BUILDING FOR HEALTH

THE NEXUS OF GREEN BUILDINGS, PUBLIC HEALTH, AND THE U.N. SUSTAINABLE DEVELOPMENT GOALS

HARVARD T.H. CHAN SCHOOL OF PUBLIC HEALTH
Center for Health and the Global Environment

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HARVARD T.H. CHAN SCHOOL OF PUBLIC HEALTH
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Authors

Joseph G. Allen
Augusta Williams

Contributors

Ari Bernstein
Jose Guillermo Cedeno-Laurent
Erika Eitland
Skye Flanigan
Piers MacNaughton
John D. Spengler

For more information
Joseph G. Allen
Harvard T.H. Chan School of Public Health
jgallen@hsph.harvard.edu | www.ForHealth.org

Healthy Buildings Program
Harvard T.H. Chan School of Public Health

BUILDING FOR HEALTH

HEALTH AS THE FOUNDATION

Winston Churchill famously once declared, "We shape our buildings; thereafter they shape us." Nothing could be more true. And yet this shaping can happen in two ways: negative or positive. Buildings define our skylines, creating the bland and forgettable, or the iconic and identity-forming. Buildings can wall us off from nature or connect us to it. They can be prisons of isolation or they can connect us to community. They are symbols of economic weakness or symbols of economic might and opportunity. Buildings can waste energy, water, and materials on a grand scale, or they can be 'net zero' and laboratories for innovative technologies. They can raze the surrounding landscape for miles, or can be built in harmony with the natural landscape. Buildings can exacerbate the impacts of severe weather, or they can be places of refuge during heat waves, floods and storms. They can act as conduits for outdoor air pollution to be carried into our homes, offices and schools, or they can block or trap these pollutants at the building envelope. They can make us feel unsafe and threatened, or they can be secure and protective, providing comfort and ease of mind.

"We Shape our Buildings; Thereafter They Shape Us."

Winston Churchill

Through all of these examples, and more, buildings can act as a constant assault on our health or they can enhance our physical and emotional health and well-being. We shape our buildings, thereafter they shape **PUBLIC HEALTH.**

Within the four walls, they influence the air we breathe, the water we drink, the light we see (or don't) and all of the other '9 Foundations of a Healthy Building' that determine **OCCUPANT HEALTH.**

As the global population continues to rise in our 'Race to 9 Billion', the demand for new buildings and cities increases accordingly, straining our natural systems and **RESOURCE HEALTH** as we strive to build for today without stealing from tomorrow.

And buildings are engines of economic growth and innovation, providing opportunity for work and advancing **ECONOMIC HEALTH**.

Last, buildings are a major consumer of energy globally, a production system that currently relies on fossil fuels. These fuel sources threaten our **ENVIRONMENTAL HEALTH** by polluting our air, water and food systems, and are the cause of global climate change, perhaps the largest public health threat we face today.

"Quite simply, buildings are at the epicenter of our sustainable urbanization efforts that will determine our current and future health."

Joseph Allen,
Harvard University

INTRODUCTION: A CHANGING WORLD

Rapid Urbanization

In 1800, the Earth was inhabited by less than 1 billion people (US Census Bureau, 2017). By 1900 it was about 1.5 billion people (US Census Bureau, 2017). A little over 100 years later and the Earth is home to 7 billion people, and we are rapidly heading toward 9 billion by 2045 (United Nations, 2017). For thousands of years we have organized ourselves on this planet around our buildings. Over millennia, our buildings turned into villages and then towns and then, eventually, into cities. But an important change has recently happened. For the first time in our collective history, more people are living in urban areas than outside of them.

And this trend is only growing; it is projected that two-thirds of the world's population will live in urban areas by 2050 (United Nations, 2014). Urban growth will impact cities of all sizes – from cities with less than 500,000 people to the mega-cities that boast populations over 10 million – but the fastest growth will be seen in mid-sized cities of about 1 million people (United Nations, 2014). Combine these staggering figures of population growth and rapid urbanization with the knowledge that most people spend the vast majority of their time indoors (Klepeis, 2001) and it becomes evident that buildings will have an outsized impact on health globally.

"When you think of the urbanization that's going on around the world now, we will see a doubling of our built environment before our century is over. We better do it right, both energy-wise and materials-wise, to optimize the human condition in those places."

John D. Spengler, Harvard University

Unsustainable Use of Natural Resources

Today we are using the equivalent of 1.5 Earths to maintain our current standard of living (Ewing et al., 2010). As our population and cities have expanded, many natural resources have been overly taxed to keep pace with this growth, creating unsustainable demands on the ecosystem. Urban development in recent decades has led to the endangerment of many species and habitats, and the proximity between natural resources and cities is decreasing over time (Mcdonald et al., 2008). By 2050, 5 billion people are expected to live in water stressed areas (Schlosser et al., 2014). Over 3 billion people depend on the ocean for their livelihood, but over 40% of oceans are negatively impacted by humans via depletion of ecosystems, the destruction of fisheries, and pollution from sanitation waste and consumer product chemicals that are persistent in our environment (United Nations, 2015; Wright et al., 2015). Urban population growth has been stated to be the largest driver of deforestation in this century (DeFries et al., 2010), and the utilization of forests and agricultural land for urban expansion or building materials has had many downstream environmental and economic impacts. Over half of agricultural land in the world has been degraded in moderate or severe ways, impacting 1.5 billion people, primarily the world's poorest populations (United Nations, 2015).

The Changing Climate

Compounding the challenges presented by urbanization and natural resource constraints are the

impending threats of climate change across the globe. As consumers of 40% of energy globally, an energy system currently dominated by greenhouse gas-producing fossil fuel combustion, buildings are central to the climate change discussion. Since the 1880s, global temperatures have increased by 0.85°C (1.53°F) (United Nations, 2015), and they are expected to increase another 2-3°C (3.6-5.4°F) by the end of the century, depending upon global greenhouse gas emission in the near future (UN SDGs site). Heatwaves are becoming more frequent, severe, and intense, with many cities facing 2-3 times as many heatwave days by 2100. From 1901-2010, sea levels rose 19cm (0.6ft), on average, and are expected to rise an additional 24-63cm (0.8-2ft) by the end of the century, depending on geographic location (United Nations, 2015). According to a report by the National Academies (2011), our heaviest rainfall events are producing 20% more precipitation than in the last century, increasing the likelihood of flooding events. However, some areas of the globe are projected to experience drier conditions, with droughts becoming more probable in the future, Because of their resource footprints, energy consumption, and land use for development, the buildings that we live and work in are contributing to climate change, and yet will also

"A look at the forecasts in the U.S. government's National Climate Assessment for the year 2100 makes you realize how many lives could be saved, how many illnesses could be prevented, by doing what we already know how to do to mitigate climate change. Reducing greenhouse gases in the Earth's atmosphere may be the greatest public health intervention ever."

