INVESTING IN HUMAN HEALTH

THE SCIENCE BEHIND DARWIN HOME WELLNESS INTELLIGENCE

Delos™
Innovate Well

OVERVIEW

At Delos, our mission is to serve as the world's leading catalyst for enhanced health and well-being in the environments where we live, work, sleep and play. We aim to improve the health and well-being of individuals, families and communities via the DARWIN Home Wellness Intelligence network, which is engineered to passively enhance indoor environmental quality in real-time.

In this document, we introduce the importance of physical environments to human health and outline Delos' scientific approach to helping create home environments that are conducive to optimal health, well-being, performance and comfort. We then provide an overview of some of the key population-level health concerns in the US. Finally, we explain the key components of DARWIN: air filtration, water purification, circadian lighting, and enhanced sleep solutions, and detail how these components positively impact environmental parameters as well as the potential health and well-being outcomes for the residents.

1. INTRODUCTION

1.1. The Built Environment: A Key Determinant of Health

The physical environment plays an important role in determining our health status.[1,2] Although it is not often considered as an opportunity for health promotion compared to other determinants such as health services, the built environment has a profound impact on our health and well-being and is a critical target for efforts to improve population and individual health. The physical environment comprises a wide variety of factors which include natural as well as built environments, air and water quality, among others (Figure 1).[2]

Historically, people have spent most of their lives outdoors, experiencing both the dangers and benefits of the natural environment.

Natural environment, such as plants, weather, or climate change

Built environment, such as buildings or transportation

Water and air quality

Worksites, schools, and recreational settings

Housing, homes, and neighborhoods

Exposure to toxic substances and other physical hazards

Physical barriers, especially for people with disabilities

Aesthetic elements, such as good lighting, trees, or benches

Today, in contrast, we spend around 90% of our lives indoors.[3] While our transition to indoor environments has provided us with many advantages – such as protection against the elements – it has also created a fundamental disconnect with the power of nature, and its central impact on our biology. Modern living has had a massive, increasingly negative impact on our overall well-being, with sedentary lifestyles, unhealthy diets, pollution and nature-deprivation leading to increased health concerns, stress, social isolation and loneliness. Our efforts to maintain healthier lifestyles can be significantly undermined by seemingly subtle forces such as the quality of indoor air and water, thermal comfort and the quality of lighting. Indoor environments can influence almost every aspect of our lives – from our moods and energy levels to how well we sleep and how productive we are throughout the day.

The global patterns of disease and their associated risk factors have shifted dramatically in the last half century. While the incidence of communicable diseases has decreased, non-communicable chronic diseases now play a much larger role in population health. Chronic illnesses, including cardiovascular diseases, diabetes and obesity, are among the leading causes of death worldwide. Unfortunately, traditional healthcare delivery systems are ill-equipped to prevent these conditions, as they often arise due to a lifetime of unhealthy behaviors and, in most cases, are caused by modifiable behavioral and environmental risk factors.

2. POPULATION HEALTH IN THE UNITED STATES

2.1. Healthcare Expenditure in the United States

US healthcare spending has been on a constant rise over the past several decades, increasing from 2.4 trillion (or 14.5% of the GDP) in 2005 to 3.3 trillion (or 17.9% of the GDP) in 2016.[4] National healthcare spending is projected to rise at an average rate of 5.5% per year from 2017 to 2026, reaching $5.7 trillion by 2026 (Figure 6). [5]

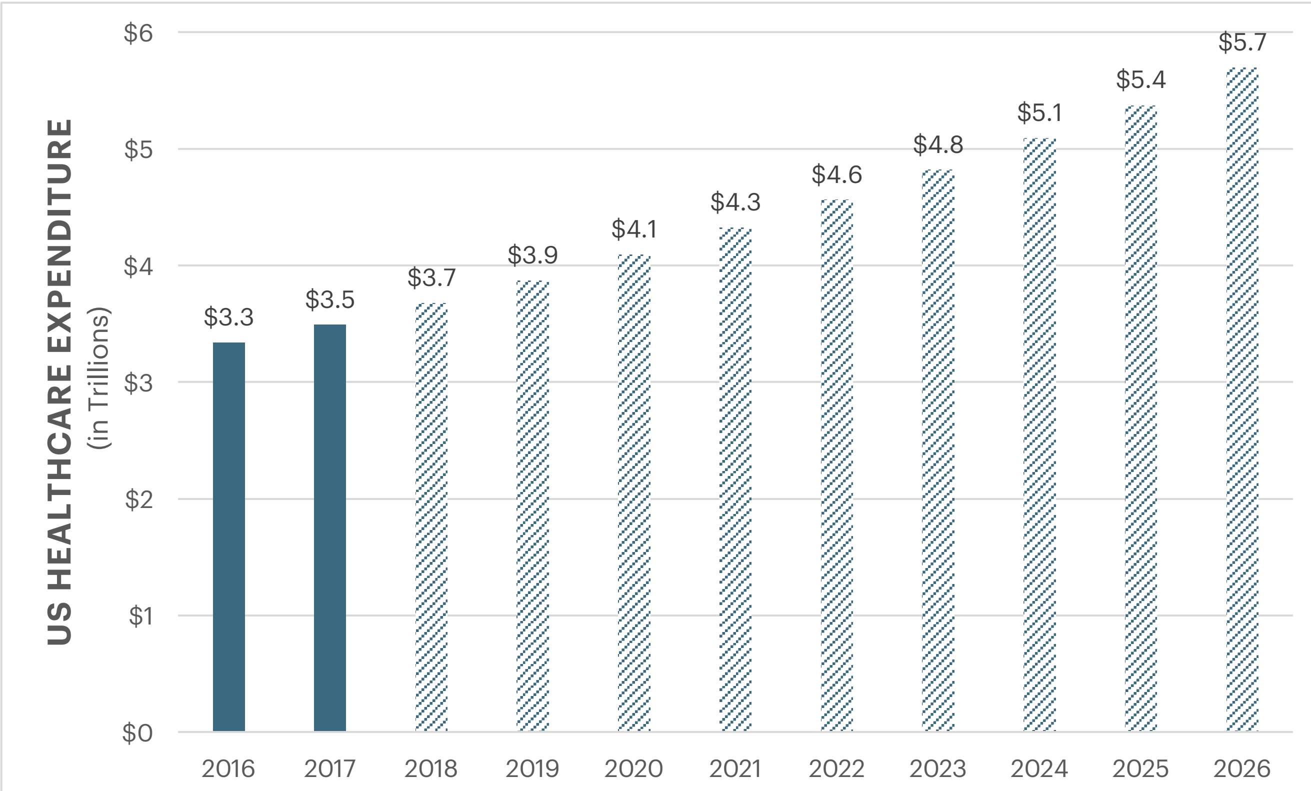

Figure 6. Projected Health expenditures in the United States (USD).
Source: Centers for Medicare & Medicaid Services, Office of the Actuary; US Department of Commerce, Bureau of Economic Analysis; and US Bureau of the Census. https://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/NationalHealthExpendData/NationalHealthAccountsProjected.html

The average household spending on healthcare has increased from $4,612 in 2016 to $4,928 in 2017; approximately 7% over the course of a single year.[6] US per capita healthcare spending is the highest in the world,[7] more than double that of most other G20 member countries, according to OECD data (Figure 7).[4] . However, despite spending more on healthcare, the American population has a shorter life expectancy and experiences more injuries and illnesses than populations in other high-income countries.[8] Indeed, a comparison of life expectancy rates in 2017 between the US and 10 other high-income countries (the UK, Canada, Germany, Australia, Japan, Sweden, France, Denmark, the Netherlands, and Switzerland) shows that life expectancy in the US was the lowest of the 11 countries at 78.59 (average of 82.17 years for the 10 remaining countries).[9]

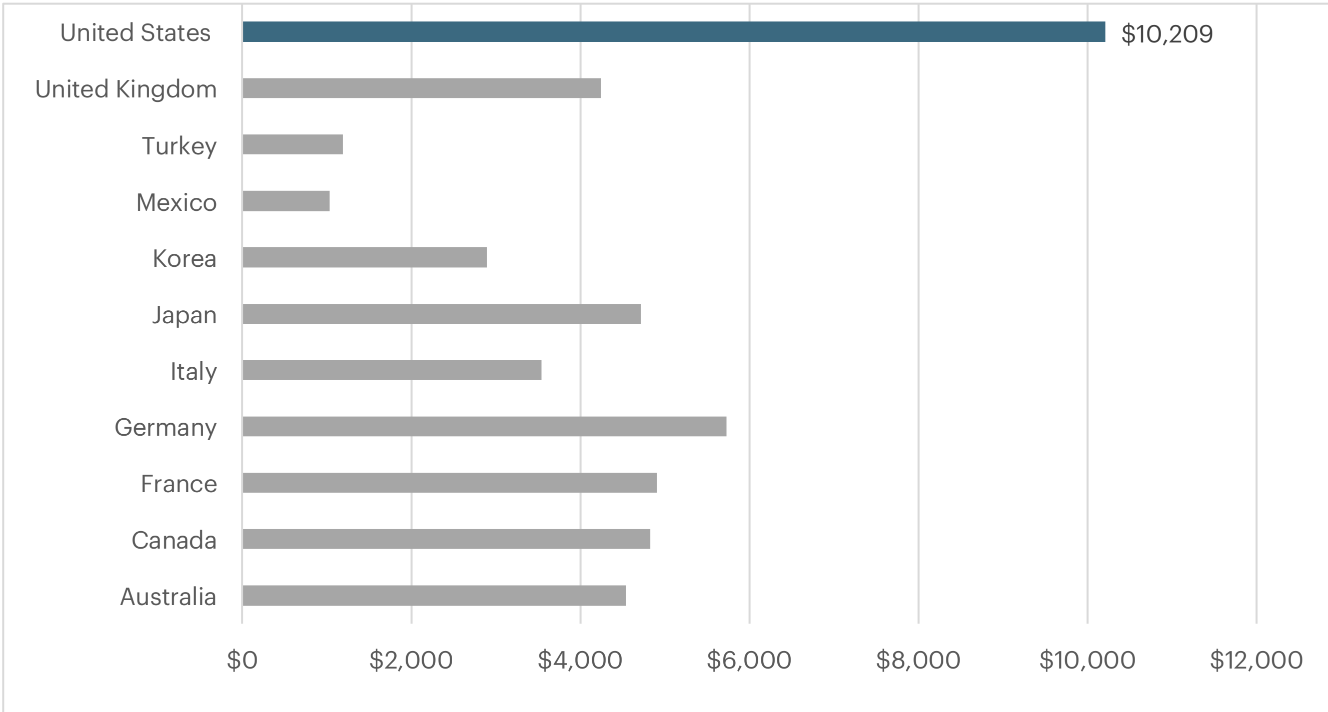

Figure 7. Per capita health expenditure (USD) in the United States in comparison with other G20 countries, in 2017. Source: OECD (2018), Health spending (indicator). doi: 10.1787/8643de7e-en (Accessed on 13 December 2018)

While many factors contribute to the disparity in health outcomes, the U.S. Centers for Disease Control and Prevention (CDC) notes that the American population uses preventive services only at about half the recommended rate.[10] Preventive health interventions can promote health and reduce overall healthcare costs by changing the need for expensive treatments. Focusing on preventive initiatives is particularly important in the US due to the high prevalence of chronic diseases and their substantial cost.[11]

