NAAVA

breathe

Science behind Naava

An introduction to the various scientific fields which Naava is based on

NAAVA

Content

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NAAVA

Introduction

Wherever nature surrounds us, we have fresh air. We feel happier, healthier and more energized. Only recently have we experienced a rapid change in our environment, as we have moved from rural to urban environments, disengaging ourselves from nature. We are surrounded by a human made environment of buildings, vehicles, noise and pollution, and spend more time indoors than outdoors. We do not experience the natural world around us the way we once did; we've lost the protective and health promoting benefits it has provided us throughout our history.

We believe, that healthy air should be a human right. Today, this is not the case. It has been estimated, that by the year 2050, 66% of the world's population will be living in environments with little green space and only limited contact with nature[1]. Today, over 90% of people living in urban areas are exposed to air quality that exceeds the limits set by the World Health Organization[2]. According to the WHO, around 7 million people die prematurely due to air pollution each year, making it the world's single largest environmental health risk[3]. In 2012, one out of every nine deaths was the result of air pollution-related conditions, and 11.6% of all global deaths. The truth is air pollution affects everyone on our planet, wherever they live.

Only about 3 of the 7 million deaths are due to ambient (outdoor) air pollution. We are not protected from pollution inside our buildings, where we spend approximately 90% of our time[4] – on the contrary. The amount of pollution can be 10 times higher indoors compared to the city air outdoors[5,6,7,8]; sometimes it can exceed even 100–1000 times the concentration[9]. The already polluted outdoor air is drawn in and mixed with indoor pollutants. Exhaust fumes, dust and smoke leak in through mechanical ventilation systems and the shell of buildings, and different chemicals from construction and surface materials, furniture and technical equipment evaporate into the air we breathe. And we breathe over 15 000 liters of it every day[5,9,10]. Indoor air pollution has been ranked in the top five risks to public health by the US Environmental Protection Agency (US EPA) and its Science Advisory Board (SAB) due to its impact on people's health in urban areas all over the world[11]. Poor indoor air quality has been linked to a staggering 65,000–150,000 deaths every year in U.S. alone[12]. It is no wonder that sick building syndrome (SBS) has become so common, causing symptoms that cannot be related to any illness, but rather to the time spent in a building with indoor air problems[13]. These building-related symptoms are often blamed on heating, ventilation, air conditioning systems, air filtration, volatile organic compounds (VOCs), particulate matter (PM), and microbes, such as molds and bacteria[14,15,16,17,18]. We have sealed ourselves indoors, away from the air we were meant to live and breathe in. Instead, we have created synthetic, even sterile air, which is now making us feel ill.

Nature does not only provide us with fresh air to breathe, but has a more complex, deep effect on our physiological and psychological health. We were built to live in rural landscapes, and disconnecting ourselves from nature fights against our innate need to be a part of it. In modern society, when we have less opportunities to interact with nature, we must bring nature to us. This document introduces you to the scientific background behind the innovative Naava greenwall, and shows how we combine nature with state-of-the-art technology to bring nature's gifts inside our buildings.

The story behind Naava

Naava was born when one of our founders – Niko Järvinen – who studied microbes, met with another founder member – Aki Soudunsaari – who had been suffering from indoor air problems.

Historically, we have always used natural solutions to solve big problems. Green walls have been used to cool houses and to reuse water, while microbes have been used to make food and fermented alcohol. The industrial 20th century and exponential population growth has resulted in excessive waste and pollution problems and natural solutions are, again, being implemented to solve some of the world's biggest issues. First landfill sites and later waste water cleaning facilities adopted microbial cleaning as the best option to clean and remediate polluted soil and water. Even modern individual housing uses biological cleaning of gray waste waters by infiltration. We need microbes to clean the soil we eat from and the water we drink. So why not the air we breathe?

Naava has harnessed advances in information technology and biological sciences and has made it possible to treat air the same way we have treated land and water: The Naava solution is fully operational.

In 1973, NASA scientists identified 107 different kinds of VOCs inside the Skylab space station. An environmental scientist B. C. Wolverton had been assigned to study waste water cleaning with plants[20], and was then tasked to continue his work in bioremediation to improve air quality. He evaluated the potential of leaves, roots, soil, and associated microorganisms of plants to reduce indoor air pollution, and found that the latter destroy and convert pollutants into new biomass. His research showed, that the more air allowed to circulate through the roots of the plants, the more effectively they cleaned pollution from the air[19].

As already discussed, air quality is not only a problem in space stations; every indoor environment may well be suffering from it. The solution NASA has tested and proven has now been developed further to be applied where it is most needed and Naava is at the forefront of this. Naava's solution fixes several problems in the common artificial indoor environment. By bringing plants indoors and enhancing their ability to naturalize the air, we are able to create a more natural and healthier environment.

> If man is to move into closed environments, on Earth or in space, he must take along nature's life support system.
>
> - Wolverton 1989, NASA report[19]

Nature’s benefits

One could argue that the story of Naava actually began billions of years ago, from the moment when the first cells evolved to harness the power of the planet’s elements to fuel their own reproduction. Among these organisms, a vast variety of life was formed: the world we see today is the result of a long coexistence between those life forms. To understand our world as it is now, we need to realize that it is not isolated in time or space. We are a product of our history and surroundings, which affect our lives in ways we might not even realize.

From stone age to office age

Humans have a tendency to seek the presence of nature; having a walk in the park, bringing plants indoors, preferring a window seat, having family pets. In the United States and Canada, more people visit zoos than attend all of the professional sporting events combined[21,22], and in the US alone there are 40 million pet cats and 55 million pet dogs[23,24]. Even in ancient Egypt, Persian settlements, and in Medieval Chinese villages, homes were connected to extensive gardens. We recognize the joy and benefits we gain from connecting with nature, and scientific evidence can give us an explanation behind its power. Over the course of millions of years, we have evolved in nature: as a consequence, we have an innate affiliation with nature called
"[25,26].

“

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> From a genetic standpoint, humans living today are Stone Age hunter-gatherers displaced through time to a world that differs from that for which our genetic constitution was selected.
>
> - Eaton et al. 1988[27]

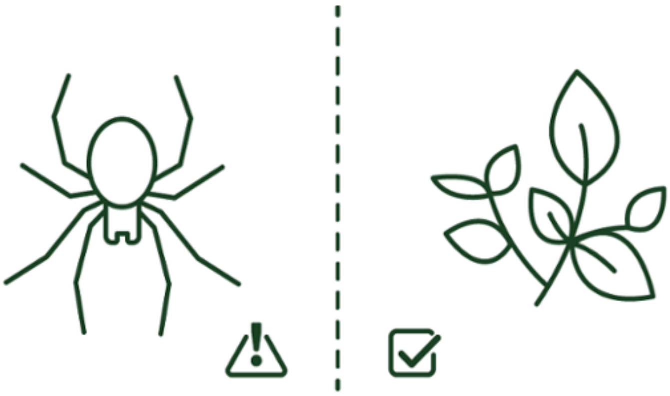
Environment of Evolutionary Adaptation (EEA) is a term used to describe qualities of the environment we have adapted to live in[28]. Our ancestors lived a life of hunting and gathering, relying on nature to provide resources necessary for survival. Sun gave light and warmth; trees gave shelter; vegetation gave food, materials and medicinal treatments; rivers and watering holes provided food and water for drinking. From a theoretical perspective, the presence of plants and other natural elements are an integral part of the human EAA. Deviations from the way of life we have adapted to are referred as mismatches[27]. Some of them are beneficial (i.e. modern medicine), but negative mismatches or discords can cause stress and contribute to disease or reduced quality of life[29,30]. As highly complex organs, our brains are especially vulnerable to these discords as they require substantial development after birth largely moulded by interactions with the environment. High prevalence of mental problems in modern societies could be explained by the presence of such discords. Our brains and bodies have been shaped by our environment, which has changed to include new human made structures. The history of building “proper” housing has been estimated to be a mere 6000 years old. Now, as the landscape of the Earth changes more rapidly than ever due to human influence[31], it has become more important than ever to understand the relationship we have with nature. Even though we as a species are capable of adapting our behaviour greatly in order to thrive in our modern environment, our brains and physiology are inherited from the ancestors who evolved in very different conditions. We carry the traits that made the survival possible for them.

Biophilia – love of life

The idea of an evolutionary basis for the need of “nature-connectedness” was proposed by an influential biologist Edward O. Wilson, who also coined the more globally recognized term “biodiversity”[25,32]. He proposed that contact with nature is a universal, basic human need, and not a matter of cultural or individual preference. It has been suggested that our brains have evolved to prefer living amongst a high diversity of plant and animal life for food and resources, high vegetation for refuge and protection, and natural water sources for drinking and bathing[33]. It is no coincidence that many of the natural features which are found to be aesthetically pleasing were also crucial for the survival of our species.

Supporting evidence for the biophilia hypothesis includes biophobia: the *fear* of nature. Fear is a powerful response to situations or stimuli that could potentially be harmful to us or pose a threat to our survival, and because of its evolutionary significance, fears are highly heritable[34,35,36]. As Charles Darwin (1877) first proposed, we have prepotent fears that have been preserved in us through evolution[37,38]. Humans, and other animals, have been studied to be more likely to fear certain situations or stimuli compared to others. Most common fears are related to natural phenomena, such as spiders, snakes, sharks, heights, and enclosed places[39]. Some of these fears seem irrational, as they rarely pose an actual threat in our modern environment. Researchers have found that responses to conditioned fear (such as guns and frayed electric wires) extinguish faster than those related to more primitive fear (such as snakes and spiders)[40]. Fear is often associated with acute situations such as facing a dangerous animal, but our physical environments also impact us depending on our innate instincts to assess potential risk and survival (picture 1). Humans respond with caution to, for example, spatially restricted spaces, as they might contain hidden dangers and limit escape opportunities[41].

People prefer natural, open settings with visual depth compared to restricted spaces[42,43]. Water is the most preferred element in natural landscapes among healthy vegetation and diversity[44,45,46]. When compared to urban scenes, an overwhelming preference towards natural scenes emerges despite cultural differences or other demographic variables[47,48]. The difference can be seen in the brain activity too, as viewing rural scenery activates the region of the brain that is associated with pleasure. Urban scenery does not trigger this[49]. When we introduce artificial elements (e.g. power lines) to otherwise natural scenes, the positive impact of the landscape drops significantly[41].

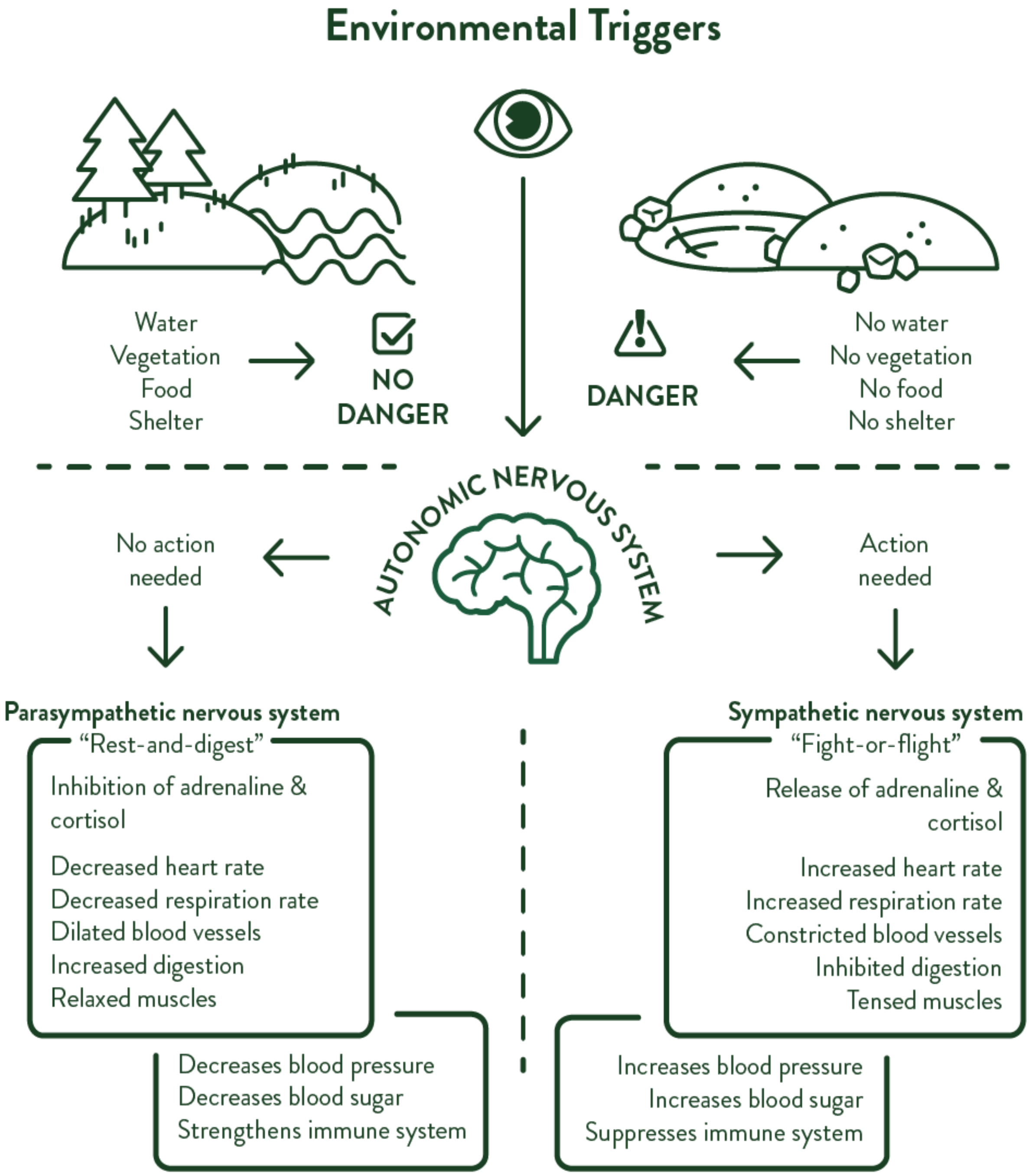


Picture 1. Just as we avoid natural stimuli that indicates danger (biophobia), advantages provided by specific features in the surroundings could have been so central to survival, that natural selection favoured individuals who responded to them by approach (biophilia)[41]. Many theories about the benefits of nature draw on biophilia hypothesis, suggesting a fundamental role on stress recovery and restoration as well as cognitive function.

It has been suggested that the effects could be due to the visual value of nature; some people simply find natural elements pleasing to the eye. Biophilic theory introduces an unconscious mechanism behind the value of nature: The preference for natural environments are likely mediated by perceptions of the environment's potential to provide restoration from stress. In contrast, the lack of plants and other natural elements may indicate an unsafe environment and cause our brains to induce stressful reactions. This suggests that even individuals who do not express appreciation for plants and nature in general, could still experience negative effects from their absence[50].

The restorative power of nature

When we face something we are afraid of, we experience a physical reaction. Our heartbeat and breathing hastens, muscles tense and our digestive processes slow down. This is caused by activation of our sympathetic nervous system, and is known as the "fight-or-flight" or acute stress response[51]. The purpose of this reaction is to prepare us for a challenging situation, whether it is fighting or fleeing. Together with the "rest-and-digest" reaction of the parasympathetic nervous system, our autonomic nervous system keeps a balance between stress and rest through a process called allostasis[52,53,54]. Imbalance, however, can lead to chronic stress and so called allostatic load[55,56,57]. While short term stress is important in some situations, frequent or chronic activation of the stress response can result in physiological wear and tear caused by exposure to stress hormones like adrenaline, and cortisol. Adrenaline is responsible for the immediate stress reaction, whereas cortisol is released continuously during stress. Cortisol regulates those body functions that are not crucial in a survival situation, such as reproductive drive. There are dozens of studies confirming how harmful long-term effects chronic stress has for our health and well-being, causing conditions such as high blood pressure[58,59], heart disease[60,61,62] , type two diabetes[63], inhibition of growth[64], suppression of the immune system[65], metabolic damage[66], and mental health problems[67,68,69] among many others. Common causes for chronic stress derive from our modern environment and fast paced lifestyle, both of which can be psychologically demanding. Work, especially, is one of the most significant contributors for stress and stress-related illness[58,,66,70,71,72,73,74,75,76,77]. The indoor work environment, therefore, is arguably in the greatest need of nature's intervention.



Picture 2. Environmental stimuli triggers physiological and psychological responses in our body in order to behave in the most beneficial way according to the situation. Environment that is lacking features essential to survival triggers our sympathetic nervous system to cause behaviour that will lead us to a safer environment. Our modern habitat is often lacking the visual cues - water, vegetation - which tell our brains it's ok to relax.