Dr. Aaron Bernstein,
Harvard University, Boston Children's Hospital

become increasingly compromised by these climate change impacts.

From the Millennium Development Goals to the Sustainable Development Goals

To meet these challenges, as well as those posed by severe poverty and inequality around the world, The United Nations (UN) developed a framework, originally known as the Sustainable Development Goals (SDGs), to encourage sustainable, equitable, and environmentally conscious development by governments, private sector, and society over the subsequent 15 years. Created in 2015, the 17 goals within the SDGs allow innovative and collaborative efforts from all countries, regardless of economic development, to simultaneously work to end global poverty while also protecting and conserving environmental resources for future generations (United Nations, 2015). This represents an important evolution. Prior to the development of the SDGs was the Millennium Development Goals (MDGs). The MDGs did not include the built environment. We now have a North Star for advancing public health without jeopardizing the future health of our planet or its inhabitants that includes discussion of the built environment.

THE NEXUS OF GREEN BUILDINGS, PUBLIC HEALTH AND THE U.N. SDGS

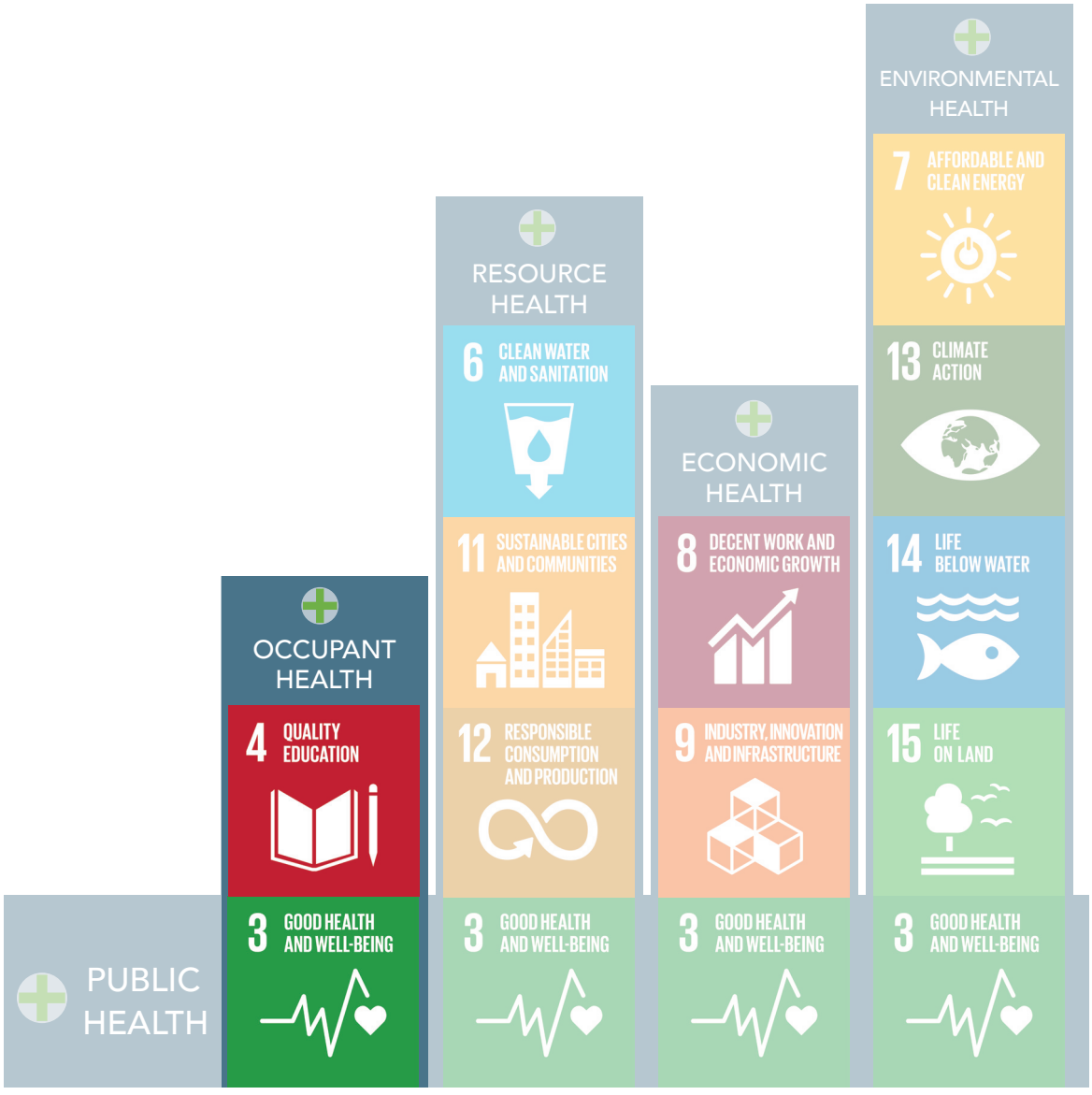
Goal 3 – Good Health and Well-Being Ensure healthy lives and promote well-being for all at all ages

Using the UN SDGs as the starting framework we posed a question: What is the role of buildings in advancing the SDGs and addressing the challenges posed by rapid urbanization, natural resource constraints, and climate change? In short, buildings play a critical role in the challenges we face, but they can also play a role in helping us overcome these challenges in sustainable and equitable ways. And one class of buildings in particular, green buildings, intersect with at least 11 of the 17 SDGs. Green buildings, with their goals of providing enhanced indoor environmental quality (OCCUPANT HEALTH), decreasing consumption of materials and water, and reducing waste (RESOURCE HEALTH) acting as platforms for technological innovation and employment (ECONOMIC HEALTH) and reducing energy consumption and concomitant pollution emissions (ENVIRONMENTAL HEALTH), are a key starting point for advancing sustainable solutions and PUBLIC HEALTH globally.

1 BUILDING SDGS
OCCUPANT HEALTH

Goal 4 – Quality Education Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

Goal 3 – Good Health and Well-Being Ensure healthy lives and promote well-being for all at all ages



OCCUPANT HEALTH

Currently, the average lifespan across the globe is 72 years (World Bank, 2015). By the time we reach this age, up to 65 years of our life will be spent indoors. Reducing the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination begins with reducing daily adverse exposures to these hazards, and a large part of this can be done indoors. In addition to removing human health risks and focusing on disease avoidance, it equally as important to optimize the wellbeing of all people and focus on health promotion. Nowhere is this more important than inside the four walls of the building for the simple reason that this is where we spend most our time.