According to the CDC, "Chronic diseases, such as heart disease, cancer, and diabetes, are responsible for 7 of every 10 deaths among Americans each year and account for 75% of the nation's health spending. These chronic diseases can be largely preventable."[10]

2.2. Overview of Key Health Issues in the United States

Chronic Disease

Chronic disease, a group of diseases that have long-lasting and persistent effects, is the leading cause of illness, disability, and death in the United States. In 2017, 10.6% of adults were diagnosed with heart disease, 5.6% with coronary heart disease, and 24.5% were diagnosed with hypertension.[12] For all three conditions, the prevalence was higher among men than women. Other major chronic diseases in the US include chronic obstructive pulmonary disease (COPD), low back pain, lung cancer, type 2 diabetes, and Alzheimer's disease.[13]

Body Weight Status

Obesity, an excess accumulation of body fat, is a significant risk factor for cardiovascular disease, type 2 diabetes, musculoskeletal disorders, and some cancers. In the US, the estimated economic cost of obesity was over $1.4 trillion annually.[14] In 2017, 30.4% of US adults aged 18 and over were obese (BMI > 30 kg/m2), and another 34.1% were overweight. Higher rates of obesity were seen in adults who were African American, Hispanic or Latino, and American Indian.[12]

Hypertension

Hypertension is a key risk factor for cardiovascular disease, and the risk of disease increases with increasing blood pressure levels. In 2015-2016, 29% of US adults had hypertension, with greater rates of prevalence in older age groups compared to younger (18-39: 7.5%; 40-59: 33.2%; 60 and over: 63.1%).[15]

Psychological Distress

Psychological distress is a major risk factor for diseases and conditions including migraine, cardiovascular disease, chronic obstructive pulmonary disease, and mood disorders, as well a significant risk factor for as risky behaviors. In 2017, 3.4% of US adults reported experiencing serious psychological distress during the past 30 days.[16]

Tobacco and Alcohol Use

Lifestyle and behavioral factors including tobacco and alcohol use significantly impact health and contribute to chronic disease burden. In 2017, 14% of adults in the US were current smokers, with prevalence of smoking found to be significantly higher among men (15.8%) than women (12.2%).[17] Alcohol use is a significant cause of morbidity and mortality in the US; 26.9% of people ages 18 or older reported to have engaged in binge drinking in the past month, and 15.1 million (6.2%) had an alcohol use disorder.[18]

Physical Activity

Insufficient physical activity is a major modifiable risk factor for chronic diseases. Most Americans do not engage in enough physical activity, with less than 5% of adults reporting participation in at least 30 minutes of physical activity each day, and only one in three adults engaging in the recommended amount of physical activity each week.[19] In 2018, 25.6% of adults reported doing no physical activity or exercise other than their regular job (within the past 30 days).[20]

Nutrition

Unhealthy diets are responsible for a significant proportion of the chronic disease burden in the United States. Throughout the country, high-income groups and people living in more advantaged neighborhoods are more likely to eat a healthy and balanced diet, and ultimately have better health outcomes. The Dietary Guidelines for Americans 2015-2020 recommends that American adults consume 5 servings of vegetables and 2 servings of fruit every day, but over 80% of American adults had vegetable intakes below the recommended amount and less than 30% consumed the recommended servings of fruit.[21] In addition, most Americans exceed the dietary recommendations for added sugar, saturated fat, and sodium intake, and overall consume too many calories.[21]

Sleep

Despite recommendations from the National Sleep Foundation that adults sleep seven to nine hours a night,[22] over one-third of all American adults report not getting enough sleep.[23] Various measures of sleep, such as timing, duration, efficiency, satisfaction, and alertness, are associated with serious adverse health outcomes, including diabetes, hypertension, depression, accidents, coronary heart disease, and mortality.[24] The timing of sleep is largely determined by a specific part of the brain which regulates the 24-hour sleep/wake cycle, otherwise known as a circadian rhythm.[25] Although sleep is regulated by internal factors (e.g., genetic sleep need, circadian rhythm), it can also be influenced by external factors, including an individual's behaviors/motivations (e.g., staying up late), habits (e.g., waking up by an alarm clock), and the environment.[26]

35% of Americans do not achieve the recommended amount of sleep per night

3. THE SCIENCE BEHIND DARWIN

All features of the DARWIN network were carefully curated to create an environment designed to improve health and well-being. DARWIN is engineered to passively address indoor environmental quality in real-time through building automation systems.

3.1. How DARWIN Improves Air Quality in the Home

3.1.1. Health Impacts of Air Pollution

Clean air is essential for optimal health. Air pollution is considered one of the greatest killers of our generation.[27] In the United States, air pollution is estimated to contribute to over 100,000 deaths per year,[28] and is a significant contributor to many noncommunicable diseases.[29] In 2015, air pollution was responsible for 19% of all cardiovascular deaths, 24% of all deaths caused by ischemic heart disease, 21% of all stroke deaths, and 23% of all lung cancer deaths globally.[30]

Research suggests that concentrations of toxins, allergens and other pollutants can be two to five times higher indoors than they are outside.[31] However, the US Environmental Protection Agency (EPA) does not regulate indoor air quality,[32] and US laws and regulations related to indoor air quality are disjointed and do not provide a comprehensive framework that addresses all potential indoor harmful exposures.

Air pollutants can enter the human body through ingestion,[33] skin absorption and direct inhalation. Once inside the body, pollutants may affect areas that are far from the initial exposure site, traveling to multiple cells, tissues, and organs.[33] Based on their type, composition and size, different contaminants can have different effects on the human body.

3.1.1.1. Airborne Particles

Airborne particles, also known as particulate matter (PM), are very small particles of solid or liquid matter that can stay suspended in the air and be transported by the wind. PM can be generated from a wide variety of sources and can be of varied composition and particle size. Some particles are large enough, or in high enough concentration, to be seen with the naked eye, while others are too small to be noticed without a microscope. Particles sized 2.5 micrometers (0.0025 millimeters) or less ($PM_{2.5}$) have received the greatest attention from scientists and government agencies due to their ability to enter the smallest regions of the lungs and therefore pose serious health concerns.[34]

$PM_{2.5}$ contributes to diabetes, COPD, stroke, ischemic heart disease, atherosclerosis, tracheal, bronchus and lung cancer, and lower respiratory infections.[35] Exposure to PM has also been linked to respiratory conditions such as allergy, asthma, airway irritation and inflammation, and tuberculosis.[36]

3.1.1.2. Gases & Chemicals

Both natural gases and gases originating from human activities can have toxic effects on human health. Additionally, some complex chemicals, found in many products used in everyday life, can emit gases called volatile organic compounds (VOCs) through a process referred to as "chemical off-gassing". These gases can diffuse in the air and may have detrimental effects on human health. Some examples of potentially harmful gases include:

Carbon dioxide: Carbon dioxide is a colorless gas, commonly emitted from the burning of coal, oil, gasoline, and natural gas. Elevated concentrations of CO_2 can contribute to reduced ability to focus, headaches, and dizziness.[37]

Formaldehyde: Formaldehyde, commonly used in cleaning products, building materials, and furniture, can diffuse in the air. When inhaled it can irritate the skin, eyes, nose, and throat. Long-term exposure can cause cancer.[38]

3.1.2. Indoor Air Quality Concerns within the Home

In the United States, indoor air quality is subject to pollution originating from both outdoor and indoor sources.

3.1.2.1. Outdoor Sources of Air Pollution

It is widely acknowledged that indoor air quality (IAQ) is significantly influenced by outdoor air quality due to forced ventilation, infiltration, and window operation. Although US air quality has significantly improved since the passage of the Clean Air Act in the 1970s, outdoor air pollution levels continue to pose a threat to human health.[31] Indeed, the EPA estimates that around 79 million tons of pollution were emitted in the US in 2017,[39] and that around 111 million Americans live in counties with pollution levels that exceed at least one of the EPA's National Ambient Air Quality Standards.[40] Major sources of pollutants in the US include mobile sources, such as automobiles; stationary sources, such as industrial sites; and biogenic sources, such as forest fires.[41] The EPA states that urban areas, areas near industrial facilities, and areas with high transportation emissions are at particularly high risk for hazardous air pollutants.[32]

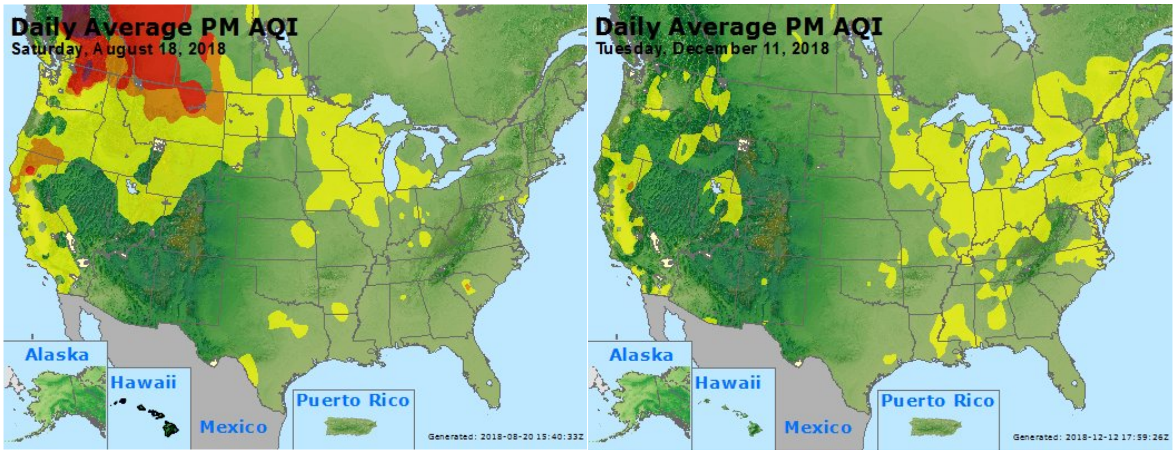

Figure 9. Sample Daily Maps of PM Air Quality Index (August 18, 2018; December 11, 2018), United States.
Source: AirNow.gov. https://airnow.gov/index.cfm?action=airnow.mapsarchivecalendar (Accessed on January 29, 2019)[42]

3.1.2.2. Special Focus: Wildfires in California

Recent wildfires in California have garnered significant attention for the large scale and widespread destruction they have caused. In July 2018, California experienced the largest wildfire in state history, which burned over 450,000 acres.[43] It was followed in November 2018 by the Camp Fire, the deadliest and most destructive in state history.[44] At least 86 people were killed, and nearly 14,000 homes were destroyed.[45]

Wildfire smoke contains a number of airborne gases and particles, which people in areas affected by wildfire or where wildfire smoke spreads may be exposed to. Specifically, the US Environmental Protection Agency states that fine particles are the principal pollutant of concern for short-term exposure.[43] Other components of concern include carbon monoxide and VOCs.[43,46] Even areas that are not directly affected by fires may experience elevated concentrations as smoke spreads.[46]

In Northern California, $PM_{2.5}$ concentration levels during the Camp Fire period rose to levels that are considered "very unhealthy" or "hazardous" by the EPA, with 417 $\mu g/m^3$ reported in Chico, 263 $\mu g/m^3$ in Sacramento, and 251 $\mu g/m^3$ in Yosemite National Park[32] (Figure 10). For comparison, average $PM_{2.5}$ levels for the ten cities with the highest levels in the world in the last year ranged from 107 to 96 $\mu g/m^3$.[47] The unhealthy air quality reached as far as the Bay Area, around 150 miles away from the fire, where $PM_{2.5}$ levels reached 247 $\mu g/m^3$.[48]