Stress recovery and attention restoration

Stress often drives people to seek relief through nature[78,79,80,81]. Providing our brains with the signals of a safe environment, our bodies and brains are allowed to restore and maintain their energy. Stress Recovery Theory (SRT)[79] states, that non-threatening natural environments promote physiological recovery and relaxation through innate, adaptive responses related to safety and survival[78]. Due to this restoring effect we are also capable of performing better on tasks that require directed attention[47,78,83,84,85,86,87]. Directed attention is the ability to control distractions through the use of inhibitory mechanisms. An environment that does not require directed attention allows a fatigued person to rest the inhibitory mechanism on which the directed attention depends, and thus recover. This is called attention restoration theory (ART). It states that attention can be categorized in two: involuntary, where attention is captured by inherently intriguing or important stimuli; and voluntary, or directed attention, where attention is directed by cognitive-control processes. The process has been proven both behaviourally and neurologically[88,89,90,91,92]. A vast amount of research supports the theory that nature are more restorative compared to urban environments[48,78,79,83,85,93,94,95,96,97,98,99,100,101,102,103,104,105].

Directed attention plays a crucial role in successful cognitive and emotional abilities[106] and short-term memory[107]. Exposure to nature improves many aspects of human health and well-being, and can be a useful way of improving concentration, performance, productivity and cognitive abilities as well. Nature therapy is already being used as an effective means to treat different problems related to these attributes. For example, studies have shown that contact with nature improves concentration of attention-deficient children[108,109,110], pregnant women[111], and newly diagnosed cancer patients[112]. Nature intervention could therefore be especially helpful when targeted to groups or situations with special needs.

Ways to connect with nature

Contact with nature has three different classes: outdoor nature contact, indoor nature contact (i.e. view from a window, natural light, live plants), and indirect nature contact (i.e. view to photographs of nature, recorded nature sounds)[113]. All of these ways to connect with nature have been linked to better health and well-being. As you would expect, direct connection has the strongest impact and indirect connection the least[114,115,116,117,118,119]. The more our modern environment includes these elements we innately consider important, the more it will support us psychologically, emotionally and functionally[26,120,121,122,123,124]. This might help in coping with extremely difficult life situations, such as poverty[105]. Activities, such as exercise, have been studied to have more positive effects in natural settings than similar activities in synthetic environments[125]. Incorporating nature to our urban environment is undoubtedly beneficial in many aspects[126]. It is fairly simple to bring the benefits of nature into our buildings by bringing some of its elements indoors, such as plants and natural light.

Having potted plants indoors has many healing effects on our physical and mental health[127]. There are many studies that have compared different health variables in rooms that either have or do not have plants, and have found some amazing results: people in rooms with plants compared to rooms with no plants have experienced reduced pain[128,129], lower blood pressure[128,130,131], less headaches[132], less discomfort[132,123,133], reduced coughing and dry throats and even less itchy skin conditions[134]. In some cases overall sick leave from school and work is reduced[135,136,137] and we've seen shortened average hospitalization time[129]; it has even been studied that plants and nature can lead to quicker healing after surgery[96,128,129]. Mental health effects include reduced nervousness and anxiousness[128,129,138], pressure[130], cortisol levels[127], misbehaviour[135], as well as creating overall positive emotions and sense stimulation[139]. In addition, people prefer rooms with plants in general, and report that they feel more comfortable and friendly[128,130,135]. Replacing plants with some other visual features, such as screens or images of nature, does not have the same effect as having real plants indoors[140]. For example, when studying pain perception and discomfort, more people could achieve keeping their hands submerged in ice water for 5 minutes in a room with plants compared to a room with equal aesthetic value achieved by other visually pleasing objects[133]. This result demonstrates that the positive benefits of plants are not simply due to their decorative value.

Contact with nature is also suggested to have a more profounding effects on whole human societies rather than merely benefits on single individuals and their communities. Contact with nature increases relatedness to nature – this means, that the more nature contact there is, the more we will feel connected with it[102]. This could provide a route to increase environmentally sustainable behaviour. As nature relatedness is a significant predictor of happiness, sustainable behaviour and happiness could simultaneously be increased by spending more time connecting with nature[141,142,143]. Contact with nature nurtures biophilic attitudes, enhancing willingness to conserve nature: it is important to stay in touch with nature, as it reminds us of our origins and the values we should hold onto to conserve the environment[144,145,146,147]. The importance for motivation to protect our environment in turn needs no explanations.

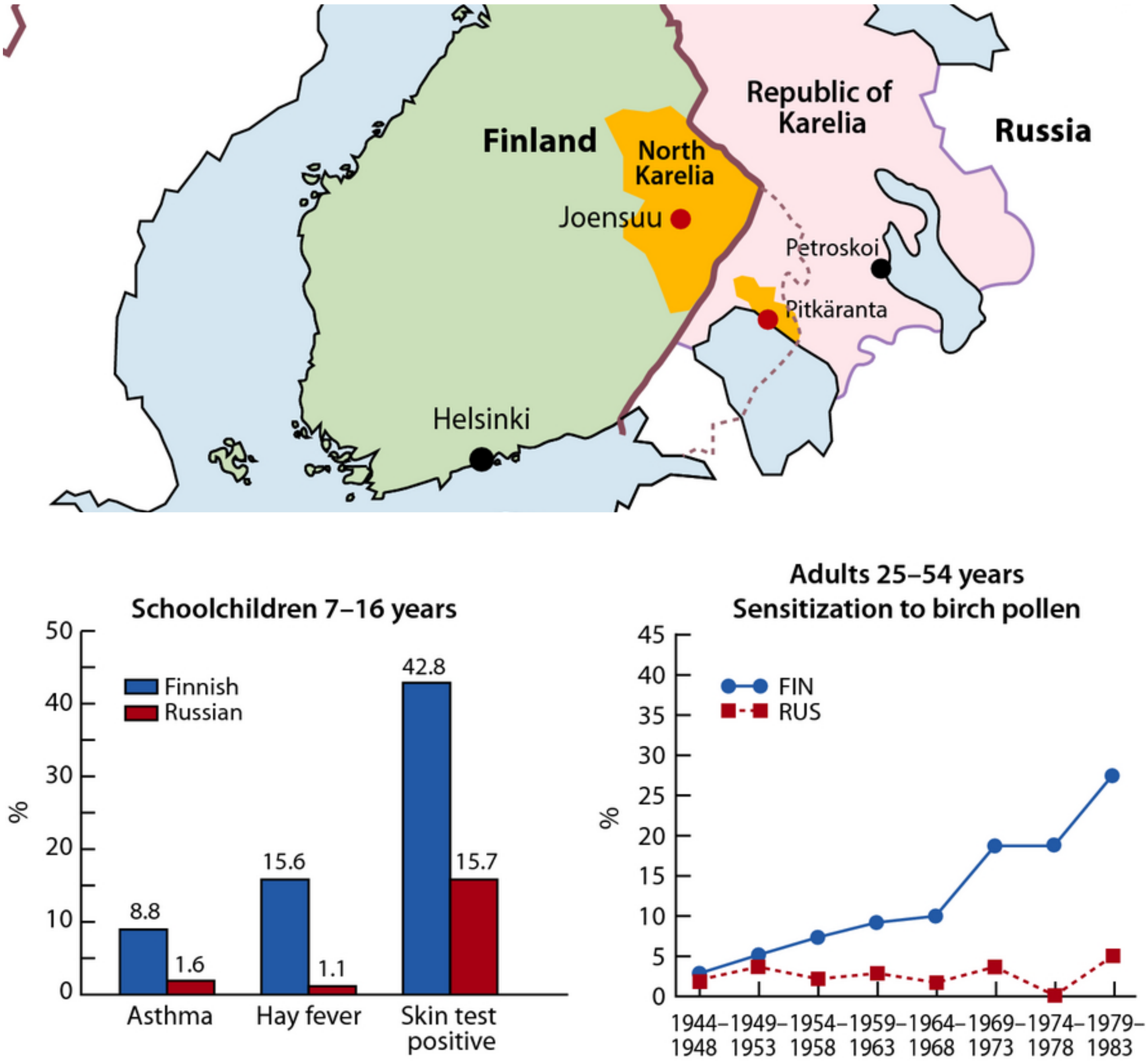
Loss of old friends

What we have also lost among the natural sense stimuli by isolating ourselves from nature, is the actual physical contact with the diversity of life. Our biology has been shaped by an interaction with a diverse combination of life from flora and fauna to microbial organisms. Just as in the biophilic theory, the loss of diversity in our modern environments is an evolutionary mismatch. Rapidly declining biodiversity around us and quickly increasing prevalence of allergies, asthma, and other chronic inflammatory disorders have raised a hypothesis that these two phenomena are connected[148,149]. This 'hygiene hypothesis' suggests that the main cause for the rise in these disorders is the lessened exposure of our immune systems to a diverse assembly of micro-organisms, which is due to the loss of biodiversity, urbanization, excessive hygiene and use of antimicrobial products. For these reasons it is also known as the 'biome depletion theory' or the 'old friends hypothesis': we are so dependent on microbes we have evolved with, that our immune systems can not develop nor function correctly without them[150,151]. Being in contact with them, especially in infancy and early childhood, trains our bodies to know when they need to react – but just as importantly, when there is no need to react. Environments that are rich in microbial diversity aid our bodies to create a balance in protecting ourselves against not just pathogens, but allergic and autoimmune diseases as well[152,153,154,155,156].

Various immunological and autoimmune diseases are much more common in the industrialized world compared to developing world, and even between different living standards among the same countries[157,158]. The length of time since arrival is also in relation to prevalence of these diseases on immigrants[159,160,161]. Effect of the differences between the standard of living have been studied in detail for example in the Karelia project since 1998: asthma and allergy prevalence between Finland and Russia has been studied since 1998[162]. Rapid economic growth and urbanization have created a large socioeconomic gap between Finnish and Russian Karelia, showing one of the highest leaps in living and health standards in the world[163]. The Russian region used to be a part of Finland until 1944, and the two populations share the same ancestry. There is a dramatic difference in the prevalence of allergies and asthma across the border (picture 3). It was found that in Finland, adults suffer from them more frequently[164], and almost 45% of Finnish children had at least one positive response to the tested allergens, when in Russia this was only 15.7%[165]. In addition, the children in Finland had increased sensitization to most of the allergens in comparison to their mothers. These results could not be explained by genetics[166,167], but rather by the microbiological diversity inside the homes[168] and in drinking water[169]. Similar results have been found in Germany, where it was discovered that children who grew up in farms and were exposed to a wider range of microbes, obtained protection against asthma[170]. It has been suggested that increase in asthma prevalence is due to something missing in the modern environment rather than some toxic element directly causing it[171]. It has been found that microbiota in asthmatic airways is indeed disturbed[172]..

When the children were tested again as teenagers, it was observed that healthy individuals in Finland had more diverse living environment with green space, natural areas and plants. This contributed to the larger counts and variation of microbes on their skin compared to atopic children[173]. This association between diverse environment and living conditions with atopic diseases has been observed more than once: Ilkka Hanski made a hypothesis that it could be related to microbes on plant surfaces, as they may enrich the microbiota on the skin, and therefore enhance its interaction with the immune system[155]. Reaffirming this hypothesis are the numerous studies of the importance of gut bacteria to our health, unbalanced microbiota being linked to obesity[174], diabetes[175], and allergy[176]. The imbalance is then treated by introducing healthy bacteria, such as probiotics, to the system[177].

There are several mechanisms behind the associations between diversity loss and increased prevalence of immunological diseases that need to be studied in further detail to fully assess the problem, but it is clear that interactions with natural environmental features increases health and general human well-being in urban areas[178]. Plant microbiomes are an important source for indoor microbiomes, stabilizing the indoor ecosystem by enhancing biodiversity[179]. They could act as counterparts against pathogens within the microbial ecosystems, thus avoiding outbreaks.



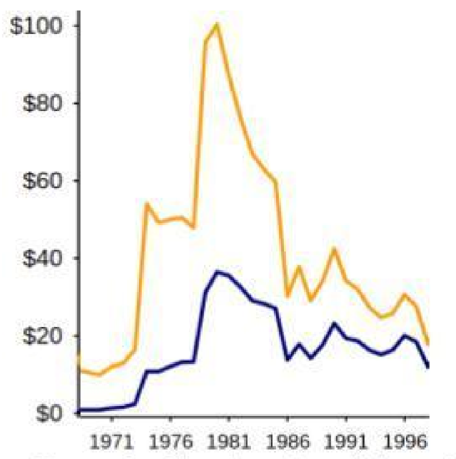
Picture 3. The difference of asthma, hay fever, and allergies in Finnish and Russian Karelia[180].

Indoor environmental quality

Studies for over thirty years have shown how big of an impact buildings have on our health and well-being[181,182,183,184]. They define how much we are exposed to both outdoor and indoor pollutants, noise, temperature and its changes, they affect our circadian rhythm and therefore our alertness through lighting, and they can either isolate us from nature, or connect us to it. All of these factors contribute to IEQ (indoor environmental quality), which describe the quality of a building in relation to the health and well-being of those who occupy it. They are often used when defining green building standards, which are fairly new: the trends in construction have changed along history, only recently to involve the well-being of occupants instead of focusing on energy-efficiency.

Changing trends in construction

Concerns of poor indoor air quality were recognized already in the 1950s, but only later turned into a global issue due to a change in the way buildings were constructed[182]. In the 1970s, the major industrial countries in the world experienced oil and energy crisis due to a conflict caused by Yom Kippur War, and later the Iranian Revolution. These events caused interruptions in Middle Eastern oil exports, raising prices and causing shortages, triggering attempts in saving energy. This led to buildings being built as airtight as possible to save costs in heating and cooling, and increase of recirculation of the air in HVAC systems. It is no coincidence that only few years later, in 1984, the term “sick building syndrome” was coined by WHO to describe symptoms that seemed to be related to the bad indoor air[185]. This energy saving trend has continued to this day with building standards that aim for as environmentally friendly, energy efficient and profitable buildings as possible[186]. Energy efficiency is good for the environment, but does not necessarily consider the people inside the buildings. Standards that assess the health of the occupants should be used to complement the environmentally friendly approach, and their importance has become increasingly recognized.



Picture 3. Oil prices show high peaks in during the 1973 oil crisis 1979 energy crisis. Blue line shows real values, yellow is adjusted for inflation (from Energy information Administration).

Indoor environmental qualities

There are some main factors that have the most impact on the indoor environmental quality: pollution, microorganisms, moisture, temperature, light, noise, and the visual appeal. All of these listed elements contribute to how health promoting and comfortable our surroundings is.

Volatile organic compounds

Volatile organic compounds – VOCs – are a group of carbon based chemicals that evaporate relatively easy to the air in room temperature. Over 900 chemicals belonging to this category have already been recognized, and they are the biggest pollutants of our indoor air[187,188]. Some VOCs are biogenically produced by plants, animals, microbes and fungi, but some originate from anthropogenic sources such as fossil fuels, paints and coatings, adhesives and aerosols, and technical equipment such as PCs[189,190,191]. The recommended amount of total VOCs in a regular indoor space is >250 $\mu g/m^3$[192,193]. However, this value is not based on the health effects, but on the deviation of regular VOC values (higher than 90% of the measurements). Some VOCs are toxic at high levels and some are even carcinogenic, such as benzene and formaldehyde[194,195], which have been linked to increased risk of leukemia and lymphoma[196,197,198,199]. There are a multitude of symptoms VOCs can cause either by short or long term exposure: irritation of mucous membranes, skin symptoms, headache, fatigue, nausea, memory loss, even damage to kidneys, liver, and nervous system. Long term exposure can also lead to problems in the immune system. VOCs have been connected to multiple diseases, such as asthma[200] and hypersensitivity[201]. Even small concentrations of VOCs can cause sick building syndrome or building related illness[197,202,203,204,205], and as has been suggested, especially when a mixture of VOCs is present[7,206]. Some VOCs that are not toxic by themselves may be dangerous because they react with other compounds, such as ozone, in the air[207,208,209,210].

Picture 4. VOCs can be measured from the air with several methods, such as gas sensors and TVOC detectors, or they can be collected into tenax tubes, which allow a detailed analysis of the specific compounds found in the air.

Particulate matter

Particulate matter (PM) is microscopic particles found in the air, such as dust, combustion particles and cigarette smoke. Unlike VOCs which exist even in the purest of forest air, PM is often derived from human activity and is always harmful when inhaled. No safe level of PM exists. Particulates are the deadliest form of air pollution, as they enter lungs and even bloodstream causing serious illnesses: lung cancer, pulmonary disease, and cardiovascular diseases[211,212,213,214,215]. Especially PM_{10} and $PM_{2.5}$, fine particulate matter, are considered hazardous. The smaller the particle is, the easier it is for it to transport from your lungs to your blood system, which makes them extremely carcinogenic. Bigger particles tend to settle down by gravity, but small particles can stay in the air and are mostly removed by precipitation. Lung cancer rates rise 22% for every increase of 10 µg/m³ in PM_{10}, and 36% in $PM_{2.5}$[216]. During the last five years, annual PM levels have increased by 8% globally[217]. An increase of 10 mg/m³ in $PM_{2.5}$ corresponds to an average of 5.5 passively smoked cigarettes per day[218]. According to some estimates, annually over 200,000 people die prematurely due to disease caused by combustion emissions in US alone[219]. There are other consequences to PM in addition to serious health implications. Exposure to PM has significant effects on our cognitive function and productivity at work: research has found that exposure to PM decreases cognitive performance and was related on how well students performed in their test scores and whether they were eligible for college[220]. Just a 10 µm/m³ increase of $PM_{2.5}$ in the air reduced the efficiency of factory workers by 6% – put in perspective, 2.79 µg/m³ decrease in $PM_{2.5}$ increased productivity worth $19.5 billion according to a US study[221].

