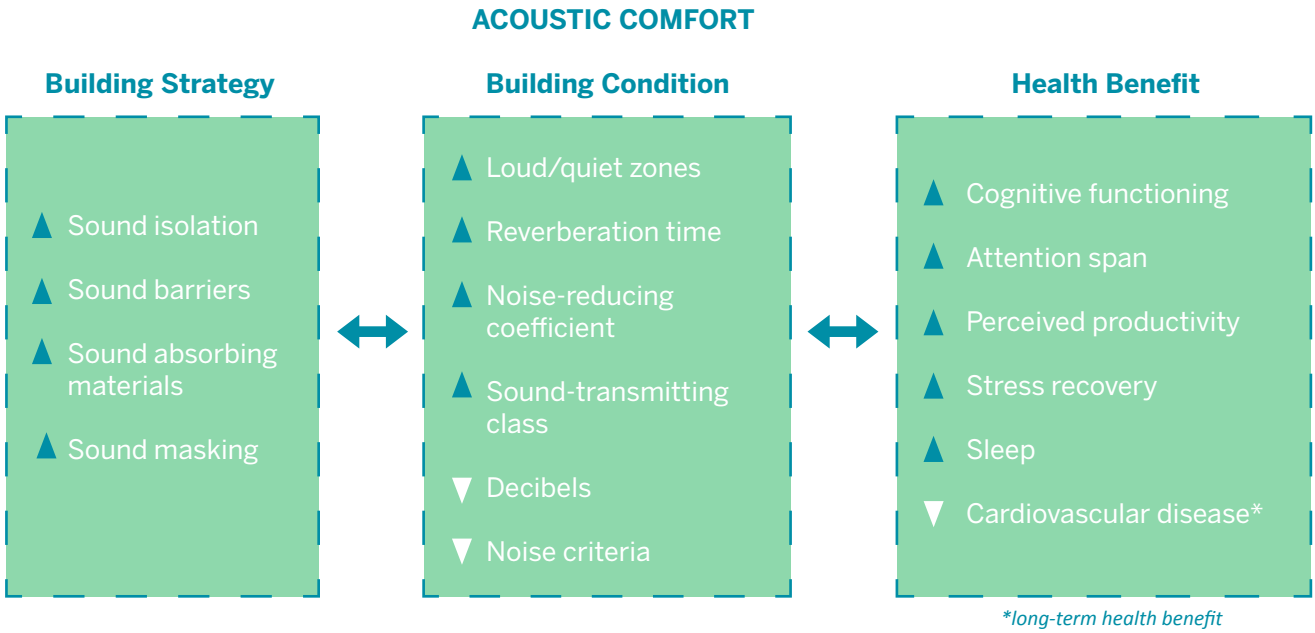

Figure 7. Acoustic comfort building health pathway

1. Psychological Bulletin

Title: Noise effect on human performance: a meta-analytic synthesis (James L. Szalma et al., 2011)

Several meta-analytical studies show the negative effect of noise on human health, further making the case for increased acoustic comfort in buildings. This paper studied the effect of different durations and types of noise in office settings on perceptual, cognitive and psychomotor performance and tasks requiring communication. The magnitude, intensity and duration of noise causes varying amounts of stress on occupants, which can in turn affect their performance on different types of tasks. This paper highlights the lack of observed data linking negative effects of stress from noise on performance, however, it does show that intermittent speech noise is more deleterious than continuous noise on cognitive performance. In addition, nonspeech continuous noise is slightly helpful to performance, while continuous speech has small negative impacts and continuous music has largely negative impacts.

2. World Health Organization

Title: Burden of disease from environmental noise: Quantification of healthy life years lost in Europe (WHO Regional Office for Europe, 2011)

Another comprehensive meta-analytical study by the WHO outlined the diverse health impacts of environmental noise, including cardiovascular disease, cognitive impairment in children, sleep disturbance, tinnitus and annoyance. The report notes that children and elderly are more vulnerable populations, while low-income communities are also more susceptible to adverse effects of environmental noise.

3. International Journal of Environmental Research and Public Health

Title: Stress recovery during exposure to nature sound and environmental noise (Jesper J Alvarsson et al., 2010)

Researchers investigated if auditory stimulation affects the sympathetic and parasympathetic recovery of the body. After completing a stressful mental arithmetic test, participants were exposed to nature or environmental sounds. Measuring skin conductance levels (sympathetic activity) and high frequency heart rate levels (parasympathetic activity) after the exposure revealed that nature sounds facilitate recovery from sympathetic activation after a psychological stressor.

Table 7. Studies showing the health impacts of acoustic conditions on occupants.