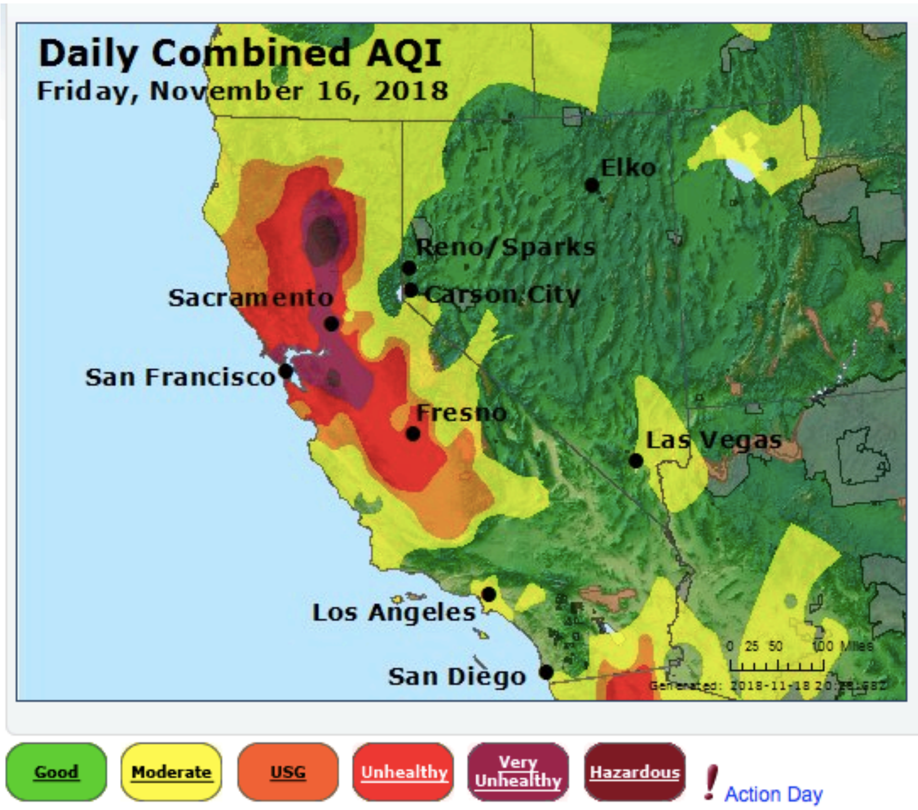

Figure 10. Air Quality Index in California During Camp Fire Period. Source: AirNow.gov.

https://airnow.gov/index.cfm?action=airnow.mapsarchivedetail&domainid=2&mapdate=20181116&tab=1 (Accessed on December 18, 2018) [49]

As previously discussed, many of these pollutants are harmful to human health. The CDC notes that exposure to wildfire smoke can hurt people's eyes, irritate the respiratory system, and worsen chronic heart and lung diseases.[50] Systematic reviews indicate that wildfires have been robustly linked to increased risk of respiratory diseases, potential increase in the risk of cardiovascular problems, as well as general increase of mortality. Populations such as children, pregnant women, the elderly, and people with preexisting underlying chronic conditions are particularly susceptible.[46,51,52] An analysis of a previous period of wildfires in California in 2003 found that average $PM_{2.5}$ increases of 70 $\mu g/m^3$ were associated with a 34% increase in hospital admissions for asthma, as well as increases in other respiratory conditions such as acute bronchitis and COPD.[53] Another analysis of 2015 wildfire events in California found that smoke exposure was associated with cardiovascular and cerebrovascular visits to the emergency department, as well as respiratory visits.[54]

Although it is too soon for a similar formal evaluation of the health impacts of the recent fires, news reports indicate that local hospitals have seen an increase in patients with respiratory complaints and other concerns known to be associated with poor air quality, particularly among susceptible populations. Reported symptoms include eye irritation, sore throats, coughing, difficulty breathing, exacerbated asthma, exacerbated pneumonia, and heart palpitations.[55,56]

Unfortunately, these wildfires are not isolated events. The incidence rate and intensity of wildfires has been increasing in the United States – likely due to settlement expansion into peri-urban and forested areas, as well as longer, drier, and warmer springs and summers.[51,57,58] These trends are expected to continue, given their relationship with ongoing climate change[59]: The Intergovernmental Panel on Climate Change anticipates that the window for high forest fire risk will increase by 10-30% in North America.[60] One study estimates that wildfires contributed 71.3% of total $PM_{2.5}$ on days exceeding regulatory $PM_{2.5}$ standards from 2004-2009 in the western US, and that under future climate change in this area, more than 82 million individuals will experience a 57% increase in frequency and 31% increase in intensity of consecutive days with high $PM_{2.5}$ attributable to wildfire.[61]

The US EPA recommends that individuals stay indoors during periods of smoke to reduce their exposure and keep indoor air as clean as possible. However, some outdoor particles may still enter the home (e.g., when people enter and exit the home). As such, indoor air filters and cleaners may be beneficial in protecting from adverse effects of smoke.[62]

3.1.2.3. Indoor Sources of Air Pollution

In addition to pollution potentially entering homes from the outdoors, indoor air quality can also become compromised due to indoor sources of pollution, including but not limited to the following:

Building Materials and Furnishings: Paints and paint ingredients are among the thousands of chemicals present in building materials. Some paint formulations may include di-isocyanates, volatile organic compounds,[63,64] cadmium in paint pigments,[65] halogenated flame retardants,[66] polyurethanes, and isocyanates.[67] These toxicants may have adverse health effects on home owners when they are exposed to high levels of the chemical or exposed for an extended period of time. For example, exposure to cadmium through inhalation can cause endocrine and respiratory problems, including breathing and airway diseases, kidney problems, and even lung cancer in extreme cases.[65] Similarly, volatile organic compounds can have a wide range of health effects, ranging from skin irritation to neurological issues, and in extreme cases, cancer.[68]

Gas Appliances: Gas appliances, such as gas stoves, emit carbon monoxide, nitrogen dioxide, and PM, each of which may lead to health effects ranging from fatigue and dizziness to asthma attacks and even death, depending on the extent of exposure.[36,69,70,71]

Solid Fuel: Household air pollution (HAP) from the combustion of solid fuel, such as wood, is among the top five environmental health risks across the globe.[72] The World Health Organization estimates that 3.8 million premature deaths from noncommunicable diseases, including stroke, ischemic heart disease, chronic obstructive pulmonary disease (COPD) and lung cancer, are due to exposure to household air pollution each year.[72] While HAP is mainly a major concern in low- and middle-income countries, where people may rely on solid fuel combustion for heating and cooking, it is estimated that in the US solid fuel is the primary heating source for more than 2.5 million households (or approximately 6.5 million people).[73] Additionally, fireplaces can contribute to indoor air pollution by generating particulate matter and carbon monoxide.

Pets, Pests and Insects: Airborne biological particulate matter from pets, pests, and insects can trigger allergic reactions, and may promote infectious diseases, digestive problems, and respiratory illnesses.[74]

3.1.3. Benefits of the DARWIN Network

Air Purification

Air constantly flows into homes and is subject to a wide range of pollutants, both from outdoor air as well as from source contaminants found within the home. Effectively managing indoor air quality through air filtration can help reduce the concentration of contaminants within the home.

In the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 52.2, filters are assigned a Minimum Efficiency Reporting Value (MERV). MERV ratings range from 1 to 16 and describe the efficiency of removing different size particles at a certain flow rate. A MERV 13 filter can remove most indoor particulate matter, such as dust, pollen, and droplet nuclei (from sneezes), and can help achieve superior indoor air quality without adding significant flow resistance to the central HVAC system. Furthermore, a supplementary activated carbon filter can remove many organic and reactive outdoor air contaminants, including TVOCs and ozone. The DARWIN network utilizes filtration – with options including MERV8 to MERV16-related filters and/or a thermally bonded activated carbon filter – to achieve and maintain improved indoor air quality. Further, the DARWIN Air Purification System is designed to keep allergens at bay by filtering out particles from outdoor air, to help remove toxins that may be prevalent in building materials and furnishings, and to reduce exposure to pathogens that can cause both short- and long-term health impacts. The DARWIN network also eliminates unwanted odors, which can improve mood, reduce stress, lower heart rate, and improve overall well-being.[75]

Responsive Purification

The DARWIN network is equipped with indoor air quality sensors that measure the levels of various pollutants in real-time, including $PM_{2.5}$ and CO_2. This network uses Delos proprietary algorithms to effectively manage indoor air quality, through circulation that helps reduce the concentration of contaminants within the home. Upon the detection of pollution spikes, the DARWIN network is engineered to modulate the HVAC ventilation rate to remediate the issue in the specific affected area(s) of the home (Figure 10).

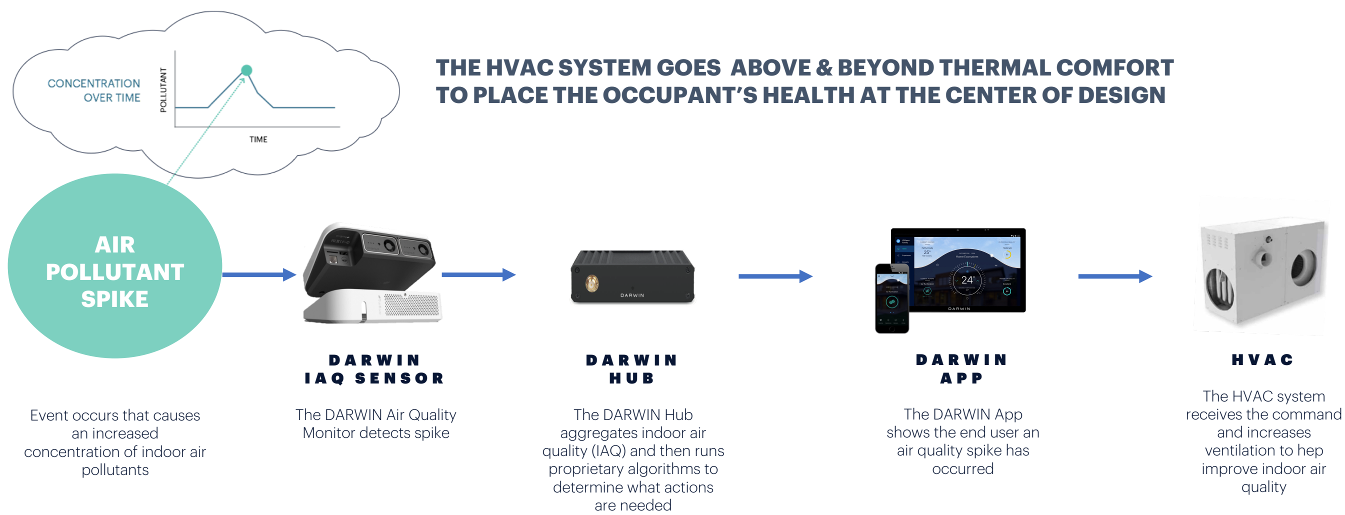

Figure 11. Overview of the DARWIN HVAC system.

The thermal environment is ranked as one of the most important contributing factors to overall occupant satisfaction with the indoor environment. Over the past several years, multiple studies of thermal comfort have highlighted the importance of providing users with control over their indoor conditions, and thus thermal comfort. It is important to note that there are differences in thermal acceptability between occupants of naturally ventilated buildings versus buildings with air-conditioning. Users of naturally ventilated buildings are more tolerant of indoor thermal conditions than users of air-conditioned buildings.[76] DARWIN is equipped with a temperature and relative humidity sensor to monitor thermal comfort within the home.