The research evidence on the importance of the indoor environment is robust. 40 years of scientific evidence have revealed the foundational aspects of human health indoors are ventilation, thermal health, air quality, moisture, dust and pests, safety and security, water quality, noise, and lighting and views (9 Foundations of a Healthy Building, 2016). For example, poor indoor air quality and ventilation are associated with increased sick building symptoms, altered infectious disease transmission, and reduced cognitive function (Daisey et al., 2003; Mendell, et al., 2008; Allen et al., 2015; Sundell et al., 2011; Glas et al., 2014; Song et al., 2016; Allen et al., 2017). Unfavorable thermal conditions have been found to negatively impact eye and throat irritation, headaches, heart rate, respiratory symptoms, mood, and thinking and performing (Bluyssen et al., 2015; Lan et al., 2011; Allen et al., 2017). And radon, a ubiquitous gas that enters our buildings from the ground below is the second leading cause of lung cancer globally.

"Under the principle of accountability, all relevant organizations should establish explicit criteria for evaluating and assessing building air quality and its impact on the health of the population and on the environment"

World Health Organization
The Right to Healthy Indoor Air

The impact of buildings on health extends into schools, as well. There are many facets to a high-quality education, of course, but the one that often gets ignored is the role of the building. There is overwhelming, scientific evidence shows that the school building influences student health, student thinking and student performance (Schools for Health, 2017). For example, student health is sensitive to thermal comfort characteristics including humidity, which have been associated with the development and exacerbation of respiratory symptoms in adults and children in schools. Low absolute humidity has been associated with increased influenza virus survival and transmissibility and the onset of seasonal influenza outbreaks (Koep et al., 2013; Myatt et al. 2010). As one example of impacts on student thinking, attention processes are significantly slower in classrooms with high carbon dioxide and low ventilation rates. Researchers observed a 5% decrement in "power of attention" in poorly ventilated classrooms, roughly equivalent to the impact that a student might feel from skipping breakfast (Coley et al., 2007). With similarly high carbon dioxide levels and low ventilation rates in school buildings, students were observed to experience greater fatigue, impaired attention span, and loss of concentration (Chatzidiakou et al., 2002); poorer performance on tests of concentration (Dorizas et al., 2015); and lower leves of focus among university students during lectures (Uzelac et al., 2015). Lastly, multiple studies have shown that when steps to mitigate poor IEQ are taken, student performance improves (Basch, 2011; Centers for Disease Control and Prevention, 2009; La Salle & Sanetti, 2016; Michael et al., 2015). A study of fifth-grade students in 54 U.S. classrooms reported evidence

of an association between ventilation rates and pupils' performance on standardized mathematics tests (Shaughnessy et al., 2006). Similarly, in a study of 100 U.S. elementary classrooms, positive associations were observed between ventilation rates and performance on standardized tests in math and reading, with researchers estimating that each 1-L/s/p increase in ventilation rate was associated with an expected increase of 2.9% and 2.7% in math and reading scores, respectively (Haverinen-Shaughnessy et al., 2011).

Green Buildings and Occupant Health

Building for health begins with optimizing the indoor environment, and green building standards have a focus on enhancing indoor air quality. For example, in one green-building standard, LEED Version 4, there are 13 credits related to IEQ included rating scheme. These include measures for filtering the air, radon-resistant construction, and ensuring adequate ventilation, with additional credits for enhanced systems and low-emitting products. In another leading green-building standard, BREAAM, "Health & Well-Being" credits account for 15% of the weighting in BREEAM assessed buildings. Initial scientific evidence suggests that taking these initiatives leads to better indoor environmental quality. Greenmark, a rating system used in Singapore and other tropical climates, the newest version features an even greater emphasis on indoor air quality and human health. Early research suggests that this focus on IEQ has an impact on health. In a review of 17 studies of green buildings and health, in general green buildings had better indoor air quality and occupants in green buildings reported greater satisfaction with indoor environmental quality (Allen et al., 2015).

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World Health Organization
The Right to Healthy Indoor Air

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2 BUILDING SDGS RESOURCE HEALTH

Goal 6 – Clean Water and Sanitation Ensure availability and sustainable management of water and sanitation for all

Goal 12 – Responsible Consumption and Production Ensure sustainable consumption and production patterns

Goal 11 – Sustainable Cities and Communities Make cities and human settlements inclusive, safe, resilient and sustainable

Goal 3 – Good Health and Well-Being Ensure healthy lives and promote well-being for all at all ages

The land needed for our cities, the materials and water needed for our buildings, and the waste generated by our buildings are putting a strain on global resource health. Vast urbanization and resource constraints have already put additional strain on limited water resources in locations across the globe. Buildings account for 12% of total water use in the US (USGBC, 2014), as they utilize water for restrooms, kitchens, laundry, heat and cooling, and landscape irrigation. The water use intensity can vary by sector and the type of building, with increasing water use reported with greater frequency of use of the building. For example, hospitals use an average of 315 gallons of water per bed per day, commercial office spaces use 13 gallons of water per person per day, on average, and hotels use an average of 102 gallons per room per day (EPA, 2012). High, and increasing, demand for water strains current supplies.

"The bonds that tie the environment to human health transcend political and geographic boundaries. What we do now will determine our collective health for generations."

Environmentalist Papers No.1

Waste generation is also quickly growing across the world, with 11 million tons expected to be produced per day by 2100, triple of today's values (Hoornweg et al., 2013). In 2014, the building construction and demolition industry generated more than 165 million tons of debris in the United States alone, consisting of concrete, wood, asphalt, metals, bricks, glass, and plastics from residential and commercial demolition and construction (EPA, 2016). Most waste ends up in landfills, leading to groundwater contamination, methane releases, and other downstream environmental impacts.

Within Goal 12 is a call for environmentally sound management of chemicals, including their release into the air, water and soil. To date, we have done the opposite. We have produced millions of pounds of 'persistent organic pollutants' for materials commonly used in buildings, from couches and chairs to insulation and carpeting. Many of these chemicals migrate out of these building products into our homes, offices, schools, and into air and dust that act as the pathway for these chemicals to enter our bodies. The chemicals also migrate into the outdoor environment and can stay there for decades or centuries. We now find many of these chemicals all corners of the globe, even in areas with no nearby sources of these chemicals, in soils located in the Arctic and in sea animals in the middle of oceans. Many of these chemicals are harmful to human and ecological health. The approach to managing these chemicals has not been responsible. Even though some are banned in a few countries, the production and use is oftentimes simply shifted to a developing country, essentially outsourcing the hazard. In other times, a persistent chemical that is identified as harmful is removed from the market, only to be replaced by a chemical that turns out to be as harmful as the banned chemical, in a repeated pattern public health scientists have termed "regrettable substitution" (Allen, 2016).