Health Impacts	Studies
Cognitive Function	• Different Effects of Adding White Noise on Cognitive Performance of Sub-, Normal and Super-Attentive School Children (2014) • The effect of background music and noise on the cognitive test performance of introverts and extraverts (2011)
Productivity	• Burden of disease from environmental noise: Quantification of healthy life years lost in Europe (2011) • Noise effect on human performance: a meta-analytic synthesis (2011)
Stress Recovery	• Stress recovery during exposure to nature sound and environmental noise (2010)
Cardiovascular Disease	• Cardiovascular effects of environmental noise exposure (2014)
Sleep	• Impact of overnight traffic noise on sleep quality, sleepiness, and vigilant attention in long-haul truck drivers: Results of a pilot study (2015) • Effect of nocturnal road traffic noise exposure and annoyance on objective and subjective sleep quality (2014)

F. VIEWS/BIOPHILIA

One of the most widely building design features studied is the effect of views and biophilia on human health and wellbeing, which can be measured by visibility or access to open and green space. Health impacts include increased cognitive functioning and positive feelings and reduced feelings of stress and cases of depression. Exploring pathways linking greenspace to health: Theoretical and methodological guidance (2017) highlights pathways for understanding three main functions of greenspace on human health: reducing harm (air pollution, noise, heat), restoring capacities (attention restoration, physiological stress recovery) and building capacities (physical activity, social cohesion).

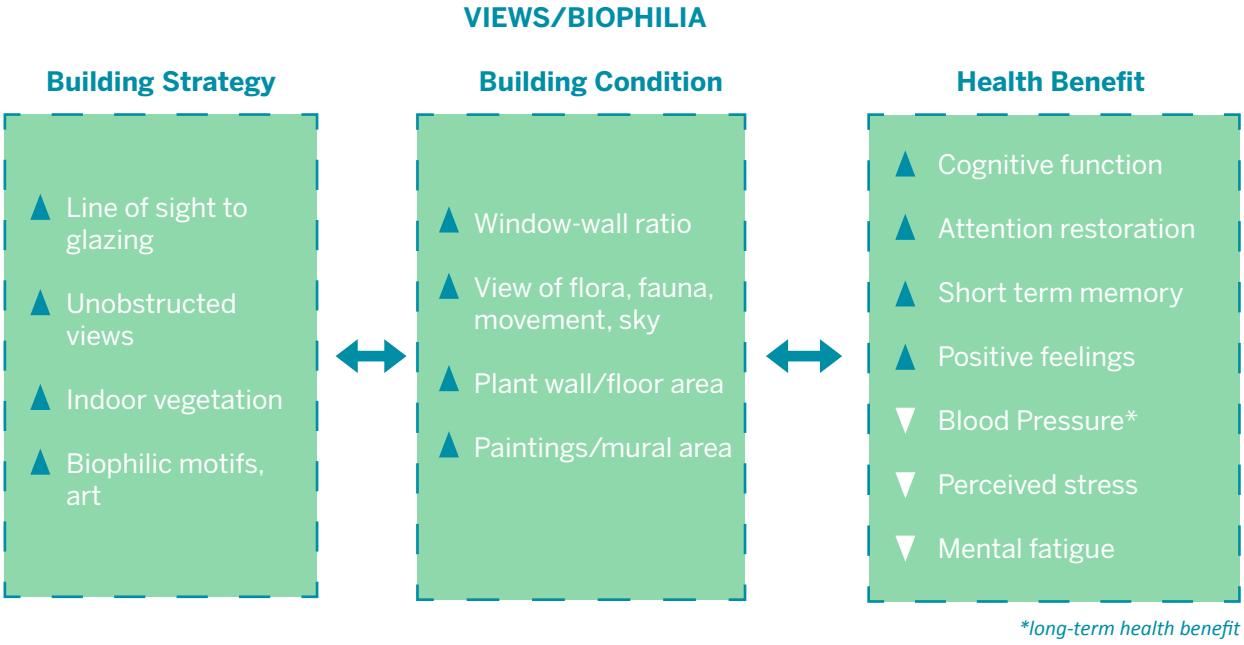

Figure 8. Views and biophilia building health pathway

1. Building and Environment

Title: Physiological and cognitive performance of exposure to biophilic indoor environment (Jie Yin et al., 2018)

This controlled experimental study measured the physiological and cognitive performance of 28 people after being in biophilic rooms and control rooms for five minutes each. The authors found that biophilic environments reduce blood pressure and skin conductance levels. These environments also improve short term memory, decrease negative emotions and increase positive emotions.

2. Environment International

Title: Effects of biophilic indoor environment on stress and anxiety recovery: A between-subjects experiment in virtual reality (Jie Yin et al., 2020)

In a follow up study, the Harvard research group found that biophilic environments perceived through virtual reality (VR) trigger similar physiological responses in participants. After being exposed to a stress task, 100 participants experienced one of four virtual office environments (three biophilic and one control). Bio-monitoring sensors measured their heart-rate variability, heart rate, skin conductance and blood pressure. Participants in biophilic indoor environments had better recovery responses in terms of stress and anxiety levels.