3.2. How DARWIN Improves Water Quality in the Home

3.2.1. Health Impacts of Water Pollution

Access to water that is clear of inorganic, organic, and biological contaminants is essential for maintaining optimal health. Humans are mostly made of water – in fact, water comprises over 50% of an adult's body weight.[77] Water is vulnerable to pollution by biological, chemical, and mineral contaminants that are harmful to both human and environmental health. These contaminants, especially in high doses, can be toxic and impair health and overall quality of life.[78] When ingested, contaminated water can affect many body systems, including digestive, cardiovascular, respiratory, nervous, urinary, and integumentary systems.[78]

Inorganic Contaminants: Some chemicals that can be found in drinking water – such as asbestos, copper, lead, and mercury – can cause adverse health effects particularly with prolonged exposure.[79] For example, lead and mercury in drinking water can cause developmental delays in children and impact their learning ability.[80] In adults, toxins in water can contribute to high blood pressure and kidney problems. Sources include runoff from industrial and agricultural processes, along with mining and other human activities.[80] Furthermore, water delivery infrastructure may compromise water quality through corrosion, which can lead to the leaching of various metals into the water, such as iron, lead, and copper.[81]

Pesticides and Herbicides: Pesticides and fertilizers used in farming regularly trickle down into our streams and leach into groundwater, making their way into our drinking water. In high doses, these contaminants can cause serious health effects, including cancer.[82]

Organic Contaminants: Organic contaminants present in water are usually the result of industrial activities. Sources of these contaminants include processes related to industrial and chemical runoff leaching into surface waters.[73] Various volatile organic compounds – such as benzene, ethylbenzene, toluene, and xylene – that may be found in water have been linked to health concerns including cancer; kidney and liver damage; nervous system problems; respiratory irritation and difficulties; and anemia.[83-87]

Microbial Contaminants: Water can also be contaminated with pathogens – including viruses, bacteria, and parasites – that can lead to waterborne diseases with symptoms such as diarrhea, abdominal discomfort, vomiting, fever and headache.[80] For example, some of the most common causes of outbreaks in US public water systems include Legionella, giardia, norovirus, and hepatitis A virus.[88]

Public Water Additives and Byproducts: Chlorination is commonly used as a disinfecting method in public water treatment systems.[89] However, several toxicological and epidemiological studies suggest that trihalomethanes (THMs), one of the main chlorination disinfection byproducts (DBPs), may be associated with adverse health effects.[90] Maternal exposure to THMs may be associated to growth retardation.[91] Studies indicate that both oral consumption and inhalation exposure to DBPs may result in increased risk of cancer.[92]

3.2.2. Water Quality Concerns in the Home

Humans have developed increasingly sophisticated systems to transport water to our homes. However, even today, with our advanced treatment technologies, it is still challenging to ensure that everyone has access to water that is free of contaminants. Conventional water treatment does not always remove contaminants effectively. Furthermore, in addition to pollution from industry and agriculture, the treatment and distribution systems meant to keep drinking water safe can also be potential sources of contamination, as pollutants can also be introduced through the water distribution infrastructures.

Although drinking water in the United States is among the safest in the world, in large part due to the requirements established by the 1974 Safe Drinking Water Act (SDWA), a number of threats to optimal water quality remain. Funding limitations have led to difficulty in maintaining aging and deteriorating infrastructure and upgrading to the latest treatment standards. It is also challenging for regulations to keep pace with the evolution of scientific knowledge regarding additional water contaminants and safe exposure levels. As previously noted, in addition to contaminants from source water, contaminants can also enter water through piping – for example, water pipes are often made from lead that can leach into water if the pipes are corroded – and EPA regulations do not require testing for all such contaminants at point-of-use.[93,94] Furthermore, around 10% of Americans drink unregulated water that is not subject to SDWA safety standards.[95]

As a result, many Americans are at risk for unsafe drinking water with respect to the contaminants previously described – which came into the national spotlight recently with Flint, Michigan's lead-contaminated water. A National Resources Defense Council analysis found that as of 2015, 18,000 US community water systems – serving almost 77 million Americans – violated at least one SDWA rule, with more than 80,000 total violations. For example, 1,100 water systems serving 3.9 million people exceeded the action level established for lead under the SDWA.[96] A recent study similarly found that 4 to 28% of the US population was affected each year since 1982 by health-based SDWA violations (i.e., standards regarding levels of contaminants and disinfectants, and treatment techniques).[97] From 2013-2014 alone, 42 drinking water-associated health outbreaks occurred in the United States, causing 1006 cases of illness, 124 hospitalizations, and 13 deaths.[98]

3.2.3. Benefits of the DARWIN Network

3.2.3.1. Water Filtration

Filtration is one of the most effective treatment methods for mitigating water quality concerns, including dissolved solids, biological contaminants and chemical contaminants such as residual chlorine. In certain specifications of the DARWIN Water Filtration System, the network utilizes a variety of options for filtration technologies to remove such contaminants.

The DARWIN Water solution is customized according to on-site water testing, third-party laboratory analysis, and regional specific research dating back 10 years. It is designed to help target harmful biological elements, chemicals, and bacteria, for great tasting water that leaves hair and skin feeling softer and smoother.

First, the DARWIN system uses sediment filters to remove sediments of a size as small as 12 microns.

Second, carbon filters can remove residual chlorine and other trace chemical contaminants such as pesticides, other volatile organic compounds, and disinfectant byproducts. Activated carbon filters adsorb chemical contaminants from the water as they pass through the filter media. The effectiveness of activated carbon in removing chemical contaminants depends on surface area among other characteristics, such that a larger surface area equates to better removal rates. For example, one pound of activated carbon provides anywhere from 60 to 150 acres of surface area.[99] The pores of activated carbon filters trap macroscopic particles and large organic molecules, while the activated surface area adsorbs small organic molecules.[99] The carbon filter also helps reduce chlorine taste and odor, providing better testing water from any sink in the home.

Another type of filter offered is ultrafiltration, which effectively removes particles in the size range of less than 0.01 to 0.1 micron. Effective removal of these contaminants in a source water results in a filtrate well suited for further treatment by downstream reverse osmosis, described in the following paragraph.

Finally, the system may include a Kinetic Degradation Fluxion (KDF) filter, which has the ability to filter certain dissolved metals, such as lead, iron, mercury, and inorganic arsenic V. The system may also use a reverse osmosis (RO) filter, which removes particles larger than 0.1 nm, including most microorganisms and many dissolved metals, such as arsenic, lead, mercury, iron etc.

2.3. How DARWIN Improves the Home Lighting Environment

2.3.1. Health Impacts of Light

Mounting research evidence indicates that the quality, type, and timing of light exposure can have a profound effect on human health, well-being and performance.[100] Most mammals, including humans, have an internal clock that keeps the sleep-wake rhythm on a roughly 24-hour cycle. The human body is naturally programmed to function on a cycle that matches the solar day.[101] Known as the circadian rhythm, this clock is synchronized by light and controls many aspects of our physiology, metabolism, and behavior, including our sleep-wake cycle[102] (Figure 11). Multiple body functions, including sleep and digestion, are regulated in part by the daily hormonal fluctuations prompted by internal circadian clocks. These hormones are released by an area in the brain called the hypothalamus.[103] The timing of hormone release is based on the timing of light exposure, which the brain receives via specialized nerve cells in the eye, called intrinsically photosensitive retinal ganglion cells (ipRGCs).

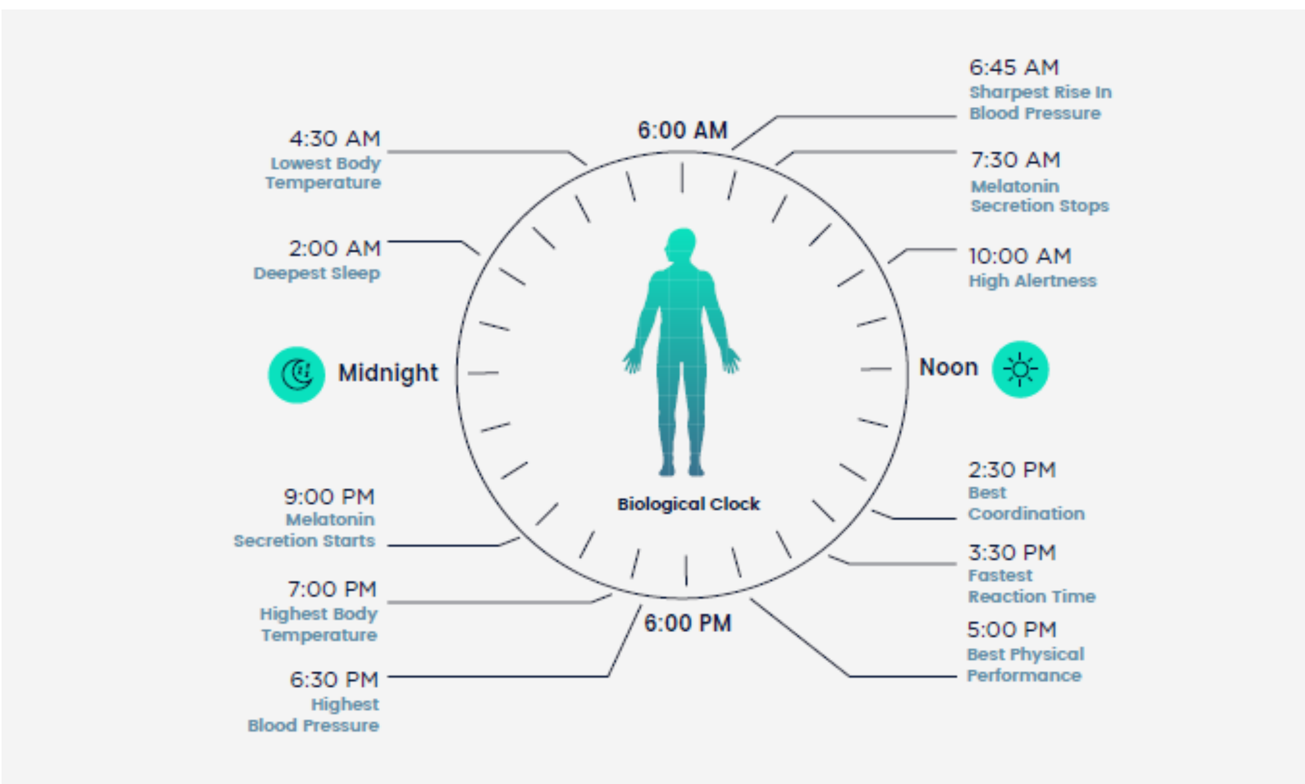

Figure 12. The human circadian rhythm.

