Key Economic and Justification Factors for Indoor Environmental Quality

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Seven Key Factors for Economic and Justification Factors for IEQ

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