3. Building Research and Information

Title: Human stress responses in office-like environments with wood furniture (Michael David Burnard et al., 2019)

Another example of incorporating biophilia indoors is through material choice. The use of natural materials, such as wood, can provide similar health impacts as direct access to nature. An experimental study was undertaken in controlled lab rooms with four test-settings: two experimental conditions (furniture made of oak wood and walnut wood) and two control conditions (white furniture with no wood). After giving participants an induced stressor, the research team measured levels of salivary cortisol concentration. They found that overall stress levels in rooms with oak wood furniture were lower than the control room.

Table 8. Studies showing the health impacts of views/biophilia on occupants.

Health Impacts	Studies
Cognitive Function	• Physiological and cognitive performance of exposure to biophilic indoor environment (2018) • Quantitative Improvement in Workplace Performance Through Biophilic Design: A Pilot Experiment Case Study (2018) • Are biophilic-design site office buildings linked to health benefits and high performing occupants? (2014)
Productivity/Focus	• Impact of views to school landscapes on recovery from stress and mental fatigue (2016) • Benefits of indoor plants on attention capacity in an office setting (2011)
Stress Recovery	• Impact of views to school landscapes on recovery from stress and mental fatigue (2016) • Human stress responses in office-like environments with wood furniture (2019) • Impact of window views on recovery-an example of post-cesarean section women (2019)
Wellbeing	• Workplace settings and wellbeing: Greenspace use and views contribute to employee wellbeing at peri-urban business sites (2015)

G. ACTIVE DESIGN

Active design in buildings is a more recent building design feature that has gained attention as an important way of promoting health in buildings. The news article, Don't Get Too Comfortable at That Desk (2017) cites several companies that are beginning to pay more attention to attractive and accessible stairs, bike racks and showers to encourage more movement during work hours and walking, running or biking to work. The health impacts of increased movement include lower risk of cardiovascular disease and diabetes and lower levels of obesity.

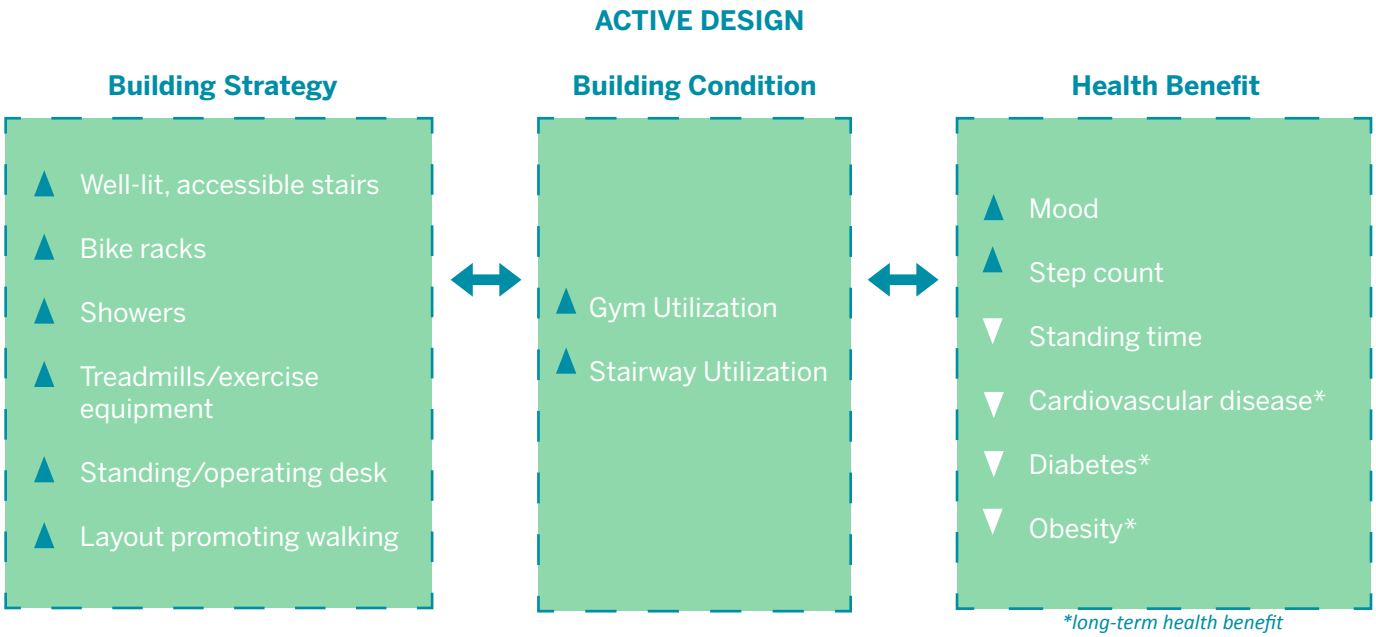

Figure 9. Active design building health pathway

1. BMJ Occupational & Environmental Medicine

Title: Effects of office workstation type on physical activity and stress (Casey M Lindberg et al., 2018)

Workstation design can directly impact occupant physical activity and stress levels. In an observational study, researchers measured the effect of workstation design on physiological stress response, physical activity and perceived stress for 231 office workers in four office buildings. The workstations belonged in one of three categories: 1) private office, 2) cubicle, 3) open bench seating. Wearable, sensor-based technology measured cardiac activity (heart rate variability) and physical activity (intensity of activity as opposed to step count). Workers in open bench seating were more physically active than those in private offices and cubicles and also experienced lower levels of perceived stress than those in cubicles. Higher physical activity was also associated with lower physiological stress levels outside the office.