Green Buildings and Resource Health

Green building strategies, net-zero approaches, and green chemistry principles hold promise to minimize the impact of buildings on our natural systems and resources. Though the specifications for green buildings vary, they all employ resource conservation principles that focus on using sustainably sourced building materials, reducing overall consumption, prioritizing reused and recycled materials, and improving land management practices within the built environment community. Environmentally friendly and green chemistry materials reduce indoor exposures to harmful chemicals. Efficient fixtures and reuse strategies can reduce the amount of water that is wasted by more than 10% compared to traditional buildings (Nat Geo, 2017). Reducing waste reduces building expenses, the environmental impact of landfills, and the extraction of new building materials. Currently, green buildings are able to divert 80 million tons of waste from going to landfills through recycling programs and reduced consumption, and this is expected to grow to 540 million tons by 2030 (Nat Geo, 2017). Green building credits can also be awarded for siting a building in protects natural habitats and resources. Tools like life cycle assessments can be utilized as a means to track resource impact on the environment, the economy, and the building occupants from its source to its disposal.

"As we peer into society's future, we - you and I, and our government - must avoid the impulse to live only for today, plundering for our own ease and convenience, the precious resources of tomorrow. We cannot mortgage the material assets of our grandchildren without risking the loss also of thier political and spiritual heritage."

Dwight D. Eisehnhower

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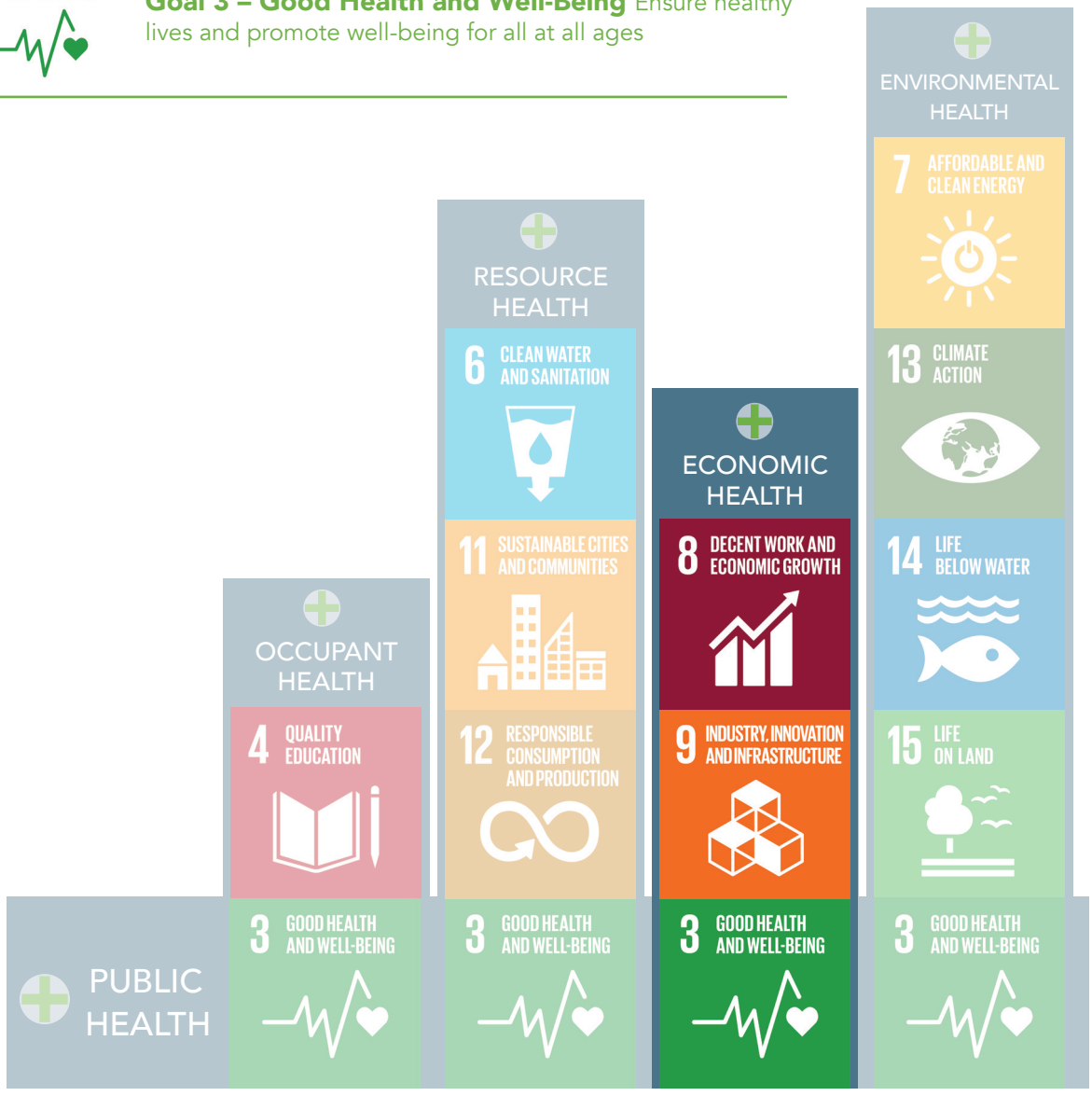
3 BUILDING SDGS ECONOMIC HEALTH

Goal 8 – Decent Work and Economic Growth à Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Goal 9 – Industry, Innovation, and Infrastructure à Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Goal 3 – Good Health and Well-Being Ensure healthy lives and promote well-being for all at all ages



Buildings are engines of economies globally. In 2010, the global construction market was worth more than $7 trillion dollars, and that is expected to increase to $10 trillion by 2020 (Global Construction Outlook, 2016). About 15-18% of the U.S. national GDP is attributed to residential properties and housing services (NAHB, 2017). Commercial real estate alone supports more than 6 million jobs and contributes almost $9 billion to the US GDP (Fuller, 2017). It is projected that the construction industry, considering both residential and commercial properties, will grow 85% by 2030, mostly in China, the US, and India (PwC).

"Green buildings provide value to all key stakeholders – investors, owners and tenants. This 'green building value trifecta' proves we can do better for people and the planet while also providing value to shareholders. Sustainable urbanization is not an either/or proposition."

John Mandyck, Chief Sustainability Officer
United Technologies

Buildings can also impact the productivity of their occupants. For example, improving indoor environmental quality in current U.S. office spaces would yield economic benefits of $20 billion annually (Fisk et al., 2011). These benefits are derived from improved productivity, lower absenteeism, reduced sick building symptoms, and improved thermal comfort. On an individual building level, Improvements to indoor environmental quality result in increasing satisfaction, attendance, and worker productivity as well as reduce sick building syndrome symptoms (Singh et al., 2010, Pei et al., 2015; MacNaughton et al., 2016; Allen et al., 2015). Just doing one of these interventions (increased ventilation rate) was estimated to yield benefits that outweighed costs by 100:1 (MacNaughton et al., 2015).