Air pollution is known to have negative effects on organisms from the cell level to whole organ systems[222]: cardiovascular, respiratory, nervous, urinary, digestive, and reproductive systems. Effects on cardiovascular system alone may lead to problems in other organs. Pollution is known to impair the capacity for blood to transfer oxygen[223] – this may cause problems with organs that require a lot of oxygen, such as the heart and the brain. This in turn may result in impaired concentration, slow reflexes, and confusion. Blood coagulation may also alter, blocking cardiac blood vessels and leading to angina or even to myocardial infarction[224]. Other cardiovascular effect pollution has been studied to have include tachycardia, increased blood pressure, anaemia[225], changes in blood indices and heart rate variability[226], and increased mortality by heart disease[227].

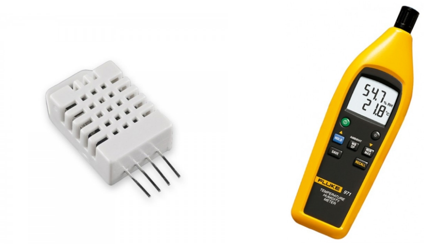
Picture 5. PM can be measured in the air by concentration (mass, for example) or size using particle counters.

Temperature and humidity

Temperature and humidity should be considered together, as they both affect each other. Optimal temperature indoors is around 20–25 degrees celsius. Too warm makes air feel stuffy and dry, and too cold in turn feels uncomfortable and could be a health risk, and it might also increase the time needed for moisture to evaporate, therefore exposing buildings to water and mold damage. There are differences in thermal comfort between men and women, as females tend to prefer air that is a few degrees warmer compared to males – that is, around 24–25 degrees of celsius[228].

Optimal air humidity indoors is between 30–40%. A good level of humidity also binds particles and impurities from the air, while a level too high exposes buildings to water and mold damages instead. Air that is too dry irritates airways, mucous membranes and skin[229], and it has also been linked to sick building syndrome[230]. Especially for people suffering from allergies and asthma, these symptoms can show up easily[231]. Too high humidity also increases chemical evaporation to the air: for example, a 35% increase in humidity raises formaldehyde evaporation from the building surface materials 1.8–2.6 times[232].

Air humidity can be measured in two ways. Absolute humidity tells how much water there is in the air, for example, as grams per a thousand liters. Relative humidity tells, how much water there is in the air relative to how much it can actually contain. This in turn depends on the temperature: cold air is able to bind less water than warm. This is the reason why relative humidity is higher the colder the temperature is, but as the amount it actually contains water is small, the relative humidity drops as the air gets warmer indoors.



Picture 6. Temperature and humidity can be monitored with simple sensors and devices.

Microbes

Humans are constantly exposed to VOCs and particulates produced by molds both outdoors and indoors. Often this exposure not harmful, but some molds can have adverse effects on human health. WHO has stated in their “Guidelines for Indoor Air Quality: Dampness and mould”, that: “Sufficient epidemiological evidence is available from studies conducted in different countries and under different climatic conditions to show that the occupants of damp or moldy buildings, both houses and public buildings, are at increased risk of respiratory symptoms, respiratory infections and exacerbation of asthma”[233]. The guideline states, that there is clinical evidence that exposure to mold and other dampness related microbial agents (spores, metabolites) increase the occurrence of diverse inflammatory and toxic responses and the risks of some rare conditions[234]. There are three different pathological mechanisms for this: infection, allergy, and toxicity[235]. Generally, mold infections occur only on people with autoimmune diseases, but mold allergy in turn is relatively common: about 1% of people have antibodies against common molds[236], and it is estimated that half of these individuals develop allergic symptoms from mold exposure. Mold spores are a common component of indoor dust, and in large quantities they can cause allergic reactions and respiratory problems, which may eventually lead to the onset of hypersensitivity or asthma[234,237,238,239]. Building related symptoms are most commonly associated with damp, water damaged premises[16,240,241] which provide a suitable environment for microbe growth as moisture is often a limiting factor for it.

Even though the health problems in damp buildings have been associated with high concentrations of fungal spores[242,243], the spore concentration in sick buildings are not necessarily higher compared to healthy ones[244,245,246,247]. Another study suggested that in addition to spore concentration, fungal fragments should also be measured[248] – however, these results indicate that allergy is not the only factor contributing to the sick building symptoms.

Molds produce metabolic byproducts and also toxins which inhibit the growth of competing micro-organisms. Some studies have found that exposure to these so called mycotoxins can be harmful, especially during long-term exposure[249,250,251,252]. When a building has toxin producing molds, dampening of surfaces causes them to produce nanodroplets that easily detach to the air[253]. Air conditioning may further break them up to smaller nanoaerosols and further spread them in the indoor air. Also some cleaning products break droplets down into nanoaerosols. Some molds produce the harmful mycotoxins in only certain conditions, varying from temperature, water activity and pH. the role of mycotoxins in building related illnesses has long been inconclusive[238], but a recent study done by the University of Helsinki found, that the toxicity of indoor dust samples collected from school buildings had a statistically significant association with building related illnesses on teachers[254]. More studies are needed to fully address the complex mechanisms behind the building related issues, and the contribution of other factors need to be included.

It has also been suggested that the toxic effects are actually caused by chronic activation of the immune system. This takes us back to the hygiene hypothesis: it has been proposed that the reason why Finnish schools are more "sick", is that they are too clean. Endotoxin levels have been found to correlate negatively with development of asthma in children, suggesting that early exposure to these toxins might give protection against it[255]. It has also been established that homes where a common disinfecting product was used, children were more prone to respiratory infections[241].

Some other explanations to the connection of mold and sick buildings include VOCs that the fungi produce while degrading the substance it grows on. Also fungicides can boost mycotoxin synthesis[256,257] – this might explain why buildings which have been treated for molds still often continue to have problems.

Picture 7. Microbial samples are collected from damaged surfaces and analyzed in a laboratory.

From sick buildings….

An unhealthy indoor environment can cause several problems from decreased performance to serious illness. There is no single factor that would alone explain the variety of symptoms related to poor IAQ, and therefore in addition to separate descriptions of them, it is necessary to explore them and their origins in coherence.

Research on environmental sensitivities is not intact, and the mechanisms behind them are still unclear in many aspects. As has been already been discussed, exposure to water damaged and moldy buildings have been associated with an onset of conditions such as sick building syndrome (SBS)[16,241,242], asthma[243], odour sensitivity and multiple chemical sensitivity (MCS)[258]. People suffering from these conditions get symptoms from exposure to e.g. VOCs or odorants in concentrations that are undetected by healthy individuals. There has long been a superstition that people with environmental sensitivities are just hypochondriac. This has been kept up by poorly executed studies, where the causality between psychological problems and indoor air symptoms have not been interpreted correctly[259]. According to the Finnish allergy and asthma federation, 10–40% of the citizens suffer from chemical sensitivities at some point in their lives, and a study found that in the U.S. about 33% of the general population reported symptoms caused by chemical sensitivities[260]. In Finland, all of the indoor air symptoms were added under one disease classification described with "elsewhere unclassified sensitivity to get symptoms from regular environmental factors". However, some of the largest and most influential medical associations, such World Health Organization and American Medical Association, do not recognize them as diseases. This is due to the fact that accurate methods for diagnosis have not yet been developed. This in turn means, that people suffering from these symptoms are in many cases left outside of any social care, even though most of the studies already confirm that SBS and MCS are indeed related to chemical exposure[258]. Even physiological differences have been found from people suffering from MCS compared to healthy individuals[261]. The situation is similar to what it used to be in case of asbestos, where the connection between exposure and symptoms was not taken seriously until scientific research had shown strong evidence. The same was seen just a few decades ago in the case of peptic ulcer.

According to research, up to 15% of work absences are caused by poor indoor air quality[262], and some studies say this number is even greater: by improving the indoor air quality, it might be possible to reduce the risk of sick leave by 35%[263]. It is clear without saying, that the aforementioned symptoms affect how well we can function and how we are feeling. The air we breathe does not only affect us physically, but it is also an important contributor to our mental well-being and performance. Poor indoor air quality can reduce productivity by 6–9% [189,221,264,265,266].

The ultimate cause for sick buildings is still uncertain and likely includes many aspects, multiple still likely to be unknown. What is certain, however, is that the air quality can cause some serious problems that can be hard to treat as the underlying reasons stay unsure. There has been several estimates of the percentage of homes that have mold problems in North America, varying from 27% to as high as 56% [257,267,268,269]. In Europe, the number of damp and moldy buildings have been reported to be between 17 to 46% for Great Britain[17,18,270,271], 15 to 18% for the Netherlands[272,273,274], and 15% for

Finland[275]. According to the questionnaire by Finnish teachers organization OAJ, during a 2 year period 4% of teachers had to be relocated due to health problems caused by poor IAQ[276]. It was reported by school principals and occupational safety and health administrators, that from those who had gotten ill, 5–9% could not return to work even after the premises had been renovated. Nationally this means thousands of teachers who have been disabled by air quality related problems.

It is important to assess the problems leading to sick buildings, and find the solutions to treat the cause and its effects on people. By making buildings healthy we ensure the people indoors stay healthy too.

...to healthy buildings

The problems caused by modern ways of living - isolation from nature and poor IEQ - has been increasingly recognized, and this has led to action on improving our living standards. Green buildings and biophilic design are keywords in future construction. Focus should be concentrated towards the people occupying the buildings alongside the environmentally friendly building standards.

Improves in IEQ has been linked to increases in worker and student performance[263,277], and contribute to absenteeism and work hours related to health issues caused by air quality problems as well as stress[278]. One study concluded, that better IEQ could lead to a 38.98 work hours more per year for each occupant of a green building[279]. Plants also seem to increase creativity[279,280]. Exposing ourselves to indoor nature does not only act as a therapeutic means to prevent health related hindrances, but it enhances our cognitive abilities[146,281,282,283], short-term memory[107], productivity[131,136,137], and creativity[283,284]. For a work environment for example, these factors are considered important. Building a habitat that promotes health and productivity of employees is worthwhile[285,286,287,288]. The physical environment of the workplace affects company's competitiveness as an employer[289]. It has been studied to be an important factor for new employees in their decision to accept a job and staying in even if they received job offers from outside the company. 67% of employees said that better physical environment is a motivating factor for their sales activities, and 62% said it also promotes their creativity. Natural elements have been shown to affect work satisfaction and organizational commitment[289].

"

> As health is not merely the absence of disease or infirmity but a positive state of complete physical, mental and social well-being, a healthy working environment is one in which there is not only an absence of harmful conditions but an abundance of health-promoting ones.
>
> - WHO, 1986

Even though saves can be made in heating and cooling of the buildings, the possible health effects caused as a byproduct cause expenses that can be hard to measure. Salaries are the biggest expenditure for companies, even a 100 times more than the energy, rent, and maintenance of the buildings all together. It has been estimated, that by improving the work environment and indoor air quality, it could be possible to create significant savings directly through cutting down negative health effects[290]. One study estimated, that the direct and indirect health effects caused by poor indoor environment affect worker productivity, causing significant costs[291]. In another study it was found, that better indoor air quality increased productivity by 15%[292]. By investing in better indoor environment, the potential saving through increased productivity were estimated to be around $40 to $250 billion in the U.S. annually, of which $20–$200 billion would be through improved worker performance alone. A study conducted in Harvard University found that better indoor air quality led to a 61–101% higher cognitive scores compared to people who spent their workdays in offices where the VOC scores were higher[293]. It is clear that contact to nature and the quality of the air we breathe affects our mental abilities, but more research would be preferred to further understand the complex mechanisms behind these relationships.

Bringing nature indoors

The current trends in construction are changing: more and more emphasis on the health of people occupying indoor environments is arising, and has led to building standards that recognize this necessity. LEED is a rating system devised by the United States Green Building Council (USGBC) evaluating the environmental performance and economical sustainability of a building[186]. This is great for the environment – but tightly built, mechanically breathing buildings are far from the natural environment we were meant to live in. Delos building company has developed another standard on side of LEED, called WELL-building standard. It aims for biophilic building design, where all the elements consider human health and well-being. More similar standards are found across the world, such as BREEAM.

Naava

Naava is based on multiple innovations and combines interdisciplinary science to improve indoor air quality. Our Naava OS artificial intelligence (AI) measures the fitness and state of the green wall so that it completes existing heating, ventilation, and air conditioning (HVAC) systems and operates optimally in all circumstances. Our NASA inspired research[19] combines this AI with selected plant species and microbial community into a unique smart green wall that facilitates in reducing hazardous VOCs[294] and particles[295] from indoor air. In addition, hydroculture-like cultivation of Naava walls in a specific non-soil based environment facilitates purification and reduces allergens from plants, as damp, organic soil acts as a good growing substrate for e.g. molds. Plants themselves do not contribute to the mold spore counts or composition indoors[296].

Biological air purification

Indoor plants have been shown to reduce many VOC pollutants[297,298,299,300,301,302,303]. By creating conditions for the plants to optimize their air purification capability, Naava biofilters are far superior to potted houseplants. The University of Eastern Finland and University of Jyväskylä have jointly studied the purification efficiency of a single simulated Naava biofilter with air circulation vs. a static potted houseplant. In real indoor conditions, a Naava normally consist of over 60 Naava biofilters. In the chamber tests, which utilized a single simulated active Naava biofilter, chemical concentrations were nearly non-existent after one hour[352]. The chamber with a potted house plant without air circulation still had 80% of the chemicals left after 1 hour. Even after 24 hours the plant hadn't removed all of the chemicals. The key is the active flow of air through the Naava biofilters, making the system far superior to houseplants in regular pots with no air circulation.

In the Finnish VTT conducted experiments, Naava filtered typical indicator VOCs efficiently from the indoor air[294]. The continuous filtering results for excessively polluted VOC concentrations of 100 ppm toluene and 200 ppm methyl-ethyl-ketone (MEK) were 25% and 50%, respectively.

Prior to partnering with Naava, Delos, a wellness real estate and technology firm, wanted to put Naava's pollutant reduction efficiency to test. Collaborating with world renowned test facility BRE and experts from the University of Technology Sydney Plants and Environmental Quality Research Group, Delos developed a rigorous single pass efficiency test protocol. With exceptional results and a class leading test protocol, Delos, BRE and UTS collaboratively sought to publish the results to further the recognition of active green wall systems and the respective health and wellness improvements that may be offered by such systems indoors. The research proves that Naava actively reduces the tested chemical i.e. volatile organic compound (VOC) commonly found in household products[351]. Getting the same results in triplicate, on average 57%, is proof of the system working continuously, not by chance. This result was based on a single pass through Naava, and as air flows over and over through Naava and its biofilters, this result means that Naava is an effective air purifier, reducing harmful pollutants from the air.

Therefore, Naava reduces the overall number of VOCs available and thus simplifies the airborne cocktail of volatiles. It seems that bioavailability of hydrophobic VOCs is smaller, i.e. the microbes cannot work with hydrophobic compounds so well. Many of the biogenic VOCs are hydrophobic[304] thereby indicating that at least part of them belong also to the natural habitat of humans. Major components of the biogenic VOCs are isoprenes and terpenes[305]. Especially terpenes have been shown to reduce stress[306,307,308], but only in natural concentrations[309]. In addition to terpenes, also higher alcohols, such as leaf alcohols produced by trees and grasses, have been suggested to induce attractive human effects[310].

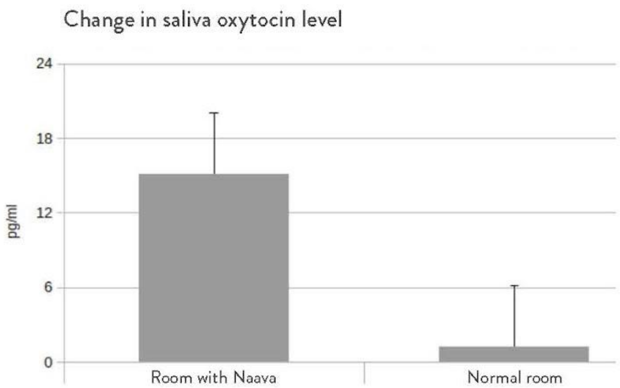
Plant root rhizome, the root microbial community, works in symbiosis with the host plants. Plants donate some of their photosynthesis products to microbes, and microbes in turn provide plants with e.g. minerals, and protect them from pathogens by suppressing them[311] and triggering beneficial responses in plant immune systems[312]. Since microbe metabolism also degrades pollutants into carbon dioxide (CO_2), water (H_2O), biomass and mineral salts[313], they are more efficient in purifying indoor air[314,315]. In a Naava wall, the indoor air is sucked through the growth media of the plants, and thus the indoor air contaminants are forced to pass through a bed of wet, microbially active media. Such biofiltration is a time-proven technology and it is commonly used in industries producing concentrated waste-gas streams, but has not been previously implemented into normal office IAQ with lower concentrations and varying contaminants[316]. Naava walls intensify the biofiltration process and bring it to our everyday environment. Naava walls, as any microbe-based biofiltration system, require two to four weeks after installation before full capacity of the wall is observable. This is due to the adaptation time the growth medium microcosm requires in order to boost the microbial activity[317,318]. This enables the Naava to dynamically adjust itself to better clean pollutants that are in each space, as they differ radically even between rooms, and adapt to changes in the pollution load.