2. BMJ

Title: Effectiveness of the Stand More AT (SMArT) Work intervention: cluster randomised controlled trial (Charlotte L Edwardson et al., 2018)

In this randomized and controlled experimental study, the research team evaluated the impact of a multicomponent intervention to reduce sitting time and measure changes in physical activity, physical, psychological and work-related health over multiple time intervals. The intervention group received a height adjustable workstation, education materials for planning and goal setting, self-monitoring tools and coaching sessions. The results showed that sitting times reduced over short, medium and long periods of time. Positive

changes in work related and psychological health were also found, such as greater job performance, work engagement and quality of life and reduced occupational fatigue, sickness presenteeism and daily anxiety.

3. Work

Title: Is Active Design changing the workplace? - A natural pre-post experiment looking at health behavior and workplace perceptions (Lina Engelen et al., 2017)

Researchers investigated the effect of Active Design on physical activity, sedentary behavior, musculoskeletal complaints and perceptions of the workplace and productivity. 118 participants who moved into a new open plan office building were asked to fill out a pre and post survey questionnaire. Participants in the new workplace tended to sit less during the day and stand more. They also reported fewer cases of lower back pain. Perceptions of the new workplace included greater satisfaction with environmental characteristics such as better light, air quality and lighting. Participants also found the new space more motivating, however, perceptions of productivity varied.

Table 9. Studies showing the health impacts of active design on occupants.

Health Impacts	Studies
Physical Activity	• Is Active Design changing the workplace? - A natural pre-post experiment looking at health behavior and workplace perceptions (2017) • Active design in affordable housing: A public health nudge (2018) • Effects of office workstation type on physical activity and stress (2018) • Moving to an "Active" Biophilic Designed Office Workplace: A Pilot Study about the Effects on Sitting Time and Sitting Habits of Office-Based Workers (2019) • Prompts to increase physical activity at points-of-choice between stairs and escalators: what about escalator climbers? (2019)
Mood/Mental Health	• Is Active Design changing the workplace? - A natural pre-post experiment looking at health behavior and workplace perceptions (2017) • Effectiveness of the Stand More AT (SMArT) Work intervention: cluster randomised controlled trial (2018) • Implementation of Active Workstations in University Libraries-A Comparison ofPortable Pedal Exercise Machines and Standing Desks (2018)
Cardiovascular Disease	• Do stair climbing exercise "snacks" improve cardiorespiratory fitness? (2019)
Diabetes	• Repeated 3-minute stair climbing-descending exercise after a meal over 2 weeks increases serum 1,5-anhydroglucitol levels in people with type 2 diabetes (2019)
Musculoskeletal System	• The effects of abdominal drawing-in maneuver during stair climbing on muscle activities of the trunk and legs (2019) • Lower limb muscle activities and gain in balancing ability following two types of stair gait intervention in adult post-chronic stroke patients: A preliminary, randomized-controlled study (2020)

H. SITE/LANDSCAPE

A lot of the research about healthy indoor environments is based in office spaces, however, the social determinants of holistic health expand much beyond the boundaries of commercial building walls. More importantly however, green buildings can leverage their health benefits to improve public health and wellbeing and population scales larger than the individual. Healthier Eating Starts on the Roof (2012) is an article in the New York Times that delves into the concept of urban agriculture and the associated health impacts on diet. Green spaces, permeable surfaces and roof gardens are all site and landscape strategies that can improve mental health, increase resiliency and encourage better nutrition.