Green Buildings and Economic Health

Often it is assumed that economic growth must come at the cost of environmental and public health. Research has shown that this is not the case. Green buildings minimize environmental impact while supporing economic health through: supporting construction jobs, increasing the value of properties for owners and developers, and supporting conditions for greater worker productivity within the building. By 2018, green construction will support 1.1 million jobs and $75.6 billion globally (Booz Allen Hamilton, 2015). In China 2 billion square meters of buildings are constructed annually, making up almost half of all new construction in the world. In the coming decades, China has mandated that 50% of new construction has to be green buildings (Yu et al., 2014). In Singapore a goal has been set to reach 80% green building adoption by 2030 (Building and Construction Authority, 2014). For owners and developers, research continues to demonstrate the beneficial return on investment for green, energy-efficient buildings over non-green facilities. Green buildings result in 3% higher rent premiums and 7% higher cash flow as well as higher occupancy rates and transaction prices (Kok & Jennen, 2012).

4 BUILDING SDGS ENVIRONMENTAL HEALTH

Goal 7 – Affordable and Clean Energy Ensure access to affordable, reliable, sustainable, and modern energy for all

Goal 13 – Climate Action Take urgent action to combat climate change and its impacts

Goal 14 – Life Below Water Conserve and sustainably use the oceans, seas, and marine resources

Goal 15 – Life on Land à Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Goal 3 – Good Health and Well-Being Ensure healthy lives and promote well-being for all at all ages

A cascade of detrimental impacts to environmental health begins with our current reliance on dirty sources of energy. And, because buildings are responsible for 40% of global energy use, and 30% of energy-related greenhouse gas emissions (Ürge-Vorsatz, D., et al., 2015), the energy needed to run our buildings is responsible for a significant fraction of the emissions of harmful air pollutants and greenhouse gases globally. The contribution is even greater when considering the indirect emissions from buildings – like the manufacturing and transport of materials, construction, and demolition. These emissions impact the climate, quality of life on land, and the quality of life below water.

"At its core, the issue of a clean environment is a matter of public health"

Gina McCarthy, Former Director, U.S. EPA

Energy use constitutes 60% of all greenhouse gas emissions in the world, making it the predominant contributor to climate change (UN SDGs site). A worldwide investment in infrastructure of $90 trillion USD will be required over the next 15 years to reach net zero greenhouse gas emissions (New Climate Economy, 2016), and climate change impacts are already testing the resiliency of cities, buildings, and natural resources across the globe. These impacts are projected to worsen in the future, with increasing frequency and severity of heatwave events, rising sea levels, more heavy precipitation events, and increased likelihood of extreme weather events (USGCRP, IPCC). Climate impacts will be seen and experienced throughout the world, and the poorest and most vulnerable of each society will continue to be predominantly impacted by these events and can exacerbate preexisting inequalities between communities (Wright et al., 2015). The damage caused by each climate disaster will also continue to increase as more buildings and infrastructure are built in climate-vulnerable areas (CBO, 2016).

On land, immediate adverse impacts to environmental health are the result emissions of health harmful air pollutants associated with dirty energy sources. Emitted pollutants, like particulate matter, sulfur dioxide, nitrogen oxides, and black carbon, are associated with cardiovascular, cerebrovascular, and respiratory diseases, and mortality, (Dockery et al., 1993; WHO, 2016) even at levels below current national standards (Di et al., 2017). In fact, in 2012 alone approximately 3.7million premature deaths were attributable to ambient air pollution and its resulting ischemic heart disease, stroke, chronic obstructive pulmonary disease, lung cancer, and acute lower respiratory infections (WHO, 2014). These emissions negatively impact other terrestrial ecosystems because fossil fuels, specifically coal, utilize more land than renewable energy projects (Bergesen et al., 2014). This land use can contribute to another 17% increase in greenhouse gas emissions as deforestation and land degradation occurs when fostering fossil fuel projects.

Our marine and terrestrial ecosystems are also impacted by these energy emissions. Oceans cover 75% of the earth's surface and contain almost all of the water on our planet (UN SDGs site). Over 3 billion people depend on this vast resource for their livelihood, but over 40% of oceans are negatively impacted by humans via pollution, depletion of ecosystems, and the destruction of fisheries (UN SDGs site; Wright et al., 2015). The oceans are absorbing large amounts of carbon dioxide from the atmosphere, acidifying aquatic environments to dangerous levels, threatening the shell and exoskeleton formation of oysters, clams, urchins, corals, and plankton, impacting entire ecosystems and food webs (NOAA, Ocean Acidification; Wright et al., 2015). Energy consumption also impacts our waters during its production; chemicals used in coal and oil extraction, many of which are carcinogens, pollute local freshwater sources, contaminating drinking water located (Berrill et al., 2016; Epstein et al., 2011).

Green Buildings and Environmental Health

Solutions to the cascade of adverse environmental health effects associated with dirty energy come at three scales: regional, building and consumer. On a regional scale, it is imperative that we move to clean energy sourced by renewables, like wind or solar, that provide stable electricity supplies, emit few-to-no greenhouse gases, and significantly reduce health harmful air pollutants. And consumers have a role to play, too, and can reduce their energy consumption, and increase their use of energy efficient products, fixtures, and technology in their homes and office spaces. But one of the biggest opportunities to improve environmental health needs to come from the building sector. Here, green buildings present an important opportunity to achieve reductions in energy use because of their focus on certifying building performance. Last, the energy that green buildings save comes with a health co-benefit. Reducing energy consumption results in fewer health harmful air pollutants and greenhouse gases emitted to the atmosphere. Through these reductions green buildings provide a societal co-benefit: improved public health. In countries with the dirtiest of fuel sources, the economic health co-benefits can be 10 times higher than the cost savings from energy (MacNaughton et al., 2017). These indirect, population-level health co-benefits of the green building movement have not been fully accounted for when exploring the benefits of better buildings. When considering that green buildings comprise less than 5% of total commercial floor space, we can realize the enormous opportunity that exists to improve human health through energy-efficient buildings.