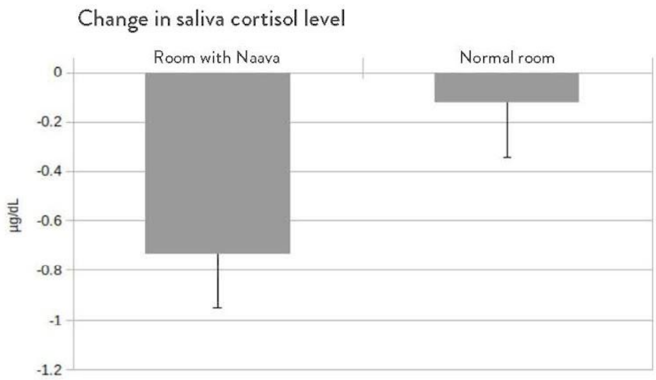
Both the reduction of indoor VOCs and CO_2 have been shown to independently improve cognitive function of indoor workers[293]. CO_2 in itself has also been shown to reduce student performance[319] and workplace productivity[320], and associated with a significant decrease in health and perceived indoor air quality[321]. Traditional potted plant microcosms have been shown to reduce the CO_2 in office air 10% with HVAC and 25% without HVAC[315]. Similar values hold true for Naava walls. Even this level of CO_2 reduction might improve cognitive function to some extent, especially if coinciding with VOC reduction[293]; but the reduction of CO_2 independently is unlikely to have a major effect. Tests in which any significant CO_2 reduction by plants have been detected have involved a high amount of very specific plant species and a very high intensity lighting, making the process impractical for regular indoor spaces[322]. For example, on a study that looked for the highest CO_2 removals by testing different species of plants, lightings, and fan speeds, could only achieve a removal of 5 grams of CO_2 in 40 minutes (that is, 7,5 g/h respectively) at the highest[323]. In comparison, an average human exhales about 35 g of CO_2 in an hour[324]. Recommended lighting for an average office is about 500 luxes – whereas the lighting needed to achieve even this level of CO_2 reduction could be more than 10.000 luxes, equivalent to a cloudy day outside. For this reason, it is controversial for any green wall system to advertise with CO_2 reduction. Although Naava walls have not yet been tested for their capability to influence indoor sulphuric and nitrogen volatiles (SOx and NOx), indoor plants have been shown to reduce SOx[325] and NOx[326,327]. Microbial rhizosphere has been shown to be effective in removal of nitrogen, especially in a low nitrogen environment[328].

NAAVA
breathe

Better focus with Naava smart green wall

Case study shows that a room with Naava makes you happier and less stressed, enabling you to decrease the chance of mistakes by 41% in tasks requiring high cognitive brain performance.

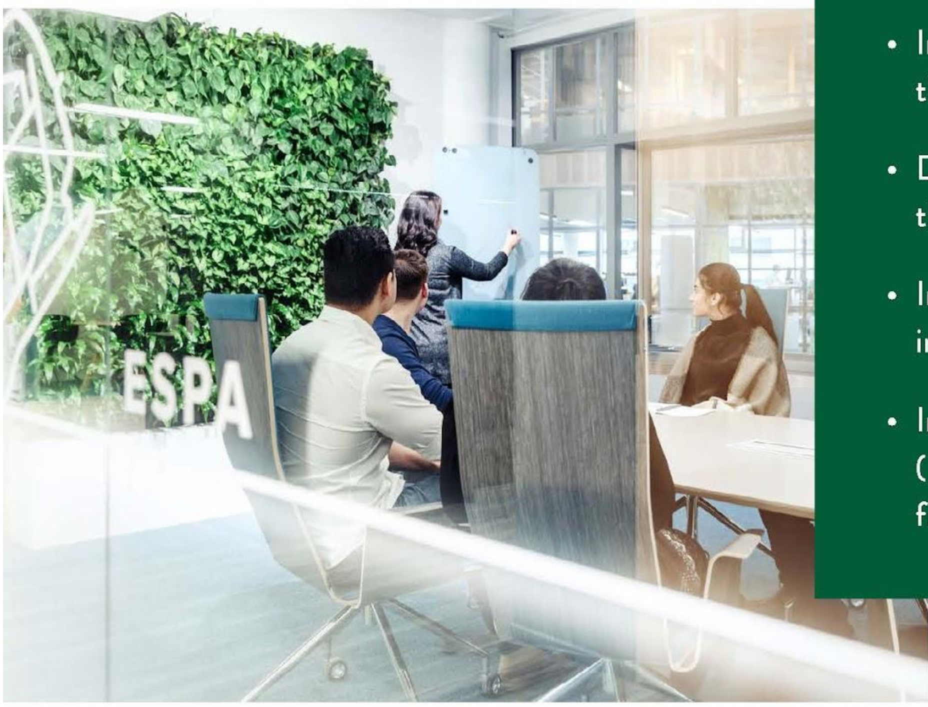




The stress relieving effect of nature has been long known. We studied whether Naava can bring some of that same natural stress relief indoors to create healthier, happier and more inspiring workplaces.

The results:

- Less mistakes in cognitive performance tasks
- Increased levels of oxytocin, the happiness hormone
- Decreased levels of cortisol, the stress hormone
- Increased environmental comfort in Naava room
- Increased heart rate variability (HRV) indicates better recovery from stress



Read the whole case study: Effects of Naava on stress parameters in natural settings **from here**

Biological water purification

Although Naava walls are not meant to be used as biological water cleaning units, they still clean water as well. In fact, this helps Naava walls to recycle its water and maintain it clean and functional between the monthly maintenances. As the water is constantly being biologically cleaned, we do not have to clean the water tanks which decreases maintenance needs, while still being able to circulate water. We systematically test water conductivity, hardness and pH, and modify them to facilitate optimal wall function.

Particle removal

Plants remove particles from the air by mechanical absorption and binding of particles to water, similar to the formation of clouds[329]. Higher humidity therefore facilitates higher binding of particles into the soil or roots of the plant. Up to date Naava green walls have not been optimized for particle removal, but still our experiments show up to 25% removal of PM2.5, the harmful 2.5 µm diameter small particles, in 10 min flow through experiments[295]. Taken together with Lohr and Pearson-Mims (1996[330]) reporting that one week presence of plants covering 2–5% of the room volume reduced the total particulate matter 15–20% respectively, the total Naava green wall efficiency in PM removal is likely to be higher in natural office environment. Although Naava is not a filter comparable to HEPA, it still is, even without optimization, able to reduce particle loads from the indoor air, especially the nearby air.

Humidity management

Naava walls take care of the plants using the Naava OS AI. The AI maintains the air humidity stable and appropriate for plants and humans. The active air circulation system pushes humidified air through the fans back into the indoor air maintaining relative humidity at a pleasant level. Dust and particulate matter condensate on water molecules and precipitate from air to horizontal surfaces where they are easily cleaned away. Sufficient moisture in the air also facilitates volatile compound and particulate matter binding to the plant root rhizosphere in the special growth medium e.g. ionically and mechanically. Often the office HVAC system is set too low in order to save in energy costs. This causes CO_2 and VOC accumulation in the indoor air. In addition, the poor or neglected maintenance of air conditioning system may facilitate impurities to build up in the HVAC system itself[331].

Feeling of dryness of the indoor air has been linked to sick building syndrome[230]. At the same time people in the sick building often suffer from worsening air quality as VOCs and CO2 accumulate in the indoor air. Also dryness itself causes several physiological defects, such as impairment of the mucociliary clearance of the respiratory tract and weakening of the tear film of the eye[332]. Naava green wall system, moisturized under the AI control, maintain the humidity in the air ideal for people while at the same time the plant rhizosphere microbes purify the air in the soil-free special growth medium. The growth medium together with monthly Naava service maintain optimal environment for plant growth and clean air.

Lights and plants

Green plants convert the energy of visible light into chemical energy via photosynthesis, fueling their growth and development. This process combines CO_2 and H_2O to create sugar, and oxygen (O) is also produced as a by-product. Photosynthesis is the driving force for producing and maintaining the oxygen content of the Earth's atmosphere[333], and plants act as one of the main carbon sinks of the Earth, removing it from the atmosphere[334]. The wavelength spectrum that plants are able to use in photosynthesis is called Photosynthetically Active Radiation (PAR), which is in the visible light range of 400-700 nm[335]. Photosynthetic organs in the plants are green pigments, chlorophylls, which best capture light at the blue portion of visible wavelengths, followed by the red portion[336].

Depending on the type of plant and the phase/purpose of its growth (germination, vegetative growth, flowering, fruiting), specific range of spectrum, luminosity and colour temperature should be used. Adjusting the combination of light types can be used to optimize the plant's development accordingly[337]. When considering lighting indoors, it is also important to create a pleasant atmosphere for people to work and live in. Our smart green walls use LED lamps: they provide energy efficient and sufficient lighting for the plants.

Naava green walls use plants that have been carefully selected to complement the function and maintenance of our product. Plant species should not cause allergies, so green plants that do not flower or pollinate are mainly used. However, flowering plants are often preferred due to their aesthetic value, and therefore we aim to also find species that are as visually interesting as they are functional to add to the selection. Plant species have evolved to live in different kind of conditions, and therefore it is important to test how they manage in a green wall. Short-term and long-term testing of the plants has been developed: first testing includes potting potential plants to Naava wall and following their success. The next step is to test them in winter conditions – lower temperature (< 20 °C) and humidity (< 30%) – and finally test them long term in different locations. Currently two species are mainly used in Naavas: the sweetheart plant (Philodendron scandens) and a species of a bird's-nest fern (Asplenium antiquum). It has been suggested that different plant species share the same ability to remove VOCs, as it is the micro-organisms rather than the plant directly, that affect the removal[398,338]; however, there are likely to be differences in the specific air purification effects between different species[339], so a mixture of different kind of plants is recommended for effective biofiltration[300]. There is evidence that the specific species we use are efficient in improving IAQ: Philodendron species has been tested to remove 30–46% of toluene and 31–47% trichloroethylene from testing chamber air[340]; ~80% of benzene; and ~90% of CO_2[338]. It has also been tested to remove octane and terpene[295]. Bird's nest ferns have been tested to increase humidity by ~10% and absorb an average of 1.38 ppm of CO_2 per hour[341]. Bird's nest ferns have been tested to also be effective in removing CO_2 and formaldehyde from the air[342,343].

We aim to increase the species diversity of our walls, but we do not add them in the expense of functionality. The benefits that a more diverse plant community would add are yet unknown, but it could be argued that as different species have different capacities to remove certain VOCs, their function would complement each other. In addition, more diverse species composition adds to the visual value of the Naava green wall.

In conclusion

40–60m^3 of air is drawn through Naava greenwall system each hour. It has been proven to improve IAQ by reducing the number of VOCs and lowering the concentrations of hazardous VOCs, moisturising air and reducing particulate matter. Good IAQ prevents many negative health effects as well as boosts many positive ones. Recognition of the importance of our indoor environment has led Naava to drive towards the same goals as the WELL building standard[344] – by combining research and development, we can design clean and healthy environments that enhance human health and well-being.

Urban environment and its high settlement density offers many benefits from economical to social advantages, but can be psychologically demanding. Contact with nature offers psychological restoration, which increases our cognitive capabilities and inhibits stress. Incorporating nature to our urban landscape and inside our buildings creates urban sustainability[128]. We can fulfill our innate affiliation with nature by combining it to the urban environment – this is what biophilic design strives for[345,346,347]. This does not only improve the well-being of urban dwellers, but nature also adds concrete, economical value of premises[348]. Green walls are a space-efficient means of increasing the density of indoor plants; the more plants, the higher the benefits[349].

By focusing on the people in the buildings and not just the green building standards, it is possible to create both environmentally sustainable and healthy buildings[350]. Our aim is to reach the world's major cities to bring the nature's air into our urban environment.

NAAVA

References

1. United Nations, 2014. *World Urbanization Prospects: The 2014 Revision*. New York: United Nations Secretariat, Population Division.
2. World Health Organization, 2016. *Ambient air pollution: A global assessment of exposure and burden of disease*. Geneva.
3. World Health Organization, 2014. *Burden of disease from Household Air Pollution for 2012*. Geneva: Public Health, Social and Environmental Determinants of Health Department.
4. Klepeis, N. E., 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 pollutants. *J Expo Anal Environ Epidemiol* 11:231–252.
5. Brown, S. K., Sim, M. R., Abramson, M. J. & Gray, C. N., 1994. Concentrations of volatile organic compounds in indoor air–a review. *Indoor air*, 4:123–134.
6. Rehwagen, M., Schlink, U. & Herbarth, O., 2003. Seasonal cycle of VOCs in apartments. *Indoor Air* 13:283–291.
7. Environment Australia, 2003. BTEX *Personal Exposure Monitoring in Four Australian Cities*. Technical Paper No. 6: EA, Canberra, ACT, Australia.
8. Edwards, R. D., Jurvelin, J., Koistinen, K., Saarela, K. & Jantunen, M., 2001. VOC source identification from personal and residential indoor, outdoor and workplace microenvironment samples in EXPOLIS-Helsinki, Finland. *Atmospheric Environment*, 35:4829–4841.
9. Zuskin, E., Schachter, E. N., Mustajbegovic, J., Pucarin-Cvetkovic, J., Doko-Jelinic, J. & Mucic-Pucic, B., 2009. Indoor air pollution and effects on human health. *Period Biol* 111:37–40.
10. Destaillats, H., Maddalena, R. L., Singer, B. C., Hodgson, A. T. and McKone, T. E., 2008. Indoor pollutants emitted by office equipment: A review of reported data and information needs. *Atmospheric Environment*, 42:1371–1388.
11. United States environmental Protection Agency, 1993. Targeting indoor air pollution: EPA's approach and progress. *Air and radiation* 62030J
12. Lomborg, B., 2003. *The skeptical environmentalist: measuring the real state of the world* (Vol. 1). Cambridge: Cambridge University Press.
13. Burge, P. S., 2004. Sick building syndrome. *Occup environ med* 61:185–190.
14. Saijo, Y., Kishi, R., Sata, F. Katakura, Y., Urashima, Y., Hatakeyama, A., Kobayashi, S., Jin, K., Kurahashi, N., Kondo, T., Gong, Y. Y. & Umemura, T., 2004. Symptoms in relation to chemicals and dampness in newly built dwellings. *Int Arch Occup Environ Health* 77:461.
15. Apter, A., Bracker, A., Hodgson, M., Sidman, J. & Leung, W. Y., 1994. Epidemiology of the sick building syndrome. *Journal of Allergy and Clinical Immunology*, 94:277–288.
16. Park, J. H., Schleiff, P. L., Attfield, M. D., Cox-Ganser, J. M. & Kreiss, K., 2004. Building-related respiratory symptoms can be predicted with semi-quantitative indices of exposure to dampness and mold. *Indoor Air* 14:425–433.
17. Platt, S. D., Martin, C. J., Hunt, S. M. & Lewis, C. W., 1989. Damp housing, mold growth, and symptomatic health state. *Br Med J* 298:1673–1678.
18. Martin, C. J., Platt, S. D. &. Hunt, S. M., 1987. Housing conditions and ill health. *Br Med J* 294:1125–1127.
19. Wolverton, B. C., Douglas, W. L. & Bounds, K., 1989. *A study of interior landscape plants for indoor air pollution abatement*. NASA Technical documents.