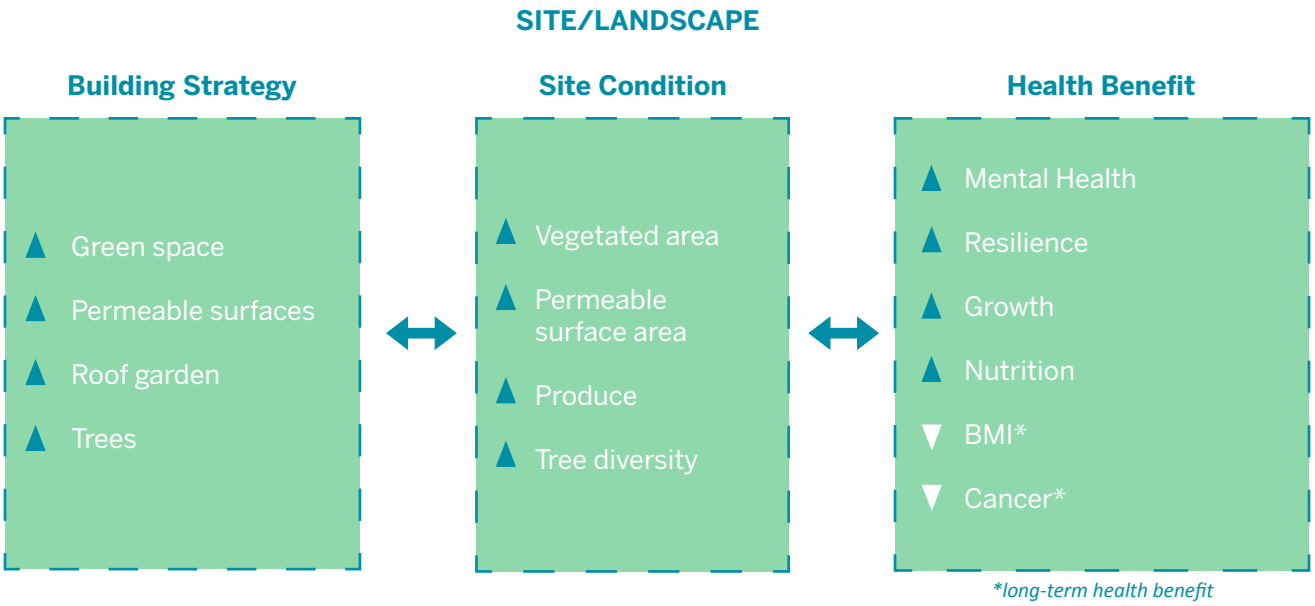

Figure 10. Site and landscape building health pathway

1. Landscape and Urban Planning

Title: More green space is linked to stress in deprived communities: Evidence from salivary cortisol patterns (Catherine Ward Thompson et al., 2012)

Existence and access to green space is one of many social determinants of health. This observational study examined population-level health effects of green space in a domestic, low socio-economic created environment. The researchers found that an increased percent of green space correlated negatively with self-reported stress levels. There was a significant negative correlation between cortisol slope (measurement of stress) and percent green space, meaning that more green space caused a lower stress response in participants.

2. U.S. Green Building Council (USGBC), E-Capital

Title: Delivering Urban Resilience (Greg Kats et al., 2018)

The authors carried out a cost benefit analysis to better understand the financial effect of deploying smart surfaces at a city-wide scale in DC, Philadelphia and El Paso. They also analyzed the health benefits of this intervention for low- and high-income communities. The study considered five smart surfaces: cool roofs, green roofs, solar PV, reflective pavements and urban trees. The benefits studied include energy cost savings, better air quality and public health, reduced stormwater runoff, climate change mitigation and increased employment.

Due to limited data, the authors state that the calculated benefits for comfort and health are likely lower than what might occur in reality.

3. Maternal Child Nutrition

Title: An agriculture-nutrition intervention improved children's diet and growth in a randomized trial in Ghana (Grace S Marquis et al., 2018)

Stunting is a physiological problem in poor, rural and low-educated communities in Ghana. This randomized controlled trial examined the effect of a yearlong intervention in agricultural training and nutritional education on diet and nutrition in children. Interventions included training in poultry farming and home gardening and educational programs in nutrition and health. Outcomes measured were diet diversity, consumption of eggs and growth metrics (length-for-age/height-for-age (LAZ/HAZ), weight-for-age, weight-for-length/weight-for-height (WLZ/HLZ). Compared to the control group, children in the intervention group met minimum diet diversity and had higher LAZ/HAZ and WAZ. They concluded that integrated interventions that increase access to healthy foods and nutritional education improve nutrition in children.

Table 10. Studies showing the health impacts of site/landscape on occupants.

Health Impacts	Studies
Cognitive Performance	• School Gardens Enhance Academic Performance and Dietary Outcomes in Children (2015)
Mental Health	• More green space is linked to stress in deprived communities: Evidence from salivary cortisol patterns (2012) • Green space as a buffer between stressful life events and health (2010) • What is the Best Dose of Nature and Green Exercise for Improving Mental Health? A Multi-Study Analysis (2010)
Healthy Eating and Water Quality	• Rooftop Gardening for Improved Food and Nutrition Security in the Urban Environment (2017) • School gardens and adolescent nutrition and BMI: Results from a national, multilevel study (2016) • An agriculture-nutrition intervention improved children's diet and growth in a randomized trial in Ghana (2018) • Feasibility of an experiential community garden and nutrition programme for youth living in public housing (2015) • LA Sprouts: A Garden-Based Nutrition Intervention Pilot Program Influences Motivation and Preferences for Fruits and Vegetables in Latino Youth (2012) • American Cancer Society guidelines on nutrition and physical activity for cancer prevention (2012) • Healthy food access for urban food desert residents: examination of the food environment, food purchasing practices, diet, and body mass index (2014)