Within the eye, light is detected by ipRGCs that send signals to the region of the brain in charge of vision, as well as the region of the brain controlling our biological clocks and circadian rhythms.[104] These cells are independent of those needed for vision, and the functions of these cells are therefore often referred to as non-visual or non-image forming. The main output of ipRGC activation is a signal sent to the suprachiasmatic nucleus, the area of the brain responsible for regulation of the hormone melatonin, which regulates sleep; the suprachiasmatic nucleus is therefore referred to as the brain's circadian clock.[105] Since the body's natural circadian rhythm does not run on a perfect 24-hour cycle, we rely on our exposure to light (traditionally sunlight) to synchronize ourselves to the regular day, a process referred to as circadian photoentrainment.[105-107]

Melatonin is a hormone produced by the brain that plays an important role in the regulation of our sleep wake-cycle.[108] Melatonin production naturally starts to increase in the evening, preparing us to fall asleep; peaks in the middle of the night; and then rapidly declines in the morning, allowing us to wake up.[101] Exposure to blue light or bright light before bedtime can suppress the release of melatonin, which can delay sleep onset and shorten sleep duration. Inversely, exposure to blue-enriched bright white light in the morning can have an energizing effect.[109] There is a direct link between light exposure and melatonin suppression, although the nature of the relationship is dose-dependent upon the quantity (intensity) and quality (spectral output) of the light source.[110] Mistimed light exposure can therefore lead to negative outcomes, such as sleep disturbance, mood disorders, affective conditions, and even circadian gene mutations.[111]

In addition to its effect on the sleep-wake cycle, light also affects many other functions of the human body, including alertness,[109] mood,[112] cognition,[109] and metabolism.[102] Disruption or desynchronization of the circadian rhythm and related hormones (e.g., through exposure to bright light at night) has been linked to obesity, diabetes, depression, metabolic disorders, and breast cancer.[113-118] Furthermore, reduced exposure to daylight is associated with depression, cognitive function impairment, and poorer work performance.[119-123]

Sources of light can vary in terms of color – from warm (orange) to cool (blue) – and in terms of intensity – from dim to bright. Lights of different colors and intensities will result in different responses from the brain.[109] Hence, in addition to the timing of light, the type of light to which we are exposed will also determine the effect on our circadian rhythms. Exposure to electric light can disrupt our natural circadian rhythm, which can directly impact our health and well-being. Daily, regularly-timed light exposure is necessary to maintain a healthy and robust circadian rhythm, called "entrainment."[124]

3.2.2. Lighting Environment in the Home

Our exposure to light in modern times is very different than it was in the past. Instead of bright, blue-spectrum sunlight in the morning, followed by warmer light in the evening, and finally total darkness, we are exposed to much dimmer levels of electric light throughout all waking hours. This constant exposure to electric light can send the wrong signal to the hypothalamus, reducing alertness during the day, and delaying or disrupting sleep patterns. Fortunately, simple design strategies, including more access to daylight through window design, brighter electric light (in the blue spectrum) during the morning and afternoon, followed by access to dimmer, warm-colored light in the evening, can help to support the circadian rhythm and promote better sleep.

Artificial light can also be utilized in beneficial ways. For example, light therapy is effective for certain affective (short-term mood) disorders, enhancing sleep quality in young and older adults, and improving circadian rhythm alignment.[125]

Indoor lighting environments not only impact our ability to perform visual tasks, but it also has non-visual effects on our comfort, mood, and biological processes through intrinsically photosensitive retinal ganglion cells (ipRGCs). Therefore, it is important that non-visual effects of light are included in the considerations for lighting design.

3.2.3. Benefits of the DARWIN Network

Light influences and regulates our body rhythms, providing the cues to keep our sleep-wake cycle aligned each day. Well-designed combinations of natural and artificial light can provide an improved lighting environment to help support occupants' natural circadian rhythms. Special lighting fixtures and controls allow indoor electric light to mimic outdoor natural light, mirroring the brightness and color of sunlight throughout the course of the day.

Circadian Lighting

The DARWIN Circadian Lighting System can simulate natural sunlight indoors to help maintain healthy circadian rhythms, and improve energy, mood and productivity. Calibrated to the home's location, the system is programmed to deliver lighting conditions that simulate the light outdoors based on the time of day. Residents can live, work, play and sleep knowing that the lighting environment automatically adjusts throughout the day to support their health and well-being.

Customizable Lighting

The DARWIN Circadian Lighting System is adjustable and can be personalized by the user. Lights are color tunable and dimmable, enabling a variety of lighting environments engineered to evoke different moods. Whether to relax before bed or energize in the morning, DARWIN provides occupants with the flexibility to adjust lighting according to their personal needs and preferences.

Energizing Mirror

Exposure to bright light can help dissipate sleep inertia, making it easier to wake up in the morning and stay more alert come evening. Using an energizing light in the bathroom minimizes disruption to the morning routine while still allowing for adequate light exposure.

3.4. How DARWIN Enhances the Sleep Environment

3.4.1. Health Impacts of Sleep

Good quality sleep is fundamental to physical and mental well-being. Scientists once believed that sleep was a state of inactivity, a time when our brains and bodies shut down during the night in preparation for the following day. We now understand that our bodies, and more importantly our minds, are quite active while we sleep. As we sleep, we cycle through four stages characterized by distinct patterns of activity, in both our brains and bodies. Each stage of sleep makes specific contributions to our mental, physical and emotional health and well-being (Figure 12). While research into the specific functions of sleep continues to advance, there is one factor all researchers agree on: sleep is an absolute necessity required to maintain optimal health and well-being. Sleep plays a regenerative role for both the mind and body. Leading researchers and institutions all agree that sleep is one of the most important activities we engage in to maintain peak physical and mental performance. In fact, the CDC now states that sleep deprivation is a public health concern.[126]

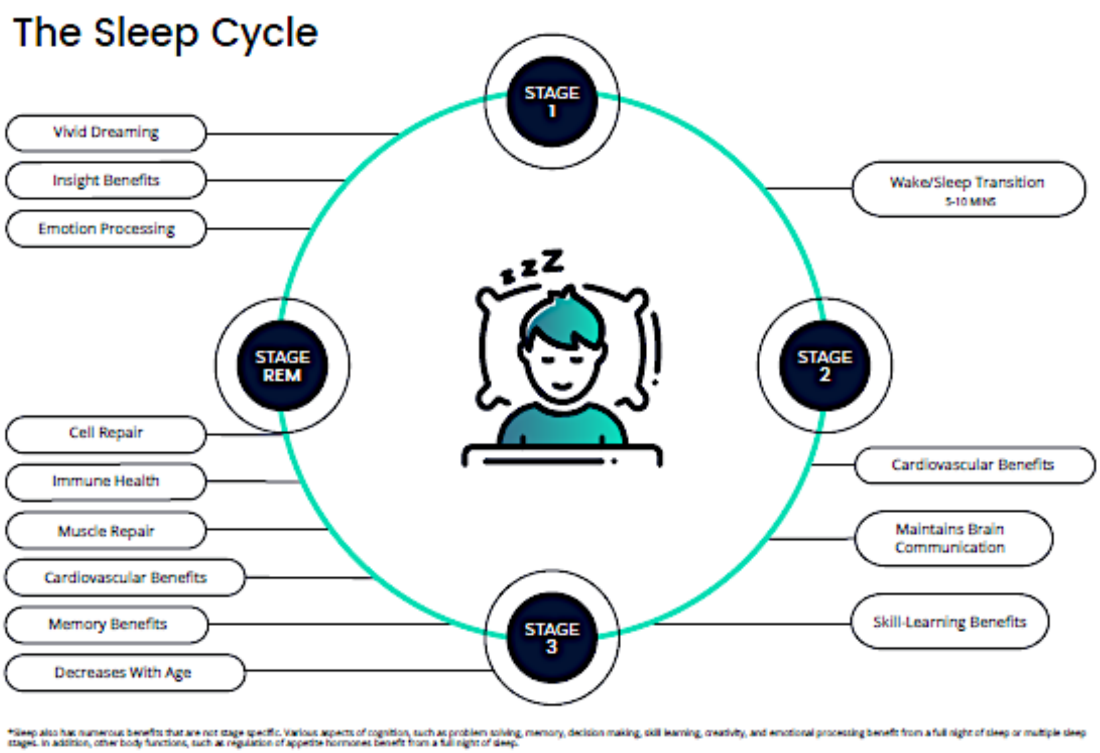

Figure 13. The stages of the sleep cycle.

Sleep is essential for overall healthy functioning across our lifespan. Substantial evidence shows that cognitive function and performance are particularly impacted by sleep. Sleep loss may result in deficits in psychomotor[127] and cognitive speed,[128] executive[129] and vigilant attention,[130] working memory, and higher-order cognitive abilities such as learning,[131,132] decision-making,[133,134,135] and problem-solving.[136,137] On a more devastating scale, insufficient sleep has been associated with various hazardous outcomes including medical and other occupational errors, motor vehicle crashes, and industrial accidents.[138] From a health perspective, prolonged sleep deprivation has been linked with myriad chronic diseases and conditions, including diabetes, hypertension, obesity, stroke, and increased mortality risk.[139] As adults age, insufficient sleep has also been associated with an increased risk of falls and decreased overall quality of life.[140] Likewise, nearly all mood and anxiety disorders are co-morbid with sleep disruptions.[141] Sleep has also been shown to impact resiliency in individuals facing highly stressful situations or trauma.[142]

3.4.2. Sleep Environment in the Home

Although biological factors such as age can affect sleep,[143] the built environment can have a significant impact as well. The bedroom plays an instrumental role in the quality of sleep achieved each night. Several parameters of the sleeping environment directly influence the quality and duration of sleep.

Lighting

Lighting is one of the most powerful external cues for the human body. Increased use of electronic devices emitting bright light (TVs, smartphones, computers, tablets) in the hours prior to going to sleep,[144-147] along with lifestyle trends encouraging people to engage in a 24-hour work cycle,[148] results in exposure to lighting at night that disturbs sleep.[149] Inappropriate exposure to light during sleep time – even in small quantities – can have dramatic impacts on circadian rhythm[150] and lead to melatonin suppression,[151] the key hormone that signals to the body that it is time to go to sleep. Even brief exposures to light at night, especially light that is of short wavelength (in the blue spectrum), can disrupt the sleep-wake cycle, making it hard to fall back to sleep, and in turn make it harder to wake up early in the morning. Specifically, exposure to artificial light at night has been found to result in increased subjective alertness and decreased sleep efficiency and total sleep time.[152] In addition, research shows that illuminance below 15 lux (at corneal level in the horizontal angle of gaze) evokes a minimal melatonin phase shift.[153] Light pollution at night has become a major concern for human health, particularly in urban settings.[154]

Thermal Comfort

Temperature is one of the key environmental factors contributing to the ability to fall asleep at night, as well as the ability to achieve restful sleep.[155] Maintenance of thermal comfort throughout the sleep cycle is critical for adequate sleep duration and sleep quality. In the 24-hour circadian cycle, core body temperature decreases during the onset of sleep and increases close to waking. This rhythm is influenced by fluctuations in daily ambient temperature that sends cues to help set the human circadian clock appropriately for sleep timing. Lower ambient temperature when going to sleep and warmer temperature closer to wake time can help promote alignment to optimal sleep cycles.[156,157] In addition, ambient temperature also affects the ease of thermoregulation to optimal core body temperature.[158,159]

Comfort

Comfort has a direct effect on our physical state as well as our mental state. The use of medium-firm or medium-firm plus memory foam mattresses has been associated with various indicators of physical discomfort such as musculoskeletal pain and lower back pain and stiffness.[160-166] Low back pain and other musculoskeletal disorders are among the top ten causes of health loss in the United

States, according to the GBD.[167] According to National Sleep Foundation surveys, 93% of Americans report that they think a comfortable mattress is important for a good night's sleep.[168]

3.4.3. Benefits of the DARWIN Network

The DARWIN network is programmed to help create a rejuvenating and comfortable sleep environment by promoting a natural transition into sleep in the evening, minimizing light pollution throughout the night, and enhancing the transition from sleep to wakefulness. Dawn Simulation and Prepare for Sleep are two DARWIN schedules which, when paired with other DARWIN features (such as the performance mattress), can help provide a more comfortable sleep environment.