20. Wolverton, B. C., & McDonald-McCaleb, R. C., 1986. Biotransformation of priority pollutants using biofilms and vascular plants. *J Miss Acad Sci*, 31:79–89.
21. Wilson, E. O., 1992. *The Diversity of Life* (Harvard University Press, Massachusetts).
22. Wilson, E. O., 1993. Biophilia and the conservation ethic in Kellert, S. R. & Wilson, E. O. (eds.), *The Biophilia Hypothesis* (Island Press, Washington DC), pp. 31–41.
23. Newby, J., 1999, The Animal Attraction (Australian Broadcasting Corporation, Sydney).
24. Shepard, P., 1993. On animal friends, in Kellert, S. R. & Wilson, E. O. (eds.), *The Biophilia Hypothesis* (Island Press, Washington DC), pp. 275–300.
25. Wilson, E. O., 1984. *Biophilia*. Harvard University Press. Cambridge, MA, USA.
26. Gullone, E. 2000. The Biophilia hypothesis and life in the 21st century: increasing mental health or increasing pathology? *J Happiness Stud* 1:293–321.
27. Eaton, S. B., Konner, M. & Shostak, M., 1988. Stone agers in the fast lane: Chronic degenerative diseases in evolutionary perspective. *Am. J. Med*, 84:739–749.
28. Buss, D. M., 2004. *Evolutionary Psychology: The New Science of the Mind*. Boston: Pearson Education, Inc.
29. Grinde, B., 2009. Can the concept of discords help us find the causes of mental diseases? *Med. Hypothesis* 73:106–109.
30. Grinde, B., 2003. Happiness in the perspective of evolutionary psychology. *J. Happiness Stud* 3: 331–354.
31. Saunders, P., 1999. 'Capitalism and the environment'. In *Thinking Through the Environment*, M. J. Smith (ed.). Routledge, London, pp. 269–279.
32. Wilson, E. O. & Peter, F. M., 1988. *Biodiversity*. National Academies Press,US.
33. Orians, G. H. & Heerwagen, J. H., 1992. *Evolved responses to landscapes*. Oxford University Press, Oxford.
34. Neale, M. C., Walters, E. E., Eaves, L. J., Maes, H. H. & Kendler, K. S., 1994. Multivariate genetic analysis of twin-family data on fear: Mixed models. *Behavior Genetics* 24:119–139.
35. Phillips, K., Fulker, D. W. & Rose, R. J., 1987. Path analysis of seven fear factors in adult twin and sibling pairs and their parents. *Genetic Epidemiology* 4:345–355.
36. Rose, R. J. & Ditto, W. B., 1983, A developmental-genetic analysis of common fears from early adolescence to early adulthood, *Child Development* 53:361–368.
37. Darwin, C., 1877. A biographical sketch of an infant. *Mind* 2:285–294.
38. Olsson, A. & Phelps, E. A., 2007. Social learning of fear. *Nature Neuroscience* 10:1095–1102.
39. Lane, B. & Gullone, E., 1999. Common fears: A comparison of self-generated and fear survey schedule generated fears of adolescents. *Journal of Genetic Psychology* 160:194–204.
40. Ohman, A., 1986. Face the beast and fear the face: Animal and social fears as prototypes for evolutionary analyses of emotion. *Psychophysiology* 23:123–145.
41. Ulrich, R. S., 1993, Biophilia, biophobia, and natural landscapes, in Kellert, S.R. & Wilson, E. O. (eds.), *The Biophilia Hypothesis* (Island Press, Washington DC), pp. 73–137.
42. Ulrich, R. S. 1986. Human responses to vegetation and landscapes. *Landscape and Urban Planning* 13:29–44.
43. Kaplan, R. & Kaplan, S., 1989. *The Experience of Nature: A Psychological Perspective*. (Cambridge University Press, New York).
44. Bernaldez, F. G., Abello, R. P. & Gallardo, D., 1989. Environmental challenge and environmental preference: Age and sex effects. *Journal of Environmental Management* 28, pp. 53–70.
45. Chokor, B. A. & Mene, S. A., 1992. An assessment of preference for landscapes in the developing world: A case study of Warri, Nigeria, and Environs. *Journal of Environmental Management* 34, pp. 237–256.
46. Shafer, E. L., Hamilton, J. F. & Schmidt, E. A., 1969. Natural landscape preferences: A predictive model. *Journal of Leisure Research* 1, pp. 187–197.

47. Kaplan, S., Kaplan, R. & Wend, J. S., 1972. Rated preference and complexity for natural and urban visual material. *Perception and Psychophysics* 12, pp. 354–356.
48. Van den Berg, A. E., Koole, S. L. & van der Wulp, N. Y., 2003. Environmental preference and restoration:(How) are they related? *Journal of environmental psychology*, 23:135–146.
49. Kim, T. H., Jeong, G. W., Baek, H. S., Kim, G. W., Sundaram, T. & Kang, H. K., 2010. Human brain activation in response to visual stimulation with rural and urban scenery pictures: A functional magnetic resonance imaging study. *Sci Total Environ* 408:2600–2607.
50. Grinde, B. & Patil, G. G., 2009. Biophilia: does visual contact with nature impact on health and well-being? *Int J Environ Res Publ Health* 6:2332–2343.
51. Cannon, W., 1932. *Wisdom of the Body*. United States: W.W. Norton & Company.
52. McCorry, L. K., 2007. Physiology of the autonomic nervous system. *American journal of pharmaceutical education* 71:78.
53. Sterling, P., Eyer, J., 1988. Allostasis: A new paradigm to explain arousal pathology. In Fisher, S. & Reason, J. T. *Handbook of life stress, cognition, and health*. Chicester, NY: Wiley
54. Copstead, L-E. & Banasik, J., 2013. *Pathophysiology* (5th ed.). St Louis, Missouri: Elsevier Saunders
55. McEwen, B. S., 2004. Protection and damage from acute and chronic stress: allostasis and allostatic overload and relevance to the pathophysiology of psychiatric disorders. *Annals of the New York Academy of Sciences*, 1032:1–7.
56. McEwen, B. S; Stellar, E., 1993. Stress and the individual. Mechanisms leading to disease. *Archives of Internal Medicine*. 153:2093–101.
57. Ogden, J., 2004. *Health Psychology: A textbook*, 3rd edition. Open University Press - McGraw-Hill Education
58. Vrijkotte, T. G., Van Doornen, L. J. & De Geus, E. J., 2000. Effects of work stress on ambulatory blood pressure, heart rate, and heart rate variability. *Hypertension*, 35:880–886.
59. Matthews, K. A., Katholi, C. R., McCreath, H., Whooley, M. A., Williams, D. R., Zhu, S. & Markovitz, J. H., 2004. Blood pressure reactivity to psychological stress predicts hypertension in the CARDIA study. *Circulation*, 110:74–78.
60. Suadicani P, Hein H. O. & Gyntelberg F., 1993. Are social inequalities as associated with the risk of ischaemic heart disease a result of psychosocial working conditions? *Atherosclerosis* 101:165–175.
61. Kivimäki, M., Leino-Arjas, P., Luukkonen, R., Riihimäki, H., Vahtera, J. & Kirjonen, J., 2002. Work stress and risk of cardiovascular mortality: prospective cohort study of industrial employees. *Bmj*, 325:857.
62. Kivimäki, M., Virtanen, M., Elovainio, M., Kouvonen, A., Väänänen, A. & Vahtera, J., 2006. Work stress in the etiology of coronary heart disease—a meta-analysis. *Scandinavian journal of work, environment & health*, pp.431–442.
63. Agardh, E. E., Ahlbom, A., Andersson, T., Efendic, S., Grill, V., Hallqvist, J., Norman, A. & Östenson, C. G., 2003. Work stress and low sense of coherence is associated with type 2 diabetes in middle-aged Swedish women. *Diabetes care*, 26:719–724.
64. Pickering, A. D., Pottinger, T. G., Sumpter, J. P., Carragher, J. F. & Le Bail, P. Y., 1991. Effects of acute and chronic stress on the levels of circulating growth hormone in the rainbow trout, Oncorhynchus mykiss. *General and Comparative Endocrinology*, 83:86–93.
65. Segerstrom, S. C. & Miller, G. E., 2004. Psychological stress and the human immune system: a meta-analytic study of 30 years of inquiry. *Psychological bulletin*, 130:601.
66. Chandola, T., Brunner, E. & Marmot, M., 2006. Chronic stress at work and the metabolic syndrome: prospective study. *Bmj*, 332:521–525.
67. Tennant, C., 2001. Work-related stress and depressive disorders. *Journal of psychosomatic research*, 51:697–704.

68. Melchior, M., Caspi, A., Milne, B. J., Danese, A., Poulton, R. & Moffitt, T. E., 2007. Work stress precipitates depression and anxiety in young, working women and men. *Psychological medicine*, 37:1119–1129.
69. Blackmore, E. R., Stansfeld, S. A., Weller, I., Munce, S., Zagorski, B. M. & Stewart, D. E., 2007. Major depressive episodes and work stress: results from a national population survey. *American Journal of Public Healt*h, 97:2088–2093.
70. Mausner-Dorsch, H. & Eaton, W. W., 2000. Psychological work environment and depression: epidemiologic assessment of the demand-control model. *Am J Public Health* 9:1765–70.
71. Melchior, M., Krieger, N., Kawachi, I., Berkman, L. F., Niedhammer, I. & Goldberg, M., 2005. Work factors and occupational class disparities in sickness absence: findings from the GAZEL cohort study. *Am J Public Health*.95:1206–12.
72. Horan, A. P., 2002. An effective workplace stress management intervention: Chicken Soup for the Soul at Work Employee Groups. *Work* 18:3–13.
73. Ganster, D. C. & Schaubroeck, J., 1991. Work stress and employee health. *Journal of management*, 17:235–271.
74. Ganster, D. C. & Rosen, C. C., 2013. Work stress and employee health A multidisciplinary review. *Journal of Managemen*t, p.0149206313475815.
75. Lloyd, C., King, R. & Chenoweth, L., 2002. Social work, stress and burnout: A review. Journal of mental health, 11:255–265.
76. Michie, S., 2002. Causes and management of stress at work. *Occupational and environmental medicine*, 59:67–72.
77. Gershon, R. R., Lin, S. & Li, X., 2002. Work stress in aging police officers. *Journal of Occupational and Environmental Medicine*, 44:160–167.
78. Ulrich, R. S., 1983. Aesthetic and affective response to natural environment. In Altman, I. & Wohlwill, J. (Eds.), *Human Behavior and Environment,* V01.6: Behavior and Natural Environmen., New York: Plenum, 85–125.
79. Herzog, T. R., Black, A. M., Fountaine, K. A., & Knotts, D., 1997. Reflection and attentional recovery as distinct benefits of restorative environments. *Journal of Environmental Psychology*, 17:165–170.
80. Staats, H., Kieviet, A., & Hartig, T., 2003. Where to recover from attentional fatigue: An expectancy-value analysis of environmental preference. *Journal of Environmental Psychology*, 23:147–157.
81. Stigsdotter, U. K., Ekholm, O., Schipperijn, J., Toftager, M., Kamper-Jørgensen, F. & Randrup, T. B., 2010. Health promoting outdoor environments-Associations between green space, and health, health-related quality of life and stress based on a Danish national representative survey. *Scandinavian Journal of Social Medicine*, 38:411–417.
82. Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M., 1991. Stress recovery during exposure to natural and urban environments. *J Environ Psychol* 11:201–230.
83. Kaplan, S., 1995. The Restorative Benefits of Nature: Toward an Integrative Framework. *J Environ Psychol* 15:169–182.
84. Berman, M. G., Jonides, J. & Kaplan, S., 2008. The Cognitive Benefits of Interacting With Nature. *Psychol Sci* 19:1207–1212.
85. Raanaas, R. K., Evensen, K. H., Rich, D., Sjøstrøm, G. & Patil, G., 2011. Benefits of indoor plants on attention capacity in an office setting. *J Environ Psychol* 31:99–105.
86. Kaplan, S., 2001. Meditation, restoration, and the management of mental fatigue. *Environment and Behavior*, 33, 480–506.
87. Kaplan, S. & Berman, M. G., 2010. Directed attention as a common resource for executive functioning and self-regulation. *Perspectives on Psychological Science,* 5:43–57.
88. James, W., 1892. Psychology: The briefer course. New York: Holt., Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I., 2002. Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience*, 14:340–347.

89. Fan, J., McCandliss, B. D., Fossella, J., Flombaum, J. I., & Posner, M. I. 2005. The activation of attentional networks. *NeuroImage*, 26:471–479.
90. Jonides, J., 1981. Voluntary vs. automatic control over the mind's eye's movement. In Long, J. B. & Baddeley, A. D. (Eds.), *Attention and performance* IX, pp. 187–203.
91. Hillsdale, N., Erlbaum, J., Buschman, T. J. & Miller, E. K., 2007. Top-down versus bottom-up control of attention in the prefrontal and posterior parietal cortices. *Science*, 315:1860–1862.
92. Corbetta, M. & Shulman, G. L., 2002. Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience*, 3:201–215.
93. Herzog, T. R., 1985. A cognitive analysis of preference for waterscapes. *Journal of Environmental Psychology*, 5:225–241.
94. Purcell, A. T., Peron, E., & Berto, R., 2001. Why do preferences differ between scene types? *Environment and Behavior*, 33:93–106.
95. Tennessen, C. H. & Cimprich, B., 1995. Views to nature: Effects on attention. *Journal of Environmental Psychology*, 15:77–85.
96. Ulrich, R. S., 1984. View through a window may influence recovery from surgery. *Science*, 224:420–421.
97. Berto, R., 2005. Exposure to restorative environments helps restore attentional capacity. *Journal of environmental psychology*, 25:249–259.
98. Hartig, T., Evans, G. W., Jamner, L. D., Davis, D. S. & Gärling, T., 2003. Tracking restoration in natural and urban field settings. *Journal of environmental psychology*, 23:109-123.
99. Felsten, G., 2009. Where to take a study break on the college campus: An attention restoration theory perspective. *Journal of Environmental Psychology*, 29:160–167.
100. Bodin, M. & Hartig, T., 2003. Does the outdoor environment matter for psychological restoration gained through running? P*sychology of Sport and Exercise* 4:141–53.
101. Laumann, K., Gärling, T. & Stormark, K. M., 2003. Selective attention and heart rate responses to natural and urban environments. *Journal of Environmental Psychology* 23:125–34.
102. Ottosson, J., & Grahn, P., 2005. A comparison of leisure time spent in a garden with leisure time spent indoors: On measures of restoration in residents in geriatric care. *Landscape Research* 30:23–55.
103. Mayer, F. S., Frantz, C. M., Bruehlman-Senecal, E. & Dolliver, K., 2008. Why is nature beneficial? The role of connectedness to nature. *Environment and Behavior* 41:607–643.
104. Tennessen, C. M., & Cimprich, B., 1995. Views to nature: Effects on attention. *Journal of Environmental Psychology* 15:77–85.
105. Kuo, F. E., 2001. Coping with poverty: Impacts of environment and attention in the inner city. *Environment and Behavior* 33:5–34.
106. Posner, M. I. & Rothbart, M. K. 2007. Research on attention networks as a model for the integration of psychological science. *Annu Rev Psychol* 58:1–23.
107. Jonides, J., Lewis, R. L., Nee, D. E., Lustig, C. A., Berman, M. G. & Moore, K. S., 2008. The Mind and Brain of Short-Term Memory. *Annu Rev Psychol* 59:193–224.
108. van den Berg, A. E., & van den Berg, C. G., 2011. A comparison of children with ADHD in a natural and built setting. *Child: Care, Health Developments* 37:430–39.
109. Taylor, A. F., & Kuo, F. E., 2009. Children with attention deficits concentrate better after walk in the park. *Journal of Attention Disorders* 12:402–09.
110. Taylor, A. F., Kuo, F. E. & Sullivan, W. C., 2002. Views of nature and self-discipline: Evidence from inner city children. *Journal of Environmental Psychology* 22:49–63.
111. Stark, M. A., 2003. Restoring attention in pregnancy: the natural environment. *Clinical Nursing Research*, 12:246–265.
112. Cimprich, B., & Ronis, D. L., 2003. An environmental intervention to restore attention in women with newly diagnosed breast cancer. *Cancer Nursing* 26:284–92.