5 APPENDIX A: CITATIONS

Health Concern	Focused Health Concern	Study Name and Year Published	Design Strategy	Rating System	Project Type
Cognitive Function	General Cognitive Function	Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environment (2016)	Indoor Air Quality	BD+C	Office
		The impact of working in a green certified building on cognitive function and health (2017)	Indoor Air Quality	BD+C	Office
		Association between substandard classroom ventilation rates and students' academic achievement (2010)	Indoor Air Quality	O+M	Schools
		Heat and Learning (2018)	Thermal Comfort	O+M	Schools
		Different Effects of Adding White Noise on Cognitive Performance of Sub-, Normal and Super-Attentive School Children (2014)	Acoustic Comfort	O+M	Schools
	Productivity /Focus	The effect of background music and noise on the cognitive test performance of introverts and extraverts (2011)	Acoustic Comfort	O+M	Schools
		Physiological and cognitive performance of exposure to biophilic indoor environment (2018)	Views/Biophilia	ID+C	Office
		Quantitative Improvement in Workplace Performance Through Biophilic Design: A Pilot Experiment Case Study (2018)	Views/Biophilia	ID+C	Office
		Are biophilic-design site office buildings linked to health benefits and high performing occupants? (2014)	Views/Biophilia	ID+C	Office
		School Gardens Enhance Academic Performance and Dietary Outcomes in Children (2015)	Site/Landscape	BD+C	Schools
		Effects of ventilation rate per person and per floor area on perceived air quality, sick building syndrome symptoms, and decision-making (2014)	Indoor Air Quality	O+M	Schools
		Blinded by the light: Occupant perceptions and visual comfort assessments of three dynamic daylight control systems and shading strategies (2019)	Light	BD+C	All
		The relationship between comfort perceptions and academic performance in university classroom buildings (2016)	Thermal Comfort	O+M	Schools
		The impact of thermal environment on occupant IEQ perception and productivity (2017)	Thermal Comfort	O+M	Office, Schools

Health Concern	Focused Health Concern	Study Name and Year Published	Design Strategy	Rating System	Project Type
Cognitive Function	Productivity /Focus	Burden of disease from environmental noise: Quantification of healthy life years lost in Europe (2011)	Acoustic Comfort	-	All
		Noise effect on human performance: a meta-analytic synthesis (2011)	Acoustic Comfort	O+M	Office, Schools
		Benefits of indoor plants on attention capacity in an office setting (2011)	Views/Biophilia	ID+C	Office
	Learning/Memory	Prevalence of exposure of heavy metals and their impact on health consequences (2018)	Water Quality	-	All
		Public Health Consequences of Lead in Drinking Water (2018)	Water Quality	-	All
		Mercury, lead and arsenic: impact on environment and human health (2016)	Water Quality	-	All
		Lead (Pb) in Tap Water and in Blood: Implications for Lead Exposure in the United States (2011)	Water Quality	-	All
	Alertness	Natural Light and Productivity: Analyzing the Impacts of Daylighting on Students' and Workers' Health and Alertness (2016)	Light	BD+C	Schools

Health Concern	Focused Health Concern	Study Name and Year Published	Design Strategy	Rating System	Project Type
Pulmonary Function	General Pulmonary Function	Household Air Pollution Exposure and Influence of Lifestyle on Respiratory Health and Lung Function in Belizean Adults and Children: A Field Study (2016)	Indoor Air Quality	BD+C	Residential
		Investigation of Acute Pulmonary Deficits Associated with Biomass Fuel Cookstove Emissions in Rural Bangladesh (2017)	Indoor Air Quality	BD+C	Residential
	Asthma	Respiratory Diseases in University Students Associated with Exposure to Residential Dampness or Mold (2016)	Indoor Air Quality	BD+C	Residential
		Volatile Organic Compounds in Anatomical Pathology Wards: Comparative and Qualitative Assessment of Indoor Airborne Pollution (2017)	Indoor Air Quality	BD+C	Healthcare
	Sick Building Syndrome	Building-Related Symptoms among Office Employees Associated with Indoor Carbon Dioxide and Total Volatile Organic Compounds (2015)	Indoor Air Quality	BD+C	Office
		Association of Sick Building Syndrome with Indoor Air Parameters (2015)	Indoor Air Quality	BD+C	Office, Residential
		Outdoor air pollution, meteorological conditions and indoor factors in dwellings in relation to sick building syndrome (SBS) among adults in China (2016)	Indoor Air Quality	BD+C	Residential
		Endotoxin, ergosterol, muramic acid and fungal DNA in dust from schools in Johor Bahru, Malaysia — Associations with rhinitis and sick building syndrome (SBS) in junior high school students (2016)	Indoor Air Quality	BD+C	Schools