Circadian Lighting Experiences

The DARWIN network is programmed to provide night lighting that is dim and of a spectrum that minimizes light in the blue band, while also providing adequate light levels for safe night-time navigation. While indoor lighting can be easily controlled, it is also important to be able to minimize exposure to light from the outdoors through fenestrations. Blackout blinds eliminate outdoor light pollution, promoting complete darkness and deeper sleep through the night.[169] Conversely, as the time to wake up approaches, DARWIN gradually increases lighting to help wake up naturally and comfortably.

Performance Mattress

A heat dissipating natural memory foam mattress provides pressure relief and contouring support for maximal comfort.

Temperature Regulation

The DARWIN network automatically adjusts the bedroom temperature to provide more comfortable sleep conditions, dipping slightly as bedtime approaches and warming up again in the morning, to help the body temperature align with the circadian day and night.

Biophilic Sounds

DARWIN utilizes nature sounds to recreate a natural morning experience, to wake up more peacefully and orient to the start of the day.

CONCLUSION

Delos shares the CDC's viewpoint that "preventing disease is key to improving America's health and keeping rising health costs under control. When we invest in prevention, the benefits are broadly shared. Children grow up in communities, homes, and families that nurture their healthy development, and adults are productive and healthy."[10] Preventing illness and improving health and well-being is a major challenge that requires us to rethink our healthcare spending, which usually employs a reactive approach of addressing health conditions once they arise. A more proactive approach to health and well-being may help to reduce the burden of disease and disability by preventing (or delaying) their development, allowing people to live healthier for longer.

Research suggests that the home can be used as a conduit to affect health as both a preventative and reactive tool for short-term issues as well as chronic diseases. DARWIN Home Wellness Intelligence is designed to support health and well-being within the home, for example by removing specific harmful agents in the air and water that may ultimately enter our bodies. Of special note, DARWIN utilizes custom-programmed lighting technology to produce specific physiological responses based on the time of day and customized to the human condition. This is important to enhancing sleep quality, a critical driver of human health, as sleep deficiency can raise the risk for chronic health problems. One third of our lives should be dedicated to sleep; however, most Americans are not achieving good sleep quality, both in terms of the amount of time spent sleeping, or in terms of achieving the full sleep cycle. Environmental factors (including artificial light, outdoor light pollution, noise pollution, comfort, temperature, and air quality) have a tremendous influence on our ability to obtain a good night's sleep. DARWIN positively impacts our sleep environment and can support our overall health and well-being by eliminating or removing these harmful elements from the sleep environment.

The building and developer communities have long participated in the environmental sustainability movement, and an appropriate next step is investing in healthy homes. Offering the DARWIN network sends a strong signal that homebuilders care about health and well-being and of the human health condition at large. Given that we spend on average 90% of our time indoors,[3] Americans now have a large and untapped opportunity to use our homes to promote health and well-being. For homebuyers, an investment in DARWIN is an investment in supporting health for the whole family.

For the first time, Delos has created a research-based intelligence network that allows people to use their homes as the framework to help support health and wellness. The DARWIN™ Home Wellness

Intelligence Network is designed to promote wellness in the home and to mitigate environmental factors that impact our health, happiness and well-being. As the first-ever wellness intelligence network for the home, DARWIN utilizes research-backed science and technology, including intelligent algorithms calibrated to the home, to provide an environment designed to support health, well-being and performance.

The DARWIN Home Wellness Intelligence Network is based on the research established to date by the scientific community. Delos is committed to furthering this research through an ongoing collaboration with the Well Living Lab (in Rochester, Minnesota) and by continuing to apply the latest research findings to our industry offerings.

REFERENCES

1. World Health Organization. The determinants of health: Introduction. 2010; https://www.who.int/hia/evidence/doh/en/.
2. U.S. Department of Health and Human Services. Determinants of Health. *Healthy People 2020* 2019; https://www.healthypeople.gov/2020/about/foundation-health-measures/Determinants-of-Health.
3. Klepeis NE, Nelson WC, Ott WR, et al. The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. *Journal of Exposure Science and Environmental Epidemiology*. 2001;11(3):231.
4. OECD. Health resources - Health spending - OECD Data. 2018; http://data.oecd.org/healthres/health-spending.htm.
5. Centers for Medicare and Medicaid Services. National Health Accounts Projected. 2018; https://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/NationalHealthExpendData/NationalHealthAccountsProjected.html.
6. U. S. Bureau of Labor Statistics. CONSUMER EXPENDITURES--2017. 2018; https://www.bls.gov/news.release/cesan.nr0.htm.
7. World Health Organization. Global Health Expenditure Data Explorer. http://apps.who.int/nha/database/Select/Indicators/en.
8. Institute of Medicine. US health in international perspective: Shorter lives, poorer health. In. Washington, DC: National Academies Press; 2013.
9. Institute for Health Metrics and Evaluation (IHME). GBD Compare. 2018. Available at: http://ihmeuw.org/4nxr.
10. CDC. Preventive Health Care. 2018; https://www.cdc.gov/healthcommunication/toolstemplates/entertainmented/tips/PreventiveHealth.html.
11. Institute for Health Metrics and Evaluation (IHME). GBD Compare. 2018. Available at: http://ihmeuw.org/4axi.
12. National Center for Health Statistics. Tables of Summary Health Statistics for U.S. Adults: 2017 National Health Interview Survey. 2018.
13. Institute for Health Metrics and Evaluation (IHME). GBD Compare. 2018. Available at: http://ihmeuw.org/4q8s.
14. Waters H, Devol R. *Weighing Down America: The Health and Economic Impact of Obesity*. Milken Institute;2016.
15. Fryar CD, Ostchega Y, Hales CM, Zhang G, Kruszon-Moran D. Hypertension Prevalence and Control Among Adults: United States, 2015-2016. *NCHS data brief*. 2017(289):1-8.
16. National Center for Health Statistics. FastStats - Mental Health. 2017; https://www.cdc.gov/nchs/fastats/mental-health.htm.
17. Centers for Disease Control and Prevention. Current Cigarette Smoking Among Adults in the United States | CDC. 2019; https://www.cdc.gov/tobacco/data_statistics/fact_sheets/adult_data/cig_smoking/.
18. National Institute on Alcohol Abuse and Alcoholism. Alcohol Facts and Statistics. 2018; https://www.niaaa.nih.gov/alcohol-health/overview-alcohol-consumption/alcohol-facts-and-statistics.

19. President’s Council on Sports, Fitness & Nutrition. Facts & Statistics. 2017; https://www.hhs.gov/fitness/resource-center/facts-and-statistics/index.html.
20. America's Health Rankings. Annual Report - Physical Activity in United States in 2018. 2019; https://www.americashealthrankings.org/explore/annual/measure/Sedentary/state/ALL.
21. U.S. Department of Health and Human Services & U.S. Department of Agriculture. *2015-2020 Dietary Guidelines for Americans*. 2015. Available at https://health.gov/dietaryguidelines/2015/guidelines/.
22. Ohayon M, Wickwire EM, Hirshkowitz M, et al. National Sleep Foundation's sleep quality recommendations: first report. *Sleep Health*. 2017;3(1):6-19.
23. Liu Y, Wheaton AG, Chapman DP, Cunningham TJ, Lu H, Croft JB. Prevalence of healthy sleep duration among adults—United States, 2014. *MMWR Morbidity and mortality weekly report*. 2016;65.
24. Buysse DJ. Sleep Health: Can We Define It? Does It Matter? *Sleep*.37(1):9-17.
25. Brainard GC, Hanifin JP. Photons, Clocks, and Consciousness. *Journal of Biological Rhythms*. 2005;20:314-325.
26. Carskadon MA, Dement WC. Normal human sleep: an overview. In: Kryger MH, Roth T, Dement WC, eds. *Principles and practice of sleep medicine*. 5th ed. St. Louis, MO: Elsevier Saunders; 2011:16-26.
27. Landrigan PJ. Air pollution and health. *The Lancet Public Health*. 2017;2(1).
28. Institute for Health Metrics and Evaluation (IHME). GBD Compare. 2018. Available at: http://ihmeuw.org/4p4u.
29. Forouzanfar MH, Afshin A, Alexander LT, et al. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. *The Lancet*. 2016;388(10053):1659-1724.
30. Wang H, Naghavi M, Allen C, et al. Global, regional, and national life expectancy, all-cause mortality, and cause-specific mortality for 249 causes of death, 1980–2015: a systematic analysis for the Global Burden of Disease Study 2015. *The lancet*. 2016;388(10053):1459-1544.
31. U.S. Environmental Protection Agency. *Targeting Indoor Air Pollution EPA's Approach and Progress*. 1993.
32. U.S. Environmental Protection Agency. Regulatory Information by Topic: Air. 2018; https://www.epa.gov/regulatory-information-topic/regulatory-information-topic-air.
33. Thron RW. Direct and indirect exposure to air pollution. *Otolaryngology--Head and Neck Surgery*. 1996;114(2):281-285.
34. U. S. Environmental Protection Agency. Learn About Particle Pollution Designations. [Policies and Guidance]. https://www.epa.gov/particle-pollution-designations/learn-about-particle-pollution-designations#process.
35. Institute for Health Metrics and Evaluation (IHME). GBD Compare. 2018. Available at: http://ihmeuw.org/4p4v.
36. U. S. Environmental Protection Agency. Health and Environmental Effects of Particulate Matter (PM). 2017.
37. National Library of Medicine. Carbon Dioxide. *Tox Town* 2017; https://toxtown.nlm.nih.gov/chemicals-and-contaminants/carbon-dioxide.
38. U.S. Environmental Protection Agency. Facts About Formaldehyde. https://www.epa.gov/formaldehyde/facts-about-formaldehyde.
39. U.S. Environmental Protection Agency. Air Quality - National Summary. [Data and Tools]. 2018; https://www.epa.gov/air-trends/air-quality-national-summary.
40. U. S. Environmental Protection Agency. Regulatory Information by Topic: Air. [Collections and Lists]. 2018; https://www.epa.gov/regulatory-information-topic/regulatory-information-topic-air.