113. Pretty, J., 2004. How nature contributes to mental and physical health. *Spirituality and Health International* 5:68–78.
114. Largo-Wight, E., Chen, W., Dodd, V. & Weiler, R., 2011. Healthy Workplaces: The Effects of Nature Contact at Work on Employee Stress and Health. *Public Health Rep* 126:124–13.
115. Brown, D. K., Barton, J. L. & Gladwell, V. F., 2013. Viewing natural scenes positively affects recovery of autonomic function following acute-mental stress. *Environ Sci Technol* 27:14–21.
116. Alvarsson, J. J., Wiens, S. & Nilsson, M. E., 2010. Stress recovery during exposure to nature sound and environmental noise. *J Environ Res Public Health* 7:1036–1046.
117. Kahn, P. H., Friedman, B., Gill, B., Hagman, J., Severson, R. L., Freier, N. G., Feldman, E. N., Carrère, S. & Stolyar, A., 2008. A plasma display window? The shifting baseline problem in a technologically mediated natural world. *J Environ Psychol* 28:192–199.
118. Ratcliffe, E., Gatersleben, B. & Sowden, P. T., 2013. Bird sounds and their contributions to perceived attention restoration and stress recovery. *Journal of Environmental Psychology*, 36:221–228.
119. Hartig, T., A. Book, J. Garvill, T. Olsson, & T. Garling. 1996. Environmental influences on psychological restoration. *Scandinavian Journal of Psychology* 37:378–93.
120. Heerwagen, J. & Hase, B., 2001. Building biophilia: Connecting people to nature in building design. *Environmental Design and Construction* 3:30–36.
121. Heerwagen, J. H., 2006. *Investing in people: The social benefits of sustainable design. Rethinking Sustainable Construction*. Sarasota, FL.
122. Heerwagen, J., 2009. *Biophilia, Health, and Well-being. Restorative Commons: Creating Health and Well-being through Urban Landscapes* pp. 39–57.
123. Velarde, M. D., Fry, G. & Tveit, M., 2007. Health effects of viewing landscapes - landscape types in environmental psychology. *Urban For Urban Green* 6:199–212.
124. Howell, Al. J., Dopko, R. L., Passmore, H. A. & Bruno, K., 2011. Nature connectedness: Associations with well-being and mindfullness. *Pers Individ Pref* 51:166–171.
125. Bowler, D. E., Buyung-Ali, L. M., Knight, T. M. & Pullin, A. S., 2010. A systematic review of evidence for the added benefits to health of exposure to natural environments. BMC Public Health 10.
126. Van den Berg, A. E., Hartig, T. & Staats, H., 2009. Preference for nature in urbanized societies: stress, restoration, and the pursuit of sustainability. *J Soc Issues* 63:79–96.
127. Sawada, A. & Oyabu, T., 2010. Healing effects of foliage plants using physiological and psychological characteristics. *Sensor Mater* 22:387–396.
128. Park, S-H. & Mattson, R. H., 2009. Ornamental Indoor Plants in Hospital Rooms Enhanced Health Outcomes of Patients Recovering from Surgery. *J Altern Complement Med* 15:975–980.
129. Park, S-H., 2006. *Randomized clinical trials evaluating therapeutic influences of ornamental indoor plants in hospital rooms on health outcomes of patients recovering from surgery*. Dissertation, Kansas State University, Manhattan, Kansas.
130. Smith, A. & Pitt, M. 2009. Sustainable workplaces: improving staff health and well-being using plants. *Journal of Corporate Real Estate* 11:52–63.
131. Lohr, V. I., Pearson-Mims, C. H. & Goodwin, G. K., 1996. Interior plants may improve worker productivity and reduce stress in a windowless environment. *Environ Hor* 14:97–100.
132. Fjeld, T., 2000. The Effect of Interior Planting on Health and Discomfort among Workers and School Children. *HortTechnology* 10:46–52.
133. Fjeld, T., Veiersted, B., Sandvik, L., Riise G. & Levy, F. 1998. The Effect of Indoor Foliage Plants on Health and Discomfort Symptoms among Office Workers. *Indoor Built Environ* 7:204–209.
134. Lohr, V. I. & Pearson-Mims, C. H., 2000. Physical Discomfort May Be Reduced in the Presence of Interior Plants. *HortTechnology* 10:53–58.
135. Han, K-T., 2009. Influence of Limitedly Visible Leafy Indoor Plants on the Psychology, Behavior, and Health of Students at a Junior High School in Taiwan. *Environ Behav* 41:658–692.

136. Bringslimark, T., Patil, G. G. & Hartig, T., 2006. *The association between indoor plants, stress, productivity and sick leave in office workers.* In XXVII International Horticultural Congress-IHC2006: International Symposium on Horticultural Practices and Therapy for Human 775:117–121.
137. Bringslimark, T., Hartig, T. & Patil, G. G., 2007. Psychological Benefits of Indoor Plants in Workplaces: Putting Experimental Results into Context. *HortScience* 42:581–587.
138. Chang, C-Y. & Chen, P-K., 2005. Human Response to Window Views and Indoor Plants in the Workplace. *HortScience* 40:1354–1359.
139. Rappe, E. & Lindén, L., 2004. Plants in healthcare environments: experiences of the nursing personnel in homes for people with dementia. *Acta Hortic* 639:75–81.
140. Asaumi, H., Nishina, H., Namba, R., Masui, Y. & Hashimoto, Y., 1995. Evaluation of Impression of Ornamental Foliage Plants and Psychological Rating of Rooms with Ornamental Foliage Plants by Means of Semantic Differential Method. *Shokubutsu Kojo Gakkaishi* 7:34–45.
141. Zelenski, J. M. & Nisbet, E. K., 2014. Happiness and feeling connected the distinct role of nature relatedness. *Environ Behav* 46:3–23.
142. Capaldi, C. A., Dopko, R. L. & Zelenski, J. M., 2014. The relationship between nature connectedness and happiness: a meta-analysis. *Frontiers in Psychology*, 5:976.
143. MacKerron, G. & Mourato, S., 2013. Happiness is greater in natural environments. *Global Environ Chang* 23:992–1000.
144. Zhang, W., Goodale, E. & Chen, J., 2014. How contact with nature affects children's biophilia, biophobia and conservation attitude in China. *Biol Conserv* 177:109–116.
145. Nisbet, E. K., Zelenski, J. M. & Murphy, S. A., 2009. The nature relatedness scale: Linking individuals' connection with nature to environmental concern and behavior. *Environment and Behavior,* 41:715–740.
146. Nisbet, E. K., Zelenski, J. M. & Murphy, S. A., 2011. Happiness is in our nature: Exploring nature relatedness as a contributor to subjective well-being. *Journal of Happiness Studies*, 12:303–322.
147. Mayer, F. S. & Frantz, C. M., 2004. The connectedness to nature scale: A measure of individuals' feeling in community with nature. *Journal of environmental psychology*, 24:503–515.
148. von Hertzen, L., Hanski, I. & Haahtela, T., 2011. Natural immunity. Biodiversity Loss and Inflammatory Diseases are two Global Megatrends that might be Related. *Eur Mol Biol Organ J* 12:1085–1204.
149. Hanski, I., von Hertzen, L., Fyhrquist, N., Koskinen, K., Torppa, K., Laatikainen, T., Karisola, P., Auvinen, P., Paulin, K., Mäkelä, M. J., Vartiainen, E., Kosunen, T. U., Alenius, H. & Haahtela, T., 2012. Environmental Biodiversity, Human Microbiota, and Allergy are Interrelated. *P Natl Acad Sci USA* 109:8334–8339.
150. Bilbo, S. D., Wray, G. A., Perkins, S. E. & Parker, W., 2011. Reconstitution of the human biome as the most reasonable solution for epidemics of allergic and autoimmune diseases. *Medical hypotheses,* 77:494–504.
151. Sironi, M. & Clerici, M., 2010. The hygiene hypothesis: an evolutionary perspective. *Microbes and infection*. 12:421–427.
152. Strachan, D. P., 1989. Hay fever, hygiene, and household size. *BMJ* 299:1259.
153. Strachan, D. P., 2000. Family size, infection and atopy: the first decade of the 'hygiene hypothesis'. *Thorax,* 55(Suppl 1), p.S2.
154. Rook, G. A., Martinelli, R. & Brunet, L. R., 2003. Innate immune responses to mycobacteria and the downregulation of atopic responses. Current opinion in allergy and clinical immunology, 3:337–342.
155. Rook, G. A., 2009. Review Series on Helminths, Immune Modulation and the Hygiene Hypothesis: the Broader Implications of the Hygiene Hypothesis. *Immunology* 126:3–11.
156. Matricardi, P. M., Franzinelli, F., Franco, A., Caprio, G., Murru, F., Cioffi, D., Ferrignoc, L., Palermoa, A., Ciccarelli, N. & Rosmini, F., 1998. Sibship size, birth order, and atopy in 11,371 Italian young men. *Journal of Allergy and Clinical Immunology*, 101:439–444.

157. Yemaneberhan, H., Bekele, Z., Venn, A., Lewis, S., Parry, E. & Britton, J., 1997. Prevalence of wheeze and asthma and relation to atopy in urban and rural Ethiopia. *The lancet*, 350:85-90.
158. Von Ehrenstein, O. S., Von Mutius, E., Illi, S., Baumann, L., Bohm, O. & Von Kries, R., 2000. Reduced risk of hay fever and asthma among children of farmers. *Clinical and experimental allergy*, 30:187–193.
159. Rook, G. A. W., Lowry, C. A., Raison, C. L., 2013. Microbial 'Old Friends', immunoregulation and stress resilience. *Evolution, Medicine, and Public Health*. 2013:46–64.
160. Okada, H., Kuhn, C., Feillet, H., Bach, J-F., 2010. The 'hygiene hypothesis' for autoimmune and allergic diseases: An update. *Clinical & Experimental Immunology*. 160:1–9.
161. Gibson, P. G., Henry, R. L., Shah, S., Powell, H. & Wang, H., 2003. Migration to a western country increases asthma symptoms but not eosinophilic airway inflammation. *Pediatric pulmonology*, 36:209–215.
162. Korpelainen, V., Laatikainen, T., McAlister, A. & Puska, P., 2014. *Pitkäranta project: Health collaboration across the Karelian border*. Juvenes Print, Tampere. pp. 78–82.
163. Marquez, P. V., 2006. *Dying too young: addressing premature mortality and ill health due to non-communicable diseases and injuries in the Russian Federation*. Main report 2006, Vol. 2. Washington, DC: World Bank.
164. Vartiainen, E., Petäys, T., Haahtela, T., Jousilahti, P., & Pekkanen, J., 2002. Allergic diseases, skin prick test responses, and IgE levels in North Karelia, Finland, and the Republic of Karelia, Russia. *J Allergy Clin Immun* 109:643–8.
165. von Hertzen, L., Mäkelä, M. J., Petäys, T., Jousilahti, P., Kosunen, T. U., Laatikainen, T., Vartiainen, E. & Haahtela, T., 2006. Growing Disparities in Atopy between the Finns and the Russians: A comparison of 2 generations. *J Allergy Clin Immun* 117:151–7.
166. Zhang, G., Khoo, S. K., Laatikainen, T., Pekkarinen, P., Vartiainen, E., von Hertzen, L., Hayden, C. M., Goldblatt, J., Mäkelä, M., Haahtela, T. & Le Souëf, P. N., 2009. Opposite Gene by Environment Interactions in Karelia for CD14 and CC16 single Nucleotide Polymorphisms and Allergy. *Allergy* 64:1333–41.
167. Zhang, G., Candelaria, P., Mäkelä, J. M., Khoo, S. K., Hayden, M. C., von Hertzen, L., Laatikainen, T., Vartiainen, E., Goldblatt, J., Haahtela, T. & LeSouëf, N. P. 2011. Disparity of innate immunity-related gene effects on asthma and allergy on Karelia. *Pediatr Allergy Immunol Pulmonol* 22:621–30.
168. Pakarinen, J., Hyvärinen, A., Salkinoja-Salonen, M., Laitinen, S., Nevalainen, A., Mäkelä, M. J., Haahtela, T. & von Hertzen, L., 2008. Predominance of Gram-positive bacteria in house dust in the low-allergy risk Russian Karelia. *Environ microbiol* 12:3317–3325.
169. von Hertzen, L., Laatikainen, T., Pitkänen, T., Vlasoff, T., Mäkelä, M. J., Vartiainen, E. & Haahtela, T., 2007. Microbial content of drinking water in Finnish and Russian Karelia – implications for atopy prevalence. *Allergy* 62:288–292.
170. Ege, M. J., Mayer, M., Normand, A. C., Genuneit, J., Cookson, W. O., Braun-Fahrländer, C., Heederik, D., Piarroux, R. & von Mutius, E., 2011. Exposure to environmental microorganisms and childhood asthma. *N Engl J Med* 364:701–9.
171. Cookson, W. O. & Moffatt, M. F., 1997. Asthma: an epidemic in the absence of infection? *Science* 275:41–42.
172. Hilty, M., Burke, C., Pedro, H., Cardenas, P., Bush, A., Bossley, C.,Bossley, C., Davies, J., Ervine, A., Poulter, L., Pachter, L. & Moffatt, M. F., 2010. Disordered microbial communities in asthmatic airways. *PloS one*, 5(1), e8578.
173. Pala, G., Pignatti, P., Perfetti, L., Avanzini, M. A., Calcagno, G., Preziosi, D. & Moscato, G., 2010. Risk of atopy associated with microbial components in house dust. *Ann Allerg Asthma Im* 104:269–270.
174. Turnbaugh, P. J., Hamady, M., Yatsunenko, T., Cantarel, B. L., Duncan, A., Ley, R. E., Sogin, M. L., Jones, W. J., Roe, B. A., Affourtit, J. P. & Egholm, M., 2009. A core gut microbiome in obese and lean twins. *Nature* 457:480–484.

175. Wen, L., Ley, R. E., Volchkov, P. Y., Stranges, P. B., Avanesyan, L., Stonebraker, A. C., Hu, C., Wong, F. S., Szot, G. L., Bluestone, J. A. & Gordon, J. I., 2008. Innate immunity and intestinal microbiota in the development of Type 1 diabetes. *Nature*, 455:1109–1113.
176. Sjögren, Y. M., Jenmalm, M. C., Böttcher, M. F., Björkstén, B. & Sverremark‐Ekström, E., 2009. Altered early infant gut microbiota in children developing allergy up to 5 years of age. *Clinical & Experimental Allergy* 39:518–526.
177. Forsythe, P. & Bienenstock, J., 2010. Immunomodulation by commensal and probiotic bacteria. *Immunological investigations* 39:429–448.
178. Matsuoka, R. H. & Kaplan, R., 2008. People needs in the urban landscape: Analysis of Landscape And Urban Planning contributions. *Landscape Urban plan* 84:7–19.
179. Berg, G., Mahnert, A. & Moissl-Eichinger, C., 2014. Beneficial effects of plant-associated microbes on indoor microbiomes and human health? *Front microbiol* 5:15.
180. Haahtela, T., Laatikainen, T., Alenius, H., Auvinen, P., Fyhrquist, N., Hanski, I., von Hertzen, L., Jousilahti, P., Kosunen, T. U., Markelova, O., Mäkelä, M. J., Pantelejev, V., Uhanov, M., Zilber, E. & Vartiainen, E., 2015. Hunt for the origin of allergy – comparing the Finnish and Russian Karelia. *Clin Exp Allergy* 45:891–901.
181. Spengler, J. D. & Sexton, K., 1983. Indoor air pollution: a public health perspective. *Science*, 221:9–17.
182. Weschler, C. J., 2009. Changes in indoor pollutants since the 1950s. *Atmospheric Environment*, 43:153–169.
183. Mendell, M. J., Fisk, W. J., Kreiss, K., Levin, H., Alexander, D., Cain, W.S., Girman, J. R., Hines, C. J., Jensen, P. A., Milton, D. K. & Rexroat, L. P., 2002. Improving the health of workers in indoor environments: priority research needs for a national occupational research agenda. *American journal of public health*, 92:1430–1440.
184. Spengler, J. D., Samet, J. M. & McCarthy, J. F. 2001. *Indoor air quality handbook* pp. 9-1. New York: McGraw-Hill.
185. WHO, 1986. Indoor air quality research. *EURO Rep Stud* 103:1–64.
186. Webster, M. D., 2010. LEED Rating System. In Sustainability Guidelines for the Structural Engineer, pp. 29–39.
187. Wolkoff, P., 2003. Trends in Europe to reduce the indoor air pollution of VOCs. *Indoor Air* 13:5–11.
188. US EPA, 1989. Report to Congress on Indoor Air Quality, Vol II: Assessment and Control of Indoor Air: Effects of Individual Pollutants, Volatile Organic Compounds, pp. 3–6.
189. Bakó‐Biró, Z., Wargocki, P., Weschler, C. J. & Fanger, P. O., 2004. Effects of pollution from personal computers on perceived air quality, SBS symptoms and productivity in offices. *Indoor air* 14:178–187.
190. Sullivan, Jr., Van Ert, J. B., Krieger, G. R. & Brooks, B. O., 2001. *Indoor environmental quality and health*. In (2nd Ed) Sullivan Jr., J. B. & Krieger, G. R. (eds), Clinical Environmental Health and Toxic Exposures. Lippincott Williams & Wilkins, a Walter Kluwer Co., Philadelphia, PA, USA, pp.669–704.
191. Loveday, J., Cook, A. & Franklin, P., 2010. Exposure of Seniors with Respiratory Disease to Unflued Gas Heaters and Their Emissions. *AQCC* 44:19–23.
192. Työterveyslaitos, 2012. Haihtuvien orgaanisten yhdisteiden kokonaispitoisuuden tavoitetasot teollisten työympäristöjen yleisilmassa. Työterveyslaitos, Helsinki.
193. Valtanen, A., Hovi, H. & Tuomi, T., 2016 Työpaikkojen sisäilman VOC-viitearvot. Työterveyslaitos.
194. Godish, T., 2001. *Indoor Environmental Quality*. Lewis Publishers, CRC Press, Boca Raton, FL, USA, p. 106.
195. Nielsen, G. D. & Wolkoff, P., 2010. Cancer effects of formaldehyde: a proposal for an indoor air guideline value. *Arch Toxicol* 84:423–446.
196. Smith, K., 1987. *Biofuels, air pollution, and health: a global review*. New York: Plenum.
197. Weaver, V. M., Buckley, T. J. & Groopman, J. D., 1998. Approaches to environmental exposure assessment in children. *Environ Health Perspect* 106:827–32.