Health Concern	Focused Health Concern	Study Name and Year Published	Design Strategy	Rating System	Project Type
Pulmonary Function	General Cardiovascular Function	Cardiovascular effects of environmental noise exposure (2014)	Acoustic Comfort	ID+C	All
		Do stair climbing exercise "snacks" improve cardiorespiratory fitness? (2019)	Active Design	-	All

Health Concern	Focused Health Concern	Study Name and Year Published	Design Strategy	Rating System	Project Type
Mental Health and Well-being	General Mental Health and Well-being	Daylighting-Bias and Biophilia: Quantifying the Impact of Daylighting on Occupants Health (2011)	Light	BD+C	All
		Workplace settings and wellbeing: Greenspace use and views contribute to employee wellbeing at peri-urban business sites (2015)	Views/Biophilia	BD+C	Office
		Effectiveness of the Stand More AT (SMArT) Work intervention: cluster randomised controlled trial (2018)	Active Design	ID+C	Office
		Implementation of Active Workstations in University Libraries-A Comparison of Portable Pedal Exercise Machines and Standing Desks (2018)	Active Design	ID+C	Schools
		More green space is linked to stress in deprived communities: Evidence from salivary cortisol patterns (2012)	Site/Landscape	BD+C	All
		Green space as a buffer between stressful life events and health (2010)	Site/Landscape	BD+C	All
		What is the Best Dose of Nature and Green Exercise for Improving Mental Health? A Multi-Study Analysis (2010)	Site/Landscape	O+M	All
	Sleep / Circadian Rhythm	Impact of windows and daylight exposure on overall health and sleep quality of office workers: A case-control pilot study (2014)	Light	BD+C	Office
		The Impact of Optimized Daylight and Views on the Sleep Duration and Cognitive Performance of Office Workers (2020)	Light	BD+C	Office
		Impact of overnight traffic noise on sleep quality, sleepiness, and vigilant attention in long-haul truck drivers: Results of a pilot study (2015)	Acoustic Comfort	-	All
		Effect of nocturnal road traffic noise exposure and annoyance on objective and subjective sleep quality (2014)	Acoustic Comfort	BD+C	Residential
	Depression	Increased daylight availability reduces length of hospitalisation in depressive patients (2016)	Light	BD+C	Healthcare
		Pilot study to examine the effects of indoor daylight exposure on depression and other neuropsychiatric symptoms in people living with dementia in long-term care communities (2020)	Light	BD+C	Healthcare

Health Concern	Focused Health Concern	Study Name and Year Published	Design Strategy	Rating System	Project Type
Mental Health and Well-being	General Mental Health and Well-being	Living in a cold and damp home: frameworks for understanding impacts on mental well-being (2015)	Thermal Comfort	BD+C	Residential
		Wellbuilt for wellbeing: Controlling relative humidity in the workplace matters for our health (2019)	Thermal Comfort	BD+C	Office
		Stress recovery during exposure to nature sound and environmental noise (2010)	Acoustic Comfort	ID+C	All
		Impact of views to school landscapes on recovery from stress and mental fatigue (2016)	Views/Biophilia	BD+C	Schools
	Sleep / Circadian Rhythm	Human stress responses in office-like environments with wood furniture (2019)	Views/Biophilia	ID+C	Office
		Impact of window views on recovery-an example of post-cesarean section women (2019)	Views/Biophilia	BD+C	Healthcare
		The underlying linkage between personal control and thermal comfort: Psychological or physical effects? (2016)	Thermal Comfort	O+M	All
		Potential indicators for the effect of temperature steps on human health and thermal comfort (2016)	Thermal Comfort	O+M	All

Health Concern	Focused Health Concern	Study Name and Year Published	Design Strategy	Rating System	Project Type
Physical Activity	General Physical Activity	Is Active Design changing the workplace? - A natural pre-post experiment looking at health behavior and workplace perceptions (2017)	Active Design	BD+C	Office
		Active design in affordable housing: A public health nudge (2018)	Active Design	BD+C	Housing
		Effects of office workstation type on physical activity and stress (2018)	Active Design	ID+C	Office
		Moving to an "Active" Biophilic Designed Office Workplace: A Pilot Study about the Effects on Sitting Time and Sitting Habits of Office-Based Workers (2019)	Active Design	ID+C	Office
		Prompts to increase physical activity at points-of-choice between stairs and escalators: what about escalator climbers? (2019)	Active Design	BD+C	Office
	Musculoskeletal System	The effects of abdominal drawing-in maneuver during stair climbing on muscle activities of the trunk and legs (2019)	Active Design	-	All
		Lower limb muscle activities and gain in balancing ability following two types of stair gait intervention in adult post-chronic stroke patients: A preliminary, randomized-controlled study (2020)	Active Design	-	Healthcare

Health Concern	Focused Health Concern	Study Name and Year Published	Design Strategy	Rating System	Project Type
Physical Activity	Diabetes Prevention	Repeated 3-minute stair climbing-descending exercise after a meal over 2 weeks increases serum 1,5-anhydroglucitol levels in people with type 2 diabetes (2019)	Active Design	-	All