41. National Association of Clean Air Agencies. Industrial Sources. 2018.
42. U.S. Environmental Protection Agency. AIRNow - Air Quality Maps - Archive, Monthly View. 2018; https://airnow.gov/index.cfm?action=airnow.mapsarchivecalendar.
43. U. S. Environmental Protection Agency. Wildfire Smoke Frequently Asked Questions. 2018; https://airnow.gov/index.cfm?action=topics.smoke_wildfires_faqs.
44. Wootson CR. The deadliest, most destructive wildfire in California's history has finally been contained. *Washington Post*. https://www.washingtonpost.com/nation/2018/11/25/camp-fire-deadliest-wildfire-californias-history-has-been-contained/. Published November 26, 2018. Accessed October 30, 2019.
45. California Department of Forestry and Fire Safety. Camp Fire Incident Information. 2018; http://www.fire.ca.gov/current_incidents/incidentdetails/Index/2277.
46. Youssouf H, Liousse C, Roblou L, et al. Non-accidental health impacts of wildfire smoke. *International journal of environmental research and public health.* 2014;11(11):11772-11804.
47. Berkeley Earth. City Average Particulate Air Pollution (PM2.5). 2018; http://berkeleyearth.lbl.gov/air-quality/CityAverageList.php?mode=5.
48. Bay Area Air Quality Management District. Air Monitoring Data - November 2018. 2018; http://www.baaqmd.gov/about-air-quality/current-air-quality/air-monitoring-data?DataViewFormat=monthly&DataView=aqi&StartDate=11/13/2018&ParameterId=316. Accessed December 13 2018.
49. U.S. Environmental Protection Agency. AIRNow - California, Arden Arcade-Del Paso Manor. 2018; https://airnow.gov/index.cfm?action=airnow.local_city&cityid=766.
50. U. S. Centers for Disease Control and Prevention. Wildfire Smoke. 2017. https://www.cdc.gov/disasters/wildfires/smoke.html.
51. Liu JC, Pereira G, Uhl SA, Bravo MA, Bell ML. A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke. *Environmental research.* 2015;136:120-132.
52. Reid CE, Brauer M, Johnston FH, Jerrett M, Balmes JR, Elliott CT. Critical review of health impacts of wildfire smoke exposure. *Environmental Health Perspectives.* 2016;124(9):1334-1343.
53. Delfino RJ, Brummel S, Wu J, et al. The relationship of respiratory and cardiovascular hospital admissions to the southern California wildfires of 2003. *Occupational and environmental medicine.* 2009;66(3):189-197.
54. Wettstein ZS, Hoshiko S, Fahimi J, Harrison RJ, Cascio WE, Rappold AG. Cardiovascular and Cerebrovascular Emergency Department Visits Associated With Wildfire Smoke Exposure in California in 2015. *J Am Heart Assoc.* 2018;7(8).
55. Rainey J. Scientists study long-term impact of bad air from California wildfires. *NBC News*. https://www.nbcboston.com/news/health/Scientists-Long-Term-Impact-Bad-Air-California-Wildfires-501127902.html. Published Nov. 23, 2018.
56. Granda N. Merced and Madera doctors say more children with severe symptoms are coming in. *ABC News*. https://abc30.com/merced-and-madera-doctors-say-more-children-with-severe-symptoms-are-coming-in/4729150/.Published Nov. 21, 2018.
57. Romero-Lankao P, Smith JB, Davidson DJ, et al. North America. In: Barros VR, Field CB, Dokken DJ, et al., eds. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2014:1439-1498.
58. Holden ZA, Swanson A, Luce CH, et al. Decreasing fire season precipitation increased recent western US forest wildfire activity. *Proceedings of the National Academy of Sciences.* 2018;115(36):E8349-E8357.

59. U.S. Department of Agriculture.McKenzie D, Heinsch FA, Heilman WE. Wildland Fire and Climate Change. 2011; https://www.fs.usda.gov/ccrc/topics/wildland-fire, 2018.

60. Parry M, Parry ML, Canziani O, Palutikof J, Van der Linden P, Hanson C. *Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC.* Vol 4: Cambridge University Press; 2007.

61. Liu JC, Mickley LJ, Sulprizio MP, et al. Particulate air pollution from wildfires in the Western US under climate change. *Climatic change.* 2016;138(3-4):655-666.

62. U.S. Environmental Protection Agency, U.S. Forest Service, U.S. Centers for Disease Control and Prevention, California Air Resources Board. *Wildfire Smoke: A Guide for Public Health Officials.* May 2016.

63. National Center for Healthy Homes. Potential Chemicals Found in Building Materials. http://www.nchh.org/Resources/Building-Materials-and-Products/Potential-Chemicals-Found-in-Building-Materials.aspx.

64. U.S. Environmental Protection Agency. Green building. https://archive.epa.gov/greenbuilding/web/html/about.html.

65. Prüss-Üstün A, Neira M. *Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks.* World Health Organization; 2016.

66. American Chemistry Council. Flame Retardant Basics. https://flameretardants.americanchemistry.com/Flame-Retardant-Basics/.

67. Pacheco-Torgal F, Jalali S, Fucic A. *Toxicity of building materials.* Elsevier; 2012.

68. U.S. Environmental Protection Agency. Technical Overview of Volatile Organic Compounds. [Overviews and Factsheets]. https://www.epa.gov/indoor-air-quality-iaq/technical-overview-volatile-organic-compounds.

69. U. S. Environmental Protection Agency. Carbon Monoxide's Impact on Indoor Air Quality. [Overviews and Factsheets]. https://www.epa.gov/indoor-air-quality-iaq/carbon-monoxides-impact-indoor-air-quality#Health_Effects.

70. U.S. Environmental Protection Agency. Basic Information about NO2. [Overviews and Factsheets]. 2018; https://www.epa.gov/no2-pollution/basic-information-about-no2#Effects.

71. Horvath SM. Nitrogen dioxide, pulmonary function, and respiratory disease. *Bulletin of the New York Academy of Medicine.* 1980;56(9):835.

72. World Health Organization. Household air pollution and health. *Fact sheet.* 2014;292.

73. Rogalsky DK, Mendola P, Metts TA, Martin WJ. Estimating the number of low-income Americans exposed to household air pollution from burning solid fuels. *Environmental health perspectives.* 2014;122(8):806.

74. U. S. Environmental Protection Agency. Biological Pollutants' Impact on Indoor Air Quality. [Overviews and Factsheets]. https://www.epa.gov/indoor-air-quality-iaq/biological-pollutants-impact-indoor-air-quality#Health_Effects.

75. Kadohisa M. Effects of odor on emotion, with implications. *Frontiers in systems neuroscience.* 2013;7:66.

76. Rupp RF, Vásquez NG, Lamberts R. A review of human thermal comfort in the built environment. *Energy and Buildings.* 2015;105:178-205.

77. Watson PE, Watson ID, Batt RD. Total body water volumes for adult males and females estimated from simple anthropometric measurements. *The American journal of clinical nutrition.* 1980;33(1):27-39.

78. Centers for Disease Control Prevention. Water-related Diseases and Contaminants in Public Water Systems. https://www.cdc.gov/healthywater/drinking/public/water_diseases.html.

79. World Health Organization. *Guidelines for drinking-water quality.* 2011.

80. USGS. Contaminants Found in Groundwater, USGS Water Science School. 2016; https://water.usgs.gov/edu/groundwater-contaminants.html.
81. Hong PA, Macauley Y-Y. Corrosion and leaching of copper tubing exposed to chlorinated drinking water. *Water, Air, and Soil Pollution*. 1998;108(3-4):457-471.
82. Koutros S, Lynch CF, Ma X, et al. Heterocyclic aromatic amine pesticide use and human cancer risk: results from the US Agricultural Health Study. *International journal of cancer*. 2009;124(5):1206-1212.
83. U. S. Environmental Protection Agency. National Primary Drinking Water Regulations.
84. Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Benzene*. Atlanta, GA: Agency for Toxic Substances and Disease Registry, Centers for Disease Control and Prevention; 2007 2007.
85. Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Toluene*. Atlanta, GA: Agency for Toxic Substances and Disease Registry, Centers for Disease Control and Prevention; 2000 2000.
86. U.S. Environmental Protection Agency. *Consumer factsheet on: ETHYLBENZENE*. Washington, D.C.2009.
87. Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Xylene*. Atlanta, GA: Agency for Toxic Substances and Disease Registry, Centers for Disease Control and Prevention; 2000 2007.
88. Centers for Disease Control and Prevention. Water-related Diseases and Contaminants in Public Water Systems | Public Water Systems | Drinking Water | Healthy Water | CDC. 2018; https://www.cdc.gov/healthywater/drinking/public/water_diseases.html.
89. Aieta EM, Berg JD. A review of chlorine dioxide in drinking water treatment. *Journal (American Water Works Association)*. 1986:62-72.
90. Nieuwenhuijsen MJ, Toledano MB, Eaton NE, Fawell J, Elliott P. Chlorination disinfection byproducts in water and their association with adverse reproductive outcomes: a review. *Occupational and environmental medicine*. 2000;57(2):73-85.
91. Wright J, Schwartz J, Dockery D. Effect of trihalomethane exposure on fetal development. *Occupational and Environmental Medicine*. 2003;60(3):173-180.
92. Wang G-S, Deng Y-C, Lin T-F. Cancer risk assessment from trihalomethanes in drinking water. *Science of the Total Environment*. 2007;387(1-3):86-95.
93. Weinmeyer R, Norling A, Kawarski M, Higgins E. The Safe Drinking Water Act of 1974 and its role in providing access to safe drinking water in the United States. *AMA journal of ethics*. 2017;19(10):1018.
94. Fedinick K, Wu M, Mekela Panditharatne J. *Threats on tap: Widespread violations highlight need for investment in water infrastructure and protections*. Natural Resource Defense Council 2017.
95. U. S. Environmental Protection Agency. Information about Public Water Systems. In:2018.
96. Olson E, Fedinick KP. *What's in Your Water? Flint and Beyond: An Analysis of EPA Data Reveals Widespread Lead Crisis Potentially Affecting Millions of Americans*. Natural Resources Defense Council;2016.
97. Allaire M, Wu H, Lall U. National trends in drinking water quality violations. *Proceedings of the National Academy of Sciences*. 2018;115(9):2078-2083.
98. Benedict KM, Reses H, Vigar M, et al. Surveillance for waterborne disease outbreaks associated with drinking water—United States, 2013–2014. *MMWR Morbidity and mortality weekly report*. 2017;66(44):1216.
99. Chittala G, Mogadati PS. Performance studies on a pharmaceutical wastewater treatment plant with a special reference to total dissolved solids removal. *International Journal of Life Sciences Biotechnology and Pharma Research*. 2012;1:103-112.

100. LeGates TA, Fernandez DC, Hattar S. Light as a central modulator of circadian rhythms, sleep and affect. *Nature Reviews Neuroscience*. 2014;15(7):443.
101. Reppert SM, Weaver DR. Molecular analysis of mammalian circadian rhythms. *Annual review of physiology*. 2001;63(1):647-676.
102. Huang W, Ramsey KM, Marcheva B, Bass J. Circadian rhythms, sleep, and metabolism. *The Journal of clinical investigation*. 2011;121(6):2133.
103. Sack RL, Auckley D, Auger RR, et al. Circadian rhythm sleep disorders: part I, basic principles, shift work and jet lag disorders. *Sleep*. 2007;30(11):1460-1483.
104. Hattar S, Liao H-W, Takao M, Berson DM, Yau K-W. Melanopsin-containing retinal ganglion cells: architecture, projections, and intrinsic photosensitivity. *Science*. 2002;295(5557):1065-1070.
105. Graham DM, Wong KY. Melanopsin-expressing, Intrinsically Photosensitive Retinal Ganglion Cells (ipRGCs). In: Kolb H, Nelson R, Fernandez E, Jones B, eds. *Webvision: The Organization of the Retina and Visual System*. Online: WordPress; 2008.
106. Golombek DA, Rosenstein RE. Physiology of Circadian Entrainment. *Physiology Reviews*. 2010;90:40.
107. Roenneberg T, Kumar CJ, Merrow M, et al. The human circadian clock entrains to sun time. *Current biology : CB*. 2007;17:R44-45.
108. Turek FW, Gillette MU. Melatonin, sleep, and circadian rhythms: rationale for development of specific melatonin agonists. *Sleep medicine*. 2004;5(6):523-532.
109. Chellappa SL, Steiner R, Blattner P, Oelhafen P, Götz T, Cajochen C. Non-visual effects of light on melatonin, alertness and cognitive performance: can blue-enriched light keep us alert? *PloS one*. 2011;6(1):e16429.
110. Cajochen C, Zeitzer JM, Czeisler CA, Dijk DJ. Dose-response relationship for light intensity and ocular and electroencephalographic correlates of human alertness. *Behavioural Brain Research*. 2000;115:75-83.
111. Bedrosian TA, Nelson R. Timing of light exposure affects mood and brain circuits. *Translational Psychiatry*. 2017;7(1).
112. Hampp G, Ripperger JA, Houben T, et al. Regulation of monoamine oxidase A by circadian-clock components implies clock influence on mood. *Current Biology*. 2008;18(9):678-683.
113. Cho Y, Ryu S-H, Lee BR, Kim KH, Lee E, Choi J. Effects of artificial light at night on human health: A literature review of observational and experimental studies applied to exposure assessment. *Chronobiology international*. 2015;32(9):1294-1310.
114. Challet E, Kalsbeek A. Circadian Rhythms and Metabolism. *Front Endocrinol*. 2017;8. doi:10.3389/fendo.2017.00201.
115. Plano SA, Casiraghi LP, García Moro P, Paladino N, Golombek DA, Chiesa JJ. Circadian and metabolic effects of light: implications in weight homeostasis and health. *Frontiers in neurology*. 2017;8:558.
116. Fonken LK, Nelson RJ. The effects of light at night on circadian clocks and metabolism. *Endocrine reviews*. 2014;35(4):648-670.
117. Boyce P, Barriball E. Circadian rhythms and depression. *Australian family physician*. 2010;39(5):307.
118. Hurley S, Goldberg D, Nelson D, et al. Light at night and breast cancer risk among California teachers. *Epidemiology (Cambridge, Mass)*. 2014;25(5):697.
119. Lam RW, Levitt AJ, Levitan RD, et al. Efficacy of bright light treatment, fluoxetine, and the combination in patients with nonseasonal major depressive disorder: a randomized clinical trial. *JAMA psychiatry*. 2016;73(1):56-63.
120. Figueiro MG. Disruption of circadian rhythms by light during day and night. *Current sleep medicine reports*. 2017;3(2):76-84.