198. Viegi, G., Simoni, M., Scognamiglio, A., Baldacci, S., Pistelli, F., Carrozzi, L., & Annesi-Maesano, I., 2004. Indoor air pollution and airway disease [State of the Art]. *Int J Tuberc Lung Dis* 8:1401–1415.

199. Zhang, L., Steinmaus, C., Eastmond, D. A., Xin, X. K. & Smith, M. T., 2009. Formaldehyde exposure and leukemia: a new meta-analysis and potential mechanisms. *Mutat Res* 681:150–168.

200. Cakmak, S., Dales, R. E., Liu, L., Kauri, L. M., Lemieux, C. L., Hebbern, C. & Zhu, J., 2014. Residential exposure to volatile organic compounds and lung function: results from a population-based cross-sectional survey. *Environmental Pollution*, 194:145–151.

201. Win-Shwe, T. T., Fujimaki, H., Arashidani, K. & Kunugita, N., 2013. Indoor Volatile Organic Compounds and chemical sensitivity reactions. *Clinical and Developmental Immunology,* 2013.

202. Carpenter, D., 1998. Human health effects of environmental pollutants: New insights. *Environ Monit Assess* 53:245–258.

203. Brasche, S., Bullinger, M., Gebhardt, H., Herzog, V., Hornung, P., Kruppa, B., Meyer, E., Morfield, M., Schwab, R. V., Mackensen, S., Winkens, A. & Bischof, W., 1999. Factors determining different symptom patterns of sick building syndrome - results from a multivariate analysis. In *Proceedings of Indoor Air '99*. The 8th International Conference on Indoor Air Quality and Climate, UK, 5:402–407.

204. Carrer, P., D. Alcini, D. Cavallo, F. Visigalli, D. Bollini & M. Maroni., 1999. Home and workplace complaints and symptoms in office workers and correlation with indoor air pollution. In *Proceedings of Indoor Air '99*. The 8th International Conference on Indoor Air Quality and Climate, UK, 1:129–134.

205. Kjærgaard, S. K., Mølhave, L. & Pedersen, O. F., 1991. Human reactions to a mixture of indoor air volatile organic compounds. Atmos Environ A-Gen 25:1417–1426.

206. Prah, J. D., Case, M. W. & Goldstein, G. M., 1998. Equivalence of sensory responses to single and mixed volatile organic compounds at equimolar concentratations. *Environ Health Perspect* 106:1–8.

207. Carslaw, N., 2013. A mechanistic study of limonene oxidation products and pathways following cleaning activities. *Atmos Environ* 80:507–513.

208. Wu, R., Pan, S., Li, Y. & Wang, L., 2015. Atmospheric Oxidation Mechanism of Toluene. *J Phys Chem* 118:4533–4547.

209. Fadey, M. O., Tham, K. W. & Wu, W. Y., 2015. Impact of asthma, exposure period, and filters on human responses, during exposures to ozone and its initiated chemistry products. *Indoor Air* 25:512–522.

210. Youssefi, S. & Waring, M. S., 2014. Transient secondary organic aerosol formation from limonene ozonolysis in indoor environments: Impacts of air exchange rates and initial concentration ratios. *Environ Sci Technol* 48:7899–7908.

211. Turner, M. C., Krewski, D., Pope III, C. A., Chen, Y., Gapstur, S. M. & Thun, M. J., 2011. Long-term ambient fine particulate matter air pollution and lung cancer in a large cohort of never-smokers. *Am J Resp Crit Care* 184:1374–1381.

212. Schwartz, J., 1995. Short term fluctuations in air pollution and hospital admissions of the elderly for respiratory disease. *Thorax* 50:531–538.

213. Dockery, D. W., Pope, C. A., Xu, X., Spengler, 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 US cities. *N Engl J Med* 329:1753–1759.

214. Atkinson, R. W., Anderson, H. R., Sunyer, J., Ayre, J. O. N., Baccini, M., Vonk, J. M., Boumghar, A., Forastiere, F., Forsberg, B., Touloumi, G. & Schwartz, J., 2001. Acute effects of particulate air pollution on respiratory admissions: results from APHEA 2 project. Air Pollution and Health: a European Approach. *Am J Respir Crit Care Med* 164:1860–1866.

215. Pope, C. A., Burnet, R. T., Thun, M. J., Calle, E. E., Krewski, D., Kazuhiko, I. & Thurston, G. D., 2002. Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution. J *Amer Med Assoc* 287:1132–1141.

216. Raaschou-Nielsen, O., Zorana, J. A., Beelen, R., Samoli, E., Stafoggia, M., Weinmayr, G., Hoffmann, B., Brunekreef, B. & Xun, W. W., 2013. Air pollution and lung cancer incidence in 17 European cohorts: prospective analyses from the European Study of Cohorts for Air Pollution Effects (ESCAPE). *The Lancet Oncol* 14: 813–22.
217. World Health Organization, 2016. WHO's Urban Ambient Air Pollution database – Update 2016.
218. van der Zee, S. C., Fischer, P. H. & Hoek, G., 2016. Air pollution in perspective: Health risks of air pollution expressed in equivalent numbers of passively smoked cigarettes. Environmental research 148:475–483.
219. Caiazzo, F., Ashok, A., Waitz, I. A., Yim, S. H. & Barrett, S. R., 2013. Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005. *Atmospheric Environment* 79:198–208.
220. Lavy, V., Ebenstein, A. & Roth, S., 2014. *The impact of short term exposure to ambient air pollution on cognitive performance and human capital formation* (No. w20648). National Bureau of Economic Research.
221. Chang, T., Zivin, J. S. G., Gross, T. & Neidell, M. J., 2014. *Particulate pollution and the productivity of pear packers* (No. w19944). National Bureau of Economic Research.
222. Kampa, M. & Castanas, E., 2008. Human health effects of air pollution. *Environ Pollut* 151:362–367.
223. Badman, D. G. & Jaffe, E. R., 1996. Blood and air pollution: state of knowledge and research needs. *Otolaryngol Head Neck Surg* 114:205–208.
224. Vermylen, J., Nemmar, A., Nemery, B. & Hoylaerts, M. F., 2005. Ambient air pollution and acute myocardial infarction. *J Thromb Haemost* 3:1955–1961.
225. Huang, Y. C. & Ghio, A. J., 2006. Vascular effects of ambient pollutant particles and metals. *Curr Vasc Pharmacol* 4:199–203.
226. Ghio, A. J. & Huang, Y. C. T., 2004. Exposure to concentrated ambient particles (CAPs): a review. *Inhal toxicol,* 16:53–59.
227. Dalton, T. P., Kerzee, J. K., Wang, B., Miller, M., Dieter, M. Z., Lorenz, J. N., Shertzer, H. G., Nerbert, D. W. & Puga, A., 2001. Dioxin exposure is an environmental risk factor for ischemic heart disease. *Cardiovasc Toxicol* 1:285–298.
228. Kingma, B. & van Marken Lichtenbelt, W., 2015. Energy consumption in buildings and female thermal demand. *Nature climate change*, 5:1054–1056.
229. Reinikainen, L. M., Jaakkola, J. J. & Seppänen, O., 1992. The effect of air humidification on symptoms and perception of indoor air quality in office workers: a six-period cross-over trial. *Arch Environ Occup Health* 47:8–15.
230. Sundell, J. & Lindvall, T., 1993. Indoor Air Humidity and Sensation of Dryness as Risk Indicators of SBS. *Indoor Air* 3: 382–390.
231. Arundel, A. V., Sterling, E. M., Biggin, J. H. & Sterling, T. D., 1986. Indirect health effects of relative humidity in indoor environments. *Environmental Health Perspectives*, 65:351.
232. Parthasarathy, S., Maddalena, R. L., Russell, M.L. & Apte, M. G., 2011. Effect of temperature and humidity on formaldehyde emissions in temporary housing units. *Journal of the Air & Waste Management Association*, 61:689–695.
233. WHO Regional Office for Europe., 2008. *Guidelines for Indoor Air Quality: Dampness and mould.*
234. Luong, A. & Marple, B. F. 2004. Allergic fungal rhinosinusitis. *Curr Allergy Asthma Rep* 4:465–70.
235. Bush, R. K., Portnoy, J. M., Saxon, A., Terr, A. I. & Wood, R. A., 2006. The medical effects of mold exposure. *J Allergy Clin Immunol* 117:326–333.
236. Horner, W. E., Helbing, A., Salvaggio, J. E. & Lehrer, S. B., 1995. Fungal allergens. *Clin Microbiol Rev* 8:161–79.

237. Jaakkola, M. S., Nordman, H., Piipari, R., Uitti, J., Laitinen, J., Karjalainen, A., Hahtola, P. & Jaakkola, J. J., 2002. Indoor dampness and molds and development of adult-onset asthma: a population-based incident case-control study. *Environ Health Persp* 110:543.
238. Bush, R. K. & Prochnau, J. J., 2004. Alternaria-induced asthma. *J Allergy Clin Immunol* 113:227–34.
239. Committee on the Assessment of Asthma and Indoor Air. Division of Health Promotion and Disease Prevention, 2002. Institute of Medicine. *Clearing the air: asthma and indoor air exposure*. Washington (DC): The National Academy Press.
240. Engvall, K., Norrby, C. & Norbäck, D., 2001. Sick building syndrome in relation to building dampness in multi-family residential buildings in Stockholm. *Int Arch Occup Environ Health* 74:270–278.
241. Borràs-Santos, A., Jacobs, J. H., Täubel, M., Haverinen-Shaughnessy, U., Krop, E. J., Huttunen, K., Hirvonen, M. R., Pekkanen, J., Heederik, D. J., Zock, J. P. & Hyvärinen, A., 2013. Dampness and mould in schools and respiratory symptoms in children: the HITEA study. *Occupational and environmental medicine* 70:681–687.
242. Platt, S. D., Martin, C. J., Hunt, S. M. & Lewis, C. W., 1989. Damp housing, mold growth, and symptomatic health state. *Br Med J* 298:1673–1678.
243. Waegemaekers, M., van Wageningen, N., Brunekreef, B. & Boleij, J. S. M., 1989. Respiratory symptoms in damp houses. *Allergy* 44:192–198.
244. Flannigan, B., McCabe, E. M. & McGarry, R., 1991. Allergenic and toxigenic microorganisms in houses. *J Appl Bacteriol* 70:61–73.
245. Hyvärinen, A., Reponen, T., Husman, T., Ruuskanen, J. & Nevalainen, A., 1993. Characterizing mold problem buildings—concentrations and flora of viable fungi. *Indoor Air* 3:337–343.
246. Nevalainen, A., A.-L. Pasanen, M. Niininen, T. Reponen, M. J. Jantunen, & Kalliokoski, P., 1991. The indoor air quality in Finnish homes with mold problems. *Environ Int* 17:299–302.
247. Strachan, D. P., B. Flannigan, E. M. McCabe & F. McGarry., 1990. Quantification of airborne moulds in the homes of children with and without wheeze. *Thorax* 45:382–387.
248. Górny, R. L., Reponen, T., Willeke, K., Schmechel, D., Robine, E., Boissier, M., & Grinshpun, S. A., 2002. Fungal fragments as indoor air biocontaminants. *Applied and Environmental Microbiology* 68:3522–3531.
249. Andersson, M. A., Nikulin, M., Köljalg, U., Andersson, M. C., Rainey, F., Reijula, K., Hintikka, E-L. & Salkinoja-Salonen, M., 1997. Bacteria, molds and toxins in water damaged building materials. *Appl Envir Microbiol* 63:387–397.
250. Andersson, M. A., Mikkola, R., Helin, J., Andersson M. C. & Salkinoja-Salonen, M. S., 1998. A novel sensitive bioassay for the detection of Bacillus cereus emetic toxin and related depsipeptide ionophores. *Appl Envir Microbiol* 4:1338–1343.
251. Andersson, M. A., Mikkola, R., Helin, J., Rainey, F., Kroppenstedt, R., Sivonen, K. & Salkinoja-Salonen, M. S., 1998. Mitochondrial toxin produced by Streptomyces strains isolated from indoor environment is valinomycin. *Appl Env Microbiol* 64:4767–4773.
252. Andersson M., Tsitko, I., Vuorio, R. & Salkinoja-Salonen, M., 1999. Mycobacteria and related genera are major colonizers of a wall in a children's day care center. In Johanning, E. (ed.), *Bioaerosols, Fungi and Mycotoxins: Health Effects, Assessment, Prevention and Control*. Eastern New York Occupational and Environmental Health Center, Albany, New York, USA, pp. 396–402.
253. Salo, J., Andersson, M. A., Mikkola, R., Kredics, L., Viljanen, M. & Salkinoja-Salonen, M., 2015. *Vapor as a carrier of toxicity in a health troubled building*. ISIAQ Healthy Buildings Paper ID346, Eindhoven The Netherlands, pp.18–20.
254. Salin, J. T., Salkinoja-Salonen, M., Salin, P. J., Nelo, K., Holma, T., Ohtonen, P. & Syrjälä, H., 2017. Building-related symptoms are linked to the in vitro toxicity of indoor dust and airborne microbial propagules in schools: A cross-sectional study. *Environmental Research* 154:234–239.

255. Tischer, C., Casas, L., Wouters, I. M. , Garcia-Esteban, G. D., Gehring, U., Hyvärinen, A., Oldenwening, M., Kerkhof, M., Sunyer, J., Stand, M., Thiering, E., Torrent, M. & Heinrich, J., 2015. Early exposure to bio-contaminants and asthma up to 10 years of age: results of the HITEA study. *Eur Respir J* 45:328–337.
256. Bohnert, M., Wackler, B. & Hoffmeister, D., 2010. Spotlights on advances in mycotoxin research. *Appl Microbiol Biotechnol* 87:1–7.
257. Dales, R. E., Burnett, R. & Zwanenburg, H., 1991. Adverse health effects among adults exposed to home dampness and molds. *Am Rev Respir Dis* 143:505–509.
258. Caress, S. M. & Steinemann, A. C., 2003. A review of a two-phase population study of multiple chemical sensitivities. *Environmental health perspectives*, 111:1490.
259. Davidoff, A. L. & Fogarty, L., 1994. Psychogenic origins of multiple chemical sensitivities syndrome: a critical review of the research literature. *Archives of Environmental Health: An International Journa*l, 49:316–325.
260. Donnay, A. H., 1999. On the Recognition of Multiple Chemical Sensitivity in Medical Literature and Government Policy. *International Journal of Toxicology*. 18:383–392.
261. De Luca, C., Scordo, M.G., Cesareo, E., Pastore, S., Mariani, S., Maiani, G., Stancato, A., Loreti, B., Valacchi, G., Lubrano, C. & Raskovic, D., 2010. Biological definition of multiple chemical sensitivity from redox state and cytokine profiling and not from polymorphisms of xenobiotic-metabolizing enzymes. *Toxicology and applied pharmacology*, 248:285–292.
262. Seppänen, O. & Palonen, J., 1998. Sisäilmaston kansantaloudelliset vaikutukset. SIY Raportti 10. Sisäilmayhdistys ry.
263. Milton, D. K., Glencross, P. M. & Walters, M. D., 2000. Risk of sick leave associated with outdoor air supply rate, humidification, and occupant complaints. *Indoor air*, 10:212–221.
264. Fanger, O. P., 2006. What is IAQ? *Indoor Air* 16:328–334.
265. Kosonen, R. & Tan, F., 2004. The effect of perceived indoor air quality on productivity loss. *Energ Buildings* 36:981–986.
266. Wyon, D. P., 2005. The effects of indoor air quality (IAQ) on performance, behaviour and productivity. Pollution atmosphérique 2005:35–41.
267. Spengler, J. D., Neas, L., Nakai, S, Dockery, D., Speizer, F., Ware, J. & Raizanne, M., 1993. *Respiratory symptoms and house characteristics*, In Kalliokoski, P., Jantunen, M. & Seppänen, O. (eds.), Health effects. Proceedings of Indoor Air 93 Conference, vol. 1. Gummerus Oy, Jyväskylä, Finland, pp. 165–171.
268. Crandall, M. S. & Sieber, W. K., 1996. The National Institute of Occupational Safety and Health indoor environmental evaluation experience. Part one: building environmental evaluations. *Appl Occup Environ Hyg* 11:533–539.
269. Ellringer, P. J., Boone, K. & Hendrickson, S., 2000. Building materials used in construction can affect indoor fungal levels greatly. *Am Ind Hyg Assoc J* 61:895–899.
270. Burr, M. L., Mullins, J., Merret, T. G. & Stott, N. C. H., 1985. Asthma and indoor mould exposure. *Thorax* 40:688.
271. Hunter, C. A. & Lea, R. G., 1994. The airborne fungal population of representative British homes. In. Samson, R. A., Flannigan, B., Flannigan, M. E., Verhoeff, A. P., Adan, O. C. G. & Hoekstra, E. S. (ed.), *Air quality monographs. Health implications of fungi in indoor environments, vol. 2.* Elsevier Science B. V., Amsterdam, The Netherlands, pp. 141–153.
272. Brunekreef, B., 1992. Damp housing and adult respiratory symptoms. Allergy 47:498–502.
273. van der Laan, P. C. H., 1994. Moisture problems in the Netherlands: a pilot project to solve problem in social housing, In Samson, R. A., Flannigan, B., Flannigan, M. E., Verhoeff, A. P., Adan, O. C. G. & Hoekstra, E. S. (ed.), *Air quality monographs. Health implications of fungi in indoor environments, vol. 2.* Elsevier Science B.V., Amsterdam, The Netherlands. pp. 507–516.