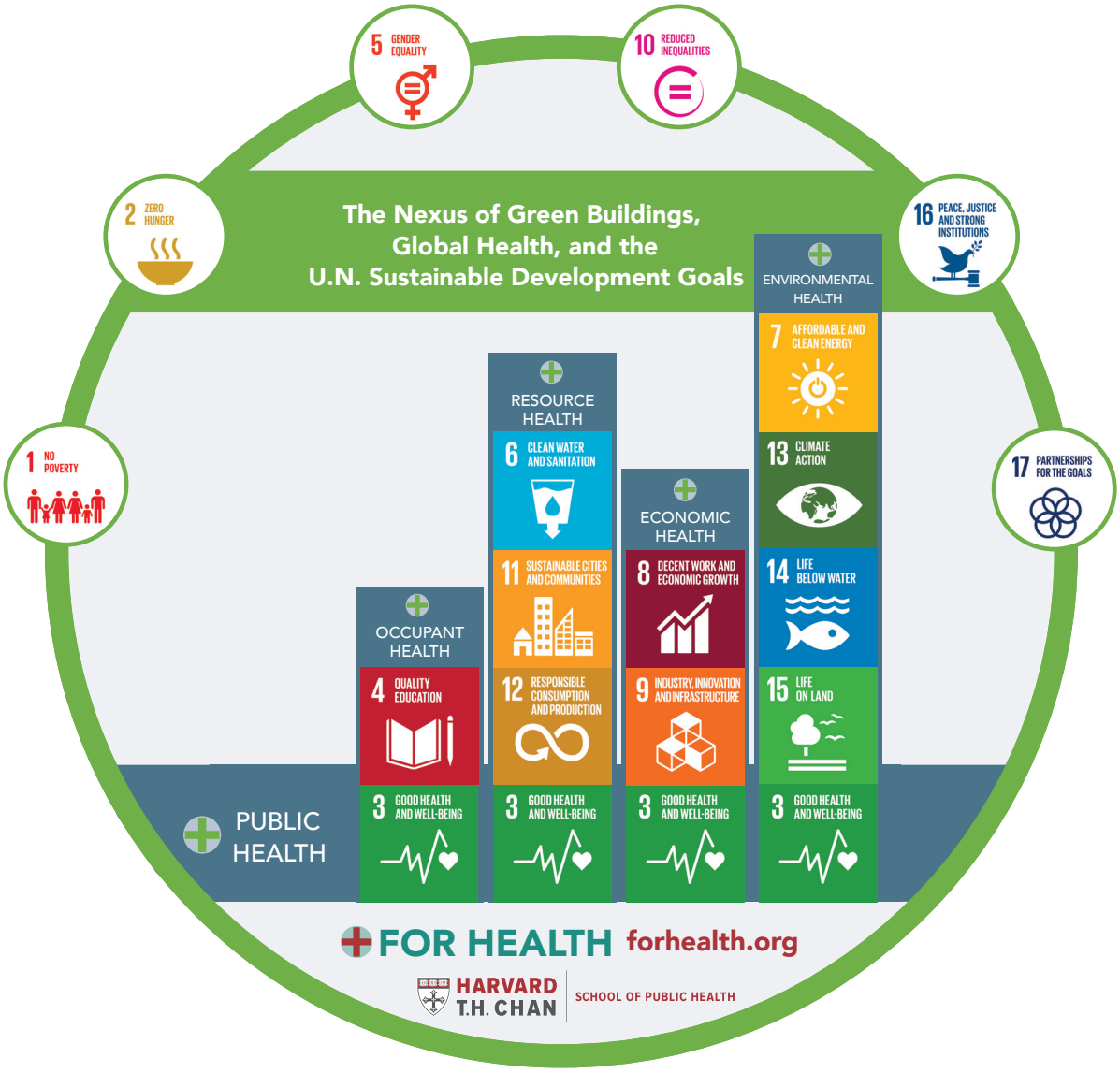
"Our goal is the health of all people, in all buildings, everywhere, every day."

Healthy Buildings Program,
Harvard T.H. Chan School of Public Health

CONCLUSION: BUILDING FOR HEALTH

Although the challenges related to rapid urbanization, natural resource constraints and climate change are daunting, they also provide an opportunity to mobilize solutions on a global scale. We now have a framework, the SDGS, that recognize the central role that buildings will play in advancing health globally. Currently, 75% of the infrastructure needed by 2050 has not yet been built (Wiener, GIB, 2014). This presents the potential for one of the greatest public health interventions ever.

Green buildings and their Building for Health principles – occupant, resource, economic and environment – will be part of the solution. As these concepts expand around the world, the concept of sustainable urbanization also needs to be a conversation that empowers all. Creating more equitable access to green building values, healthy buildings, and sustainable development is a global imperative.



REFERENCES

Allen, J., MacNaughton, P., Laurent, J. G. C., Flanigan, S. S., Eitland, E. S., & Spengler, J. D. (2015). Green Buildings and Health. Current Environmental Health Reports, 2(3), 250-258. doi: 10.1007/s40572-015-0063-y

Allen, J.G. (2016). Stop playing whack-a-mole with hazardous chemicals. *The Washington Post.* Retrieved from: https://www.washingtonpost.com/opinions/stop-playing-whack-a-mole-with-hazardous-chemicals/2016/12/15/9a357090-bb36-11e6-91ee-1adddfe36cbe_story.html?utm_term=.b52a1c74a22c

Allen, J.G., et al. (2016). Building Evidence for Health: The 9 Foundations of a Healthy Building. *Harvard TH Chan School of Public Health, Healthy Buildings Team*. Retrieved from: http://9foundations.forhealth.org/

Allen J.G., MacNaughton P., Satish U., Santanam S., Vallarino J., Spengler J.D. (2015). 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. *Environmental Health Perspectives, 124(6)*, 805-812.

Allen J.G., MacNaughton P., Cedeno Laurent J.G., Flanigan S.S., Eitland E.S., Spengler J.D. (2015). Green Buildings and Health. *Current Environmental Health Report*, *2*, 250-258.

Basch, C.E. (2011). Healthier students are better learners: A missing link in school reforms to close the achievement gap. *Journal of School Health*, *81*(10), 593–598.

Berrill, P. et al. (2016). Environmental impacts of high penetration renewable energy scenarios for Europe. *Environmental Research Letters. 11.*

Bergesen, J.D. et al. (2014). Thin-film photovoltaic power generation offers decreasing greenhouse gas emissions and increasing environmental co-benefits in the long term. *Environmental Science and Technology. 48:* 9834-9843.

Bluyssen, P. M., C. Roda, C. Mandin, S. Fossati, P. Carrer, Y. de Kluizenaar, V. G. Mihucz, E. de Oliveira Fernandes, and J. Bartzis. "Self-Reported Health and Comfort in 'modern' Office Buildings: First Results from the European OFFICAIR Study." Indoor Air 26, no. 2 (March 14, 2015): 298–317. doi:10.1111/ina.12196

Booz Allen Hamilton (2015). Green Building Economic Impact Study. USGBC. http://go.usgbc.org/2015-Green-Building-Economic-Impact-Study.html

Building and Construction Authority. (2014). 3rd Green Building Masterplan. Singapore Government. Retrieved from: https://www.bca.gov.sg/GreenMark/others/3rd_Green_Building_Masterplan.pdf

Centers for Disease Control and Prevention (2009). Health and Academic Achievement. Report by the National Center for Chronic Disease Prevention and Health Promotion, Division of Population Health. Retrieved from: http://www.cdc.gov/healthyschools/health_and_academics/pdf/health-academic-achievement.pdf.