Health Concern	Focused Health Concern	Study Name and Year Published	Design Strategy	Rating System	Project Type
Infection Control and Prevention	General Infection Control	Air pollution and temperature are associated with increased COVID-19 incidence: A time series study (2020)	Indoor Air Quality	BD+C	All
		Airborne transmission of SARS-CoV-2: The world should face the reality (2020)	Indoor Air Quality	BD+C	Office, Residential
		Evidence for probable aerosol transmission of SARS-CoV-2 in a poorly ventilated restaurant (2020)	Indoor Air Quality	O+M	Retail
		Airborne spread of infectious agents in the indoor environment (2016)	Indoor Air Quality	O+M	Office, Residential
		Role of mechanical ventilation in the airborne transmission of infectious agents in buildings (2016)	Indoor Air Quality	O+M	Office, Residential
		HVAC filtration for controlling infectious airborne disease transmission in indoor environments: Predicting risk reductions and operational costs (2013)	Indoor Air Quality	O+M	Office

Health Concern	Focused Health Concern	Study Name and Year Published	Design Strategy	Rating System	Project Type
Healthy Eating and Water Quality	General Healthy Eating and Water Quality	Rooftop Gardening for Improved Food and Nutrition Security in the Urban Environment (2017)	Site/Landscape	O+M	Residential
		An agriculture-nutrition intervention improved children's diet and growth in a randomized trial in Ghana (2018)	Site/Landscape	O+M	Residential, Community
		School gardens and adolescent nutrition and BMI: Results from a national, multilevel study (2016)	Site/Landscape	BD+C	Schools
		Feasibility of an experiential community garden and nutrition programme for youth living in public housing (2015)	Site/Landscape	ND	Residential
		LA Sprouts: A Garden-Based Nutrition Intervention Pilot Program Influences Motivation and Preferences for Fruits and Vegetables in Latino Youth (2012)	Site/Landscape	O+M	Schools, Residential
		American Cancer Society guidelines on nutrition and physical activity for cancer prevention (2012)	Site/Landscape	All	All
		Healthy food access for urban food desert residents: examination of the food environment, food purchasing practices, diet, and body mass index (2014)	Site/Landscape	ND	Cities and Communi-ties?

Health Concern	Focused Health Concern	Study Name and Year Published	Design Strategy	Rating System	Project Type
Healthy Eating and Water Quality	E.coli / Waterborne Pathogens	Effects of a large-scale distribution of water filters and natural draft rocket-style cookstoves on diarrhea and acute respiratory infection: A cluster-randomized controlled trial in Western Province, Rwanda (2019)	Water Quality	O+M	All
		A post-implementation evaluation of ceramic water filters distributed to tsunami-affected communities in Sri Lanka (2012)	Water Quality	O+M	All
		Climate and Health Co-Benefits in Low-Income Countries: A Case Study of Carbon Financed Water Filters in Kenya and a Call for Independent Monitoring (2017)	Water Quality	-	All
		Antibiotic resistance in drinking water systems: Occurrence, removal, and human health risks (2019)	Water Quality	-	All
		WHO water quality standards Vs Synergic effect(s) of fluoride, heavy metals and hardness in drinking water on kidney tissues (2017)	Water Quality	-	All
		A discussion about public health, lead and Legionella pneumophila in drinking water supplies in the United States (2017)	Water Quality	O+M	All
		A community-based evaluation of proximity to unconventional oil and gas wells, drinking water contaminants, and health symptoms in Ohio (2018)	Water Quality	-	All

BACKGROUND/INTRODUCTION

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5 APPENDIX C: RESEARCH METHODS

Search Process

The landmark research study View through a window may influence recovery from surgery (1984) by Roger Ulrich pioneered the concept of evidence-based design. It has inspired an entire field of research studying the effect of the built environment on human health and well-being. Since this anthology focuses on the first level of both the built environment and population scales, articles in this anthology study the impact of building level strategies on occupant health.

We started with sources cited in a few key systematic reviews by the USGBC, World GBC and the Harvard T. H. Chan School of Public Health, who are furthering new research in this area. We also built on work started by Kelly Worden's LEED v4 health scan. After gaining a better understanding of the health impacts of certain building conditions, we searched for more recent articles based on specific health impacts for each building strategy. These yielded 200+ sources in the form of:

- Experimental studies
- Observational studies
- Meta-analyses
- Systematic reviews
- Other reports - research briefs, etc.

Inclusion Criteria

Abstracts for all articles included were read, and in many cases, the entire article was carefully reviewed. Eventually, 106 journal and news articles were included in this review. The main criteria for inclusion were date of publication (2010 and beyond), article type (peer-reviewed journal article, reputable news source) and relevance (relating a green building strategy and building condition to a health determinant and health impact at the occupant level). For each building strategy, three key experimental or observational studies are featured with article summaries, while related articles or those cited by key systematic reviews are included in tabular format at the end of each section.