274. Verhoeff, A. P., van Wijnen, J. H., Boleij, J. S. M., Brunekreef, B., van Reenen-Hoekstra, E. S. & Samson, R. A., 1990. Enumeration and identification of airborne viable mould propagules in houses. *Allergy* 45:275–284.

275. Pirhonen, I., Nevalainen, A., Husman, T. & Pekkanen, J., 1996. Home dampness, moulds and their influence on respiratory infections and symptoms in adults in Finland. *Eur Respir J* 9:2618–2622.

276. Opetusalan Ammattiliitto OAJ, 2014. Opetusalan sisäilmatutkimus. *OAJ:n julkaisusarja* 1:2014.

277. Kaplan, R., 1993. The role of nature in the context of the workplace. *Landscape Urban Plan* 26:193–201.

278. Daly J., Burchett M.& Torpy, F., 2010. *Plants in the classroom can improve student performance*. National Interior Plantscape Association.

279. Lichtenfeld, S., Elliot, A. J., Maier, M. A. & Pekrum, R., 2012. Fertile green green facilitates creative performance. *Pers Soc Psychol B* 38:784–797.

280. Berman, M. G., Kross, E., Krpan,K. M., Askren, M. K., Burson, A., Deldin, P. J., Kaplan, S., Sherdell, L., Gotlib, I. H. & Jonides, J., 2012. Interacting with nature improves cognition and affect for individuals with depression. *Journal of Affective Disorders* 140:300–05.

281. Shin, W. S., Shin, C. S., Yeoun, P. S. & Kim, J. J., 2011. The influence of interaction with forest on cognitive function. *Scandinavian Journal of Forest Research*, 26:595–598.

282. Rich, D., 2008. *Effects of exposure to plants and nature on cognition and mood: A cognitive psychology perspective*. Dissertation Abstracts International: Section B: Sciences Engineering 68:4911.

283. Singh, A., Syal, M., Grady, S. C. & Korkmaz, S., 2010. Effects of green buildings on employee health and productivity. *Am J Public Health* 100:1665–1668.

284. Ceylan, C., Dul, J. & Aytac, S., 2008. Can the office environment stimulate a manager's creativity? *Hum Factors Ergon Manuf Serv Ind* 18:589–602.

285. Earle, H. A. 2003. Building a workplace of choice: Using the work environment to attract and retain top talent. *J Facil Manag* 2:244–257.

286. Heschong, L. Heschong Mahone Group, 2003. *Windows and offices: A study of office worker performance and the indoor environment*. California Energy Commission: Pacific Gas and Electric Company. Fair Oaks, California.

287. Robertson, I. & Cooper, C. L., 2011. *Well-being: Productivity and happiness at work*. Palgrave Macmillan.

288. American Society of Interior Designers, 1999. *Recruiting and Retaining Qualified Employees — By Design*. Washington, Williams, L. C. pp. 8–10.

289. An, M., Colarelli, S. M., O'Brien, K. & Boyajian, M. E., 2016. Why We Need More Nature at Work: Effects of Natural Elements and Sunlight on Employee Mental Health and Work Attitudes. *PloS one*, 11:5.

290. Woods, J. E., 1989. Cost avoidance and productivity in owning and operating buildings. *Occupational medicine* (Philadelphia, Pa.) 4:753–770.

291. Fisk, W., 2000. Estimates of potential nationwide productivity and health benefits from better indoor environments: an update. *Indoor air quality handbook* 4:1–38.

292. Nieuwenhuis, M., Knight, C., Postmes, T. & Haslam, S. A., 2014. The relative benefits of green versus lean office space: Three field experiments. *J Exp Psychol-Appl* 20:199.

293. Allen, J. G., MacNaughton, P., Satish, U., Santanam, S., Vallarino, J. & Spengler, J. D., 2016. 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. *Environ Health Persp* 124:805.

294. Mattila, I., Heinonen, K. & Niemeläinen, M., 2016. Viherseinän kaasumaisten epäpuhtauksien suodatuskyky. Valtion Teknillinen Tutkimuslaitos, Tampere.

295. Kangas, T., 2016. Älyviherseinän testaus ilman epäpuhtauksien pienhiukkasten suodatuksessa. Thesis, JAMK University of Applied Sciences.

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296. Torpy, F. R., Irga, P. J., Brennan, J. & Burchett, M. D., 2013. Do indoor plants contribute to the aeromycota in city buildings? *Aerobiologia* 29:321-331.

297. Yang, D. S., Pennisi, S. V., Son, K. C., & Kays, S. J., 2009. Screening indoor plants for volatile organic pollutant removal efficiency. *HortScience* 44:1377–1381.

298. Wood, R. A., Burchett, M. D., Alquezar, R., Orwell, R. L., Tarran, J. & Torpy, F., 2006. The potted-plant microcosm substantially reduces indoor air VOC pollution: I. Office field-study. *Water Air Soil Pollut* 175:163–180.

299. Orwell, R. L., Wood, R. A., Burchett, M. D., Tarran, J. & Torpy, F., 2006. The potted-plant microcosm substantially reduces indoor air VOC pollution: II. Laboratory study. *Water Air Soil Pollut* 177:59–80.

300. Orwell, R. L., Wood, R. L., Tarran, J., Torpy, F. & Burchett, M. D., 2004. Removal of benzene by the indoor plant/substrate microcosm and implications for air quality. *Water Air Soil Pollut* 157:193–207.

301. Kim, K. J., Kil, M. J., Song, J. S., Yoo, E. H., Son, K. C. & Kays, S. J., 2008. Efficiency of volatile formaldehyde removal by indoor plants: contribution of aerial plant parts versus the root zone. *J Am Soc Hortic Sci* 133:521–526.

302. Wang, Z. & Zhang, J. S., 2011. Characterization and performance evaluation of a full-scale activated carbon-based dynamic botanical air filtration system for improving indoor air quality. *Building and Environment* 46:58-768.

303. ELSadek, M., Koriesh, E., Fujii, E., Moghazy, E. & Abd El Fatah, Y., 2012. Correlation between some components of interior plants and their efficiency to reduce formaldehyde, nitrogen and sulfur oxides from indoor air. *Int Res J Plant Sci* 3:222–229.

304. Lindfors, V. & Laurila, T. 2000. Biogenic volatile organic compound (VOC) emissions from forests in Finland. *Boreal Environ Res* 5:95–113.

305. Yang, D. S., Son, K-C. & Kays, S. J., 2009. Volatile organic compounds emanating from indoor ornamental plants. HortScience 44:396–400.

306. Yatagai, M., Sato, T. & Takahashi, T., 1985. Terpenes of leaf oils from Cupressaceae. *Biochemical systematics and ecology*, 13:377–385.

307. Miyazaki, Y. & Yatagai, M., 1989. Effect of components of plant odors on human and animals. *Man and Environ*, 15:33–42.

308. Yatagai, M., Ohira, M., Ohira, T. & Nagai, S., 1995. Seasonal variations of terpene emission from trees and influence of temperature, light and contact stimulation on terpene emissions. *Chemosphere* 30:1137–1149.

309. Akutsu, H., Kikusui, T., Takeuchi, Y. & Mori, Y., 2003. Effects of alpha-pinene odor in different concentrations on stress-induced hyperthermia in rats. *J Vet Med Sci* 65:1023–1025.

310. Aoshima, H., 2012. Beneficial effects of fragrances in beverages on human health. Nutrition, well-being and health, p.119.

311. Mendes, R., Kruijt, M., de Bruijn, I., Dekkers, E., van der Voort, M., Schneider, J. H., Piceno, Y. M., DeSantis, T. Z., Andersen, G. L., Bakker, P. A. & Raaijmakers, J. M., 2011. Deciphering the rhizosphere microbiome for disease-suppressive bacteria. *Science* 332:1097–1100.

312. Van Wees, S. C., Van der Ent, S. & Pieterse, C. M., 2008. Plant immune responses triggered by beneficial microbes. *Curr Opin Plant Biol* 11:443–448.

313. Bibeau. L., Kiared, K., Leroux. A., Baezinski, R., Viel. G. & Heitz. M., 1997. Biological purification of exhaust air containing toluene vapor in a filter-bed reactor. *Can J Chem Eng* 75:921–929.

314. Wood, R. A., Orwell, R., Tarran, J., Torpy F. & Burchett, M. D., 2002. Potted-plant/growth media interactions and capacities for removal of volatiles from indoor air. *J Hortic Sci Biotechnol* 77:120-129.

315. Tarran, J., Torpy, F. & Burchett, M., 2007. Use of living pot-plants to cleanse indoor air – research review. *Environment* 3:249–256.

316. Llewellyn, M. & Dixon, D., 2011. Can Plants Really Improve Indoor Air Quality? In *Comprehensive Biotechnology* (Second Edition), Moo-Young, M. (edit.), pp. 331–338.

317. Huang, W.-H., Wang, Z., Choudhary, G., Guo, B., Zhang, J. & Ren, D., 2012. Characterization of microbial species in a regenerative bio-filter system for volatile organic compound removal. *HVAC&R Research* 18:169–178.
318. Russell, J. A., Hu, Y., Chau, L., Pauliushchyk, M., Anastopoulos, I., Anandan, S. & Waring, M. S., 2014. Indoor-biofilter growth and exposure to airborne chemicals drive similar changes in plant root bacterial communities. *Applied and environmental microbiology* 80:4805–4813.
319. 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* 16:465–468.
320. Seppänen, O., Fisk, W. J. & Lei, Q. H., 2006. Ventilation and performance in office work. *Indoor Air* 16:28–36.
321. Seppänen, O. A., Fisk, W. J. & Mendell, M. J., 1999. Association of ventilation rates and carbon dioxide concentrations with health and other responses in commercial and institutional buildings. *Indoor air* 9:226–252.
322. Pennisi, S. V. & van Iersel, M. W., 2012. Quantification of Carbon Assimilation of Plants in Simulated and In Situ Interiorscapes. *HortScience* 47:468–476.
323. Torpy, F. R., Zavattaro, M., Irga, P. J. & Burchett, M. D., 2015. *Assessing the Air Quality Remediation Capacity of the Junglefy Breathing Wall Modular Plant Wall System*. School of Life Sciences, Faculty of Science, University of Technology, Sydney, pp. 25–44.
324. Irga, P. J., Torpy, F. R. & Burchett, M. D., 2013. Can hydroculture be used to enhance the performance of indoor plants for the removal of air pollutants? *Atmos Environ* 77:267–271.
325. Lee, J-H. & Sim, W-K., 1999. Biological absorption of So_2 by Korean native indoor species. In Burchett, M. D. et al. (eds) *Towards a New Millennium in People-Plant Relationships*. Contributions from International People-Plant Symposium, Sydney, pp.101–108.
326. Yoneyama, T., Kim, H. Y., Morikawa, H. & Srivastava, H. S., 2002. Metabolism and detoxification of nitrogen dioxide and ammonia in plants. In *Air Pollution and Plant Biotechnology,* Springer Japan, pp. 221–234.
327. Coward, M., Ross, D. & Coward, S., 1996. Pilot Study to Assess the Impact of Green Plants on No_2 Levels in Homes. Building Research Establishment Note N154/96, Watford, UK.
328. Högberg, M. N., Briones, M. J., Keel, S. G., Metcalfe, D. B., Campbell, C., Midwood, A. J., Thornton, B., Hurry, V., Linder, S., Näsholm, T. & Högberg, P., 2010. Quantification of effects of season and nitrogen supply on tree below‐ground carbon transfer to ectomycorrhizal fungi and other soil organisms in a boreal pine forest. New Phytol 187:485–493.
329. Gawrońska, H. & Bakera, B., 2015. Phytoremediation of particulate matter from indoor air by Chlorophytum comosum l. plants. *Air Quality, Atmosphere & Health*, 8:265–272.
330. Lohr, V. I. & Pearson-Mims, C. H., 1996. Particulate matter accumulation on horizontal surfaces in interiors: influence of foliage plants. *Atmos Environ* 30:2565–2568.
331. Bluyssen, P. M., Coxa, C., Seppänen, O., de Oliveira Fernandes, E., Clausen, G., Muller, B. & Roulet, C-A., 2003. Why, when and how do HVAC-systems pollute the indoor environment and what to do about it? the European AIRLESS project. *Build Environ* 38:209–225.
332. Pfluger, R., Feist, W., Tietjen, A. & Neher, A., 2013. Physiological impairments at low indoor air humidity. *Gefahrstoffe Reinhaltung der Luft* 73:107–108.
333. Bryant, D. A. & Frigaard, N. U., 2006. Prokaryotic photosynthesis and phototrophy illuminated. *Trends Microbiol* 14:488–96.
334. Field, C. B., Behrenfeld, M. J., Randerson, J. T. & Falkowski, P., 1998. Primary production of the biosphere: integrating terrestrial and oceanic components. *Science* 28:237–240.
335. Buser, P. A. & Imbert, M., 1992. Vision. MIT press, Massachusetts, p.50.

336. Lambers, H., Chapin III, F. S. & Pons, T. L., 2008. Photosynthesis. In *Plant physiological ecology*. Springer New York, pp. 11–99.

337. Folta, K. M. & Childers, K. S., 2008. Light as a Growth Regulator: Controlling Plant Biology with Narrow-bandwidth Solid-state Lighting Systems. *HortScience* 43:1957–1964.

338. Brennan, J. P., 2011. *Do potted-plants improve the indoor environment?* (Doctoral dissertation).

339. Wolverton, B. C. & Wolverton, J. D., 1993. Plants and soil microorganisms: removal of formaldehyde, xylene, and ammonia from the indoor environment. *J Miss Acad Sci* 38:11–15.

340. Park, S., Kim, J., Jang, Y. K. & Sung, K., 2006. Purification Ability of Indoor Plants for Volatile Organic Compounds (VOCs). *Euro Env Imp Assess* 15:417–423.

341. Su, Y. M., 2014. CO_2 purify effect on improvement of indoor air quality (IAQ) through indoor vertical Greening. In *Transactions on Engineering Technologies*, Springer Netherlands, pp. 569–580.

342. Shujuan, Z. & Huang, T., 2010. Research progress on the elimination of indoor formaldehyde pollution by plants. *J Ecol Environ Sci* 19:3006–3013.

343. Jiahui, L. *A research of interior visual preference of green building in Taiwan- from aesthetic viewpoint*. Taipei University of Technology Thesis Institute of Design pp. 1–112.

344. *The WELL Building Standard*, 2016. Delos Living LLC, New York.

345. Kellert, S. R., Heerwagen, J. & Mador, M., 2011. *Biophilic design: the theory, science and practice bringing buildings to life*. John Wiley & Sons.

346. Kellert, S. R., 2012. Building for life: designing and understanding the human-nature connection. Island press.

347. Browning, W. D., Ryan, C. O. & Clancy, J. O., 2014. *14 patterns of biophilic design*. New York: Terrapin Bright Green, LLC.

348. Luttik, J., 2000. The value of trees, water and open space as reflected by house prices in the Netherlands. *Landscape Urban Plan* 48:161–167.

349. Jumeno, D. & Matsumoto, H., 2016. The Effects of Indoor Foliage Plants on Perceived Air Quality, Mood, Attention, and Productivity. *Journal of Civil Engineering and Architecture Research* 3:1359–1370.

350. Allen, J. G., MacNaughton, P., Laurent, J. G. C., Flanigan, S. S., Eitland, E. S. & Spengler, J. D., 2015. Green buildings and health. *Current environmental health reports* 2:250–258.

351. Torpy, F., Clements, N., Pollinger, M., Dengel, A., Mulvihill, I., He, C. & Irga P, 2018. Testing the single-pass VOC removal efficiency of an active green wall using methyl ethyl ketone (MEK). *Air Qual Atmos Health* 11:163-170.

352. Li, T., Vesala, M., Saarenheimo, J., Ahonen, V., Kärenlampi, S.B., Lande, J. D., Tiirola, M., Tervahauta, A., 2018. Biofiltration of airborne VOCs with green wall systems: microbial and chemical dynamics. *Indoor Air* 28:697-707.