Chatzidiakou, (2002).

Coley, D.A., Greeves, R., Saxby, B.K. (2007). The effect of low ventilation rates on the cognitive function of a primary school class. *International Journal of Ventilation, 6(2)*, 107-112.

Congressional Budget Office. (2016). Potential increases in hurricane damage in the United States: Implications for the federal budget. *Congress of the United States*.

Daisey, J. M., W. J. Angell, and M. G. Apte. "Indoor Air Quality, Ventilation and Health Symptoms in Schools: An Analysis of Existing Information." Indoor Air 13, no. 1 (March 2003): 53–64. doi:10.1034/j.1600-0668.2003.00153.x.

DeFries, R.S., Rudel, T., Uriarte, M., Hansen, M. (2010). Deforestation driven by urban population growth and agricultural trade in the twenty-first century. *Nature Geoscience*, *3*, 178-181.

Demographia. (2005). "Largest world urban areas: 1950". Retrieved from: http://demographia.com/db-1950metro.htm

Di, Q., Wang, Y., Zanobetti, A., Wang, Y., Koutrakis, P., Choirat, C., Dominici, F., Schwartz, J.D. (2017). Air pollution and mortality in the medicare population. *The New England Journal of Medicine 376,* 2513-2522.

Dockery, D.W., Pope III, C.A., Xu, X., Spenlger, J.D., Ware, J.H., Fay, M.E., Ferris, Jr., B.G., Speizer, F.E. (1993). An association between air pollution and mortality in six U.S. cities. *The New England Journal of Medicine, 329(24)*, 1753-1759.

Epstein, P.R. et al. (2011). Full cost accounting for the life cycle of coal. *Annals of the New York Academy of Sciences. 1219:* 73-98.

Ewing, B., Reed, A., Galli, A., Kitzes, J., Wackernagel, M. (2010). *Calculation Methodology for the National Footprint Accounts, 2010 Edition*. Oakland: Global Footprint Network.

Fisk, W., Black, D., & Brunner, G. (2011). Benefits and costs of improved IEQ in U.S. offices. *Indoor Air, 21*(5), 357-367.

Fuller, S. (2017). Economic impacts of commercial real estate, 2017 edition. NAIOP, the Commercial Real Estate Development Association. Retrieved from: http://www.naiop.org/en/Research/Our-Research/Reports/Economic-Impacts-of-Commercial-Real-Estate-2017.aspx

Glas, Bo, Berndt Stenberg, Hans Stenlund, and Anna-Lena Sunesson. "Exposure to Formaldehyde, Nitrogen Dioxide, Ozone,and Terpenes Among Office Workers and Associations with Reported Symptoms." International Archives of Occupational and Environmental Health 88, no. 5 (October 2, 2014): 613–22. doi:10.1007/s00420-014-0985-y

Global Construction Outlook. (2016). Global Construction Outlook 2020. Published by TIMetric. Retrieved from: http://marketreportsstore.com/global-construction-outlook-2020/

Haverinen-Shaughnessy, U., Moschandreas, D.J., & Shaughnessy, R.J. (2011). Association between substandard classroom ventilation rates and students' academic achievement. *Indoor Air*, *21*(2), 121–131.

Hoornweg, D. Bhada-Tata, P., Kennedy, C. (2013). Environment: waste production must peak this century. *Nature, 502(7473),* 615-617.

Intergovernmental Panel on Climate Change. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Klatte, M., Bergstrom, K. & Lachmann, T. (2013). Does noise affect learning? A short review on noise effects on cognitive performance in children. *Frontiers in Psychology, 4,* 578.

Klepeis, N.M., Nelson, W.C., Ott, W.R., Robinson, J.P., Tsang, A.M., Switzer, P., Behar, J.V., Hern, S.C., Engelmann, W.H. (2001). The National Human Activity Pattern Survey (NHAPS): A Resource for Assessing Exposure to Environmental Polluants. Ernest Orlando Lawrence Berkeley National Laboratory.

Koep, T.H., Enders, F.T., Pierret, C., Ekker, S.C., Krageschmidt, D., Neff, K.L., & Huskins, W.C. (2013). Predictors of indoor absolute humidity and estimated effects on influenza virus survival in grade schools. *BMC Infectious Diseases*, *13*(1), 1.

Kok, N. and Jennen, M. (2012). The impact of energy labels and accessibility on office rents. *Energy Policy, 46*, 489-497.

La Salle, T.P. and Sanetti, L.M.H. (2016). Implications of student health problems on achievement and engagement. *International Journal of School & Educational Psychology*, *4*(1), 10–15.

Lan, L., P. Wargocki, D. P. Wyon, and Z. Lian. "Effects of Thermal Discomfort in an Office on Perceived Air Quality, SBS Symptoms, Physiological Responses, and Human Performance." Indoor Air 21, no. 5 (April 18, 2011): 376–90.

MacNaughton, P., Pegues, J., Satish, U., Santanam, S., Spengler, J., & Allen, J. (2015). Economic, Environmental and Health Implications of Enhanced Ventilation in Office Buildings. *International Journal of Environmental Research and Public Health, 12(11),* 14709–14722. http://doi.org/10.3390/ijerph121114709

MacNaughton, P., Spengler, J., Vallarino, J., Santanam, S., Satish, U., & Allen, J. (2016). Environmental perceptions and health before and after relocation to a green building. *Building and environment*, *104*, 138-144.

Mcdonald, R.I., Kareiva, P., Forman, R.T.T. (2008). The implications of current and future urbanization for global protected areas and biodiversity conservation. *Biological Conservation, 141,* 1695-1703.

Mendell, M. J., Q. Lei-Gomez, A. G. Mirer, O. Seppnen, and G. Brunner. "Risk Factors in Heating, Ventilating, and Air-Conditioning Systems for Occupant Symptoms in US Office Buildings: The US EPA BASE Study." Indoor Air 18, no. 4 (August 2008): 301–16. doi:10.1111/j.1600-0668.2008.00531.x.

Michael, S.L., Merlo, C.L., Basch, C.E., Wentzel, K.R., & Wechsler, H. (2015). Critical connections: Health and academics. *Journal of School Health*, *85*(11), 740–758.

Myatt, T.A., Kaufman, M.H., Allen, J.G., MacIntosh, D.L., Fabian, M.P., & McDevitt, J.J. (2010). Modeling the airborne survival of influenza virus in a residential setting: the impacts of home humidification. *Environmental Health*, *9*(1), 1.

National Academies Press. (2011). Climate Change, the Indoor Environment, and Health. Chair, John D. Spengler.