121. Kent ST, McClure LA, Crosson WL, Arnett DK, Wadley VG, Sathiakumar N. Effect of sunlight exposure on cognitive function among depressed and non-depressed participants: a REGARDS cross-sectional study. *Environmental Health*. 2009;8(1):34.
122. Ruger M, Gordijn MC, Beersma DG, de Vries B, Daan S. Time-of-day-dependent effects of bright light exposure on human psychophysiology: comparison of daytime and nighttime exposure. *American Journal of Physiology-regulatory, integrative and comparative physiology*. 2006;290(5):R1413-R1420.
123. Heschong L. Windows and offices: A study of office worker performance and the indoor environment. *California Energy Commission*. 2003:1-5.
124. Schmidt TM, Chen S-K, Hattar S. Intrinsically photosensitive retinal ganglion cells: many subtypes, diverse functions. *Trends in neurosciences*. 2011;34(11):572-580.
125. Dodson ER, Zee PC. Therapeutics for circadian rhythm sleep disorders. *Sleep medicine clinics*. 2010;5(4):701-715.
126. US Centers for Disease Control and Prevention. Insufficient Sleep Is a Public Health Problem. 2015; https://www.cdc.gov/features/dssleep/index.html.
127. Dinges DF, Pack F, Williams K, et al. Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4–5 hours per night. *Sleep*. 1997;20(4):267-277.
128. Banks S, Dinges DF. Behavioral and physiological consequences of sleep restriction. *Journal of clinical sleep medicine: JCSM: official publication of the American Academy of Sleep Medicine*. 2007;3(5):519.
129. Durmer JS, Dinges DF. Neurocognitive consequences of sleep deprivation. Paper presented at: Seminars in neurology2005.
130. Lim J, Dinges DF. Sleep deprivation and vigilant attention. *Annals of the New York Academy of Sciences*. 2008;1129(1):305-322.
131. Chee MW, Chuah LY. Functional neuroimaging insights into how sleep and sleep deprivation affect memory and cognition. *Current opinion in neurology*. 2008;21(4):417-423.
132. Drummond SP, Brown GG, Gillin JC, Stricker JL, Wong EC, Buxton RB. Altered brain response to verbal learning following sleep deprivation. *Nature*. 2000;403(6770):655.
133. Harrison Y, Horne JA. One night of sleep loss impairs innovative thinking and flexible decision making. *Organizational behavior and human decision processes*. 1999;78(2):128-145.
134. Harrison Y, Horne JA. The impact of sleep deprivation on decision making: a review. *Journal of experimental psychology: Applied*. 2000;6(3):236.
135. Mckenna BS, Dickinson DL, Orff HJ, Drummond S. The effects of one night of sleep deprivation on known-risk and ambiguous-risk decisions. *Journal of sleep research*. 2007;16(3):245-252.
136. Linde L, Bergströme M. The effect of one night without sleep on problem-solving and immediate recall. *Psychological research*. 1992;54(2):127-136.
137. Nebes RD, Buysse DJ, Halligan EM, Houck PR, Monk TH. Self-reported sleep quality predicts poor cognitive performance in healthy older adults. *The Journals of Gerontology: Series B*. 2009;64(2):180-187.
138. Altevogt BM, Colten HR. *Sleep disorders and sleep deprivation: an unmet public health problem*. National Academies Press; 2006.
139. Hasler G, Buysse DJ, Klaghofer R, et al. The association between short sleep duration and obesity in young adults: a 13-year prospective study. *Sleep*. 2004;27(4):661-666.
140. Foley D, Ancoli-Israel S, Britz P, Walsh J. Sleep disturbances and chronic disease in older adults: results of the 2003 National Sleep Foundation Sleep in America Survey. *Journal of psychosomatic research*. 2004;56(5):497-502.

141. Wulff K, Gatti S, Wettstein JG, Foster RG. Sleep and circadian rhythm disruption in psychiatric and neurodegenerative disease. *Nature Reviews Neuroscience*. 2010;11(8):589.
142. Germain A. Sleep disturbances as the hallmark of PTSD: where are we now? *American Journal of Psychiatry*. 2013;170(4):372-382.
143. Ohayon MM, Carskadon MA, Guilleminault C, Vitiello MV. Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: developing normative sleep values across the human lifespan. *Sleep*. 2004;27(7):1255-1273.
144. Carter B, Rees P, Hale L, Bhattacharjee D, Paradkar MS. Association Between Portable Screen-Based Media Device Access or Use and Sleep Outcomes: A Systematic Review and Meta-analysis. *JAMA Pediatrics*. 2016;170(12):1202-1208.
145. Chang A-M, Aeschbach D, Duffy JF, Czeisler C, A. Evening use of light-emitting eReaders negatively affects sleep, circadian timing, and next-morning alertness. 2015.
146. Christensen MA, Bettencourt L, Kaye L, et al. Direct Measurements of Smartphone Screen-Time: Relationships with Demographics and Sleep. *PLoS One*. 2016;11(11):e0165331.
147. Lemola S, Perkinson-Gloor N, Brand S, Dewald-Kaufmann JF, Grob A. Adolescents' electronic media use at night, sleep disturbance, and depressive symptoms in the smartphone age. *Journal of youth and adolescence*. 2015;44(2):405-418.
148. Shochat T. Impact of lifestyle and technology developments on sleep. *Nature and science of sleep*. 2012;4:19-31.
149. Czeisler CA, Allan JS, Strogatz SH, et al. Bright light resets the human circadian pacemaker independent of the timing of the sleep-wake cycle. *Science*. 1986;233(4764):667-671.
150. Navara KJ, Nelson RJ. The dark side of light at night: physiological, epidemiological, and ecological consequences. *Journal of pineal research*. 2007;43(3):215-224.
151. Reiter RJ, Tan D-X, Korkmaz A, et al. Light at night, chronodisruption, melatonin suppression, and cancer risk: a review. *Critical Reviews™ in Oncogenesis*. 2007;13(4).
152. Yang M, Ma N, Zhu Y, et al. The Acute Effects of Intermittent Light Exposure in the Evening on Alertness and Subsequent Sleep Architecture. *Int J Environ Res Public Health*. 2018;15(3).
153. Zeitzer JM, Dijk DJ, Kronauer RE, Brown EN, Czeisler CA. Sensitivity of the human circadian pacemaker to nocturnal light: melatonin phase resetting and suppression. *The Journal of physiology*. 2000;526(3):695-702.
154. Chepesiuk R. Missing the dark: health effects of light pollution. *Environmental Health Perspectives*. 2009;117(1):A20.
155. Zulley J, Wever R, Aschoff J. The dependence of onset and duration of sleep on the circadian rhythm of rectal temperature. *Pflügers Archiv European Journal of Physiology*. 1981;391(4):314-318.
156. Joshi SS, Lesser TJ, Olsen JW, O'Hara BF. The importance of temperature and thermoregulation for optimal human sleep. *Energy and Buildings*. 2016;131:153-157.
157. Potter GD, Skene DJ, Arendt J, Cade JE, Grant PJ, Hardie LJ. Circadian Rhythm and Sleep Disruption: Causes, Metabolic Consequences, and Countermeasures. *Endocrine reviews*. 2016;37(6):584-608.
158. Yadlapalli S, Jiang C, Bahle A, Reddy P, Meyhofer E, Shafer OT. Circadian clock neurons constantly monitor environmental temperature to set sleep timing. *Nature*. 2018;555(7694):98-102.
159. Yetish G, Kaplan H, Gurven M, et al. Natural sleep and its seasonal variations in three pre-industrial societies. *Curr Biol*. 2015;25(21):2862-2868.
160. Radwan A, Fess P, James D, et al. Effect of different mattress designs on promoting sleep quality, pain reduction, and spinal alignment in adults with or without back pain; systematic review of controlled trials. *Sleep health*. 2015;1(4):257-267.
161. Jacobson BH, Wallace TJ, Smith DB, Kolb T. Grouped comparisons of sleep quality for new and personal bedding systems. *Applied Ergonomics*. 2008;39(2):247-254.

162. Jacobson BH, Gemmell HA, Hayes BM, Altena TS. Effectiveness of a selected bedding system on quality of sleep, low back pain, shoulder pain, and spine stiffness. *Journal of manipulative and physiological therapeutics*. 2002;25(2):88-92.

163. Jacobson BH, Boolani A, Dunklee G, Shepardson A, Acharya H. Effect of prescribed sleep surfaces on back pain and sleep quality in patients diagnosed with low back and shoulder pain. *Applied ergonomics*. 2010;42(1):91-97.

164. Jacobson BH, Boolani A, Smith DB. Changes in back pain, sleep quality, and perceived stress after introduction of new bedding systems. *Journal of chiropractic medicine*. 2009;8(1):1-8.

165. Jacobson BH, Wallace T, Gemmell H. Subjective rating of perceived back pain, stiffness and sleep quality following introduction of medium-firm bedding systems. *Journal of chiropractic medicine*. 2006;5(4):128-134.

166. Ancuelle V, Zamudio R, Mendiola A, et al. Effects of an adapted mattress in musculoskeletal pain and sleep quality in institutionalized elders. *Sleep Science*. 2015;8(3):115-120.

167. Institute for Health Metrics and Evaluation (IHME). GBD Compare. 2018. Available at: http://ihmeuw.org/4ou4.

168. National Sleep Foundation. *2012 Bedroom Poll*. 2012.

169. Van Den Wymelenberg K. Patterns of occupant interaction with window blinds: A literature review. *Energy and Buildings*. 2012;51:165-176.

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