National Association of Home Builders. (2017). Housing's contribution to gross domestic product (GDP). Retrieved from: https://www.nahb.org/en/research/housing-economics/housings-economic-impact/housings-contribution-to-gross-domestic-product-gdp.aspx

National Geographic. (2017). How Green Buildings Could Save Our Cities. *Urban Expeditions*. Retrieved from: http://www.nationalgeographic.com/environment/urban-expeditions/green-buildings/benefits-of-green-buildings-human-health-economics-environment/

National Oceanic and Atmospheric Administration. PMEL Carbon Program. What is Ocean Acidification. https://www.pmel.noaa.gov/co2/story/What+is+Ocean+Acidification%3F

The New Climate Economy. (2016). The Sustainable Infrastructure Imperative: Financing for Better Growth and Development. Retrieved from: http://newclimateeconomy.report/2016/

Pei, Z., Lin, B., Liu, Y., & Zhu, Y. (2015). Comparative study on the indoor environment quality of green office buildings in China with a long-term field measurement and investigation. *Building and Environment, 84,* 80-88.

Pricewater Coopers. (n.d.) Global Construction 2030. Retrieved from: https://www.pwc.com/gx/en/industries/engineering-construction/publications/pwc-global-construction-2030.html

Seabi, J., Cockcroft, K., Goldschagg, P, Greyling, M. (2015). A prospective follow-up study of the effects of chronic aircraft noise exposure on learners' reading comprehension in South Africa. *Journal of Exposure Science and Environmental Epidemiology, 25(1),* 84-88.

Schlosser, C.A., Strzepek, K., Gao, X., Gueneau, A., Fant, C., Paltsev, S., Rasheed, B., Smith-Greico, T., Blanc, Jacoby, H.D., Reilly, J.M. (2014). The Future of Global Water Stress: An Integrated Assessment. MIT Joint Program on the Science and Policy of Global Change.

Schools for Health: How School Buildings Influence Student Health, Thinking and Performance. *Harvard TH Chan School of Public Health, Healthy Buildings Team*. Retrieved from: http://schools.forhealth.org/

Shaughnessy, R.J., Haverinen-Shaughnessy, U., Nevalainen, A., & Moschandreas, D. (2006). A preliminary study on the association between ventilation rates in classrooms and student performance. *Indoor Air*, *16*(6), 465–468.

Singh, A., Syal, M., Grady, S. C., & Korkmaz, S. (2010). Effects of Green Buildings on Employee Health and Productivity. *American Journal of Public Health*, *100*(9), 1665–1668. Retrieved from: http://doi.org/10.2105/AJPH.2009.180687

Song, Xuping, Yu Liu, Yuling Hu, Xiaoyan Zhao, Jinhui Tian, Guowu Ding, and Shigong Wang. "Short-Term Exposure to Air Pollution and Cardiac Arrhythmia: A Meta-Analysis and Systematic Review." International Journal of Environmental Research and Public Health 13, no. 7 (June 28, 2016): 642. doi:10.3390/ijerph13070642.

Sundell, J., H. Levin, W. W. Nazaroff, W. S. Cain, W. J. Fisk, D. T. Grimsrud, F. Gyntelberg, et al. "Ventilation Rates and Health: Multidisciplinary Review of the Scientific Literature." Indoor Air 21, no. 3 (February 1, 2011): 191–204. doi:10.1111/j.1600-0668.2010.00703.x.

Stansfeld, S.A., Berglund, B., Clark, C., Lopez-Barrio, I., Fischer, P., Öhrström, E., & Berry, B.F. (2005). Aircraft and road traffic noise and children's cognition and health: A cross-national study. *The Lancet*, *365*(*9475*), 1942–1949.

UN. (2014). World Urbanization Prospects: Highlights. United Nations, Department of Economic and Social Affairs. Retrieved from: https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.Pdf

UN. (2015). Sustainable Development Goals: 17 Goals to Transform Our World. Retrieved from: http://www.un.org/sustainabledevelopment/

UN. (2017). "World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100." Retrieved from: https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html

Ürge-Vorsatz, D., Cabeza, L.F., Serrano, S., Barreneche, C., Petrichenko, K. (2015). Heating and cooling energy trends and drivers in buildings. *Renewable and Sustainable Energy Reviews, 41,* 85-98.

US Census Bureau. (2017). World Population: Historical Estimates of Word Population. Retrieved from: https://www.census.gov/population/international/data/worldpop/table_history.php

US Environmental Protection Agency. (2012). Water Use Tracking. Energy Star Portfolio Manager. Retrieved from: https://www.energystar.gov/sites/default/files/buildings/tools/DataTrends_Water_20121002.pdf

US Environmental Protection Agency. (2016). Advancing Sustainable Materials Management: 2014 Fact Sheet. Retrieved from: https://www.epa.gov/sites/production/files/2016-11/documents/2014_smmfactsheet_508.pdf

US Global Change Research Program. (2016). The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Retrieved from: https://health2016.globalchange.gov/

US Green Buildings Council. (2014). Green Building 101: How does water efficiency impact a building? Retrieved from: https://www.usgbc.org/articles/green-building-101-how-does-water-efficiency-impact-building

US Green Buildings Council. (2015). The Business Case for Green Building. Retrieved from: https://www.usgbc.org/articles/business-case-green-building

Uzelac, A., Gligoric, N., Krco, S. (2015). A comprehensive study of parameters in physical environment that impact students' focus during lecture using Internet of Things. Computers in *Human Behavior, 53,* 427-434.

Wiener, D. (2014). Sustainable Infrastructure as an Asset Class. Global Infrastructure Basel. Retrieved from: http://www.gib-foundation.org/content/uploads/2014/03/Sustainable-Infrastructure-as-an-Asset-Class_V7.1.pdf

World Bank. (2017). Life expectancy at birth, total years. Retrieved from: https://data.worldbank.org/indicator/SP.DYN.LE00.IN

World Health Organization. (2000). The Right to Healthy Indoor Air. Bilthoven, The Netherlands. Retrieved from: http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/pre2009/the-right-to-healthy-indoor-air

World Health Organization. (2014). "7 million premature deaths annually linked to air pollution". Retrieved from: http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/

WHO. (2016). Ambient (outdoor) air quality and health. Retrieved from: http://www.who.int/mediacentre/factsheets/fs313/en/

World Green Building Council. (2017). "Green building: Improving the lives of billions by helping to achieve the UN Sustainable Development Goals." Retrieved from: http://www.worldgbc.org/news-media/green-building-improving-lives-billions-helping-achieve-un-sustainable-development-goals

Wright, H., Hug, S., Reeves, J. Impact of climate change on Least Developed Countries: are the SDGs possible? The International Institute for Environment and Development.

Yu, S., Evans, M., Shi, Q. (2014). Analysis of the Chinese Market for Building Energy Efficiency. *Pacific Northwest National Laboratory.* Retrieved from: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22761.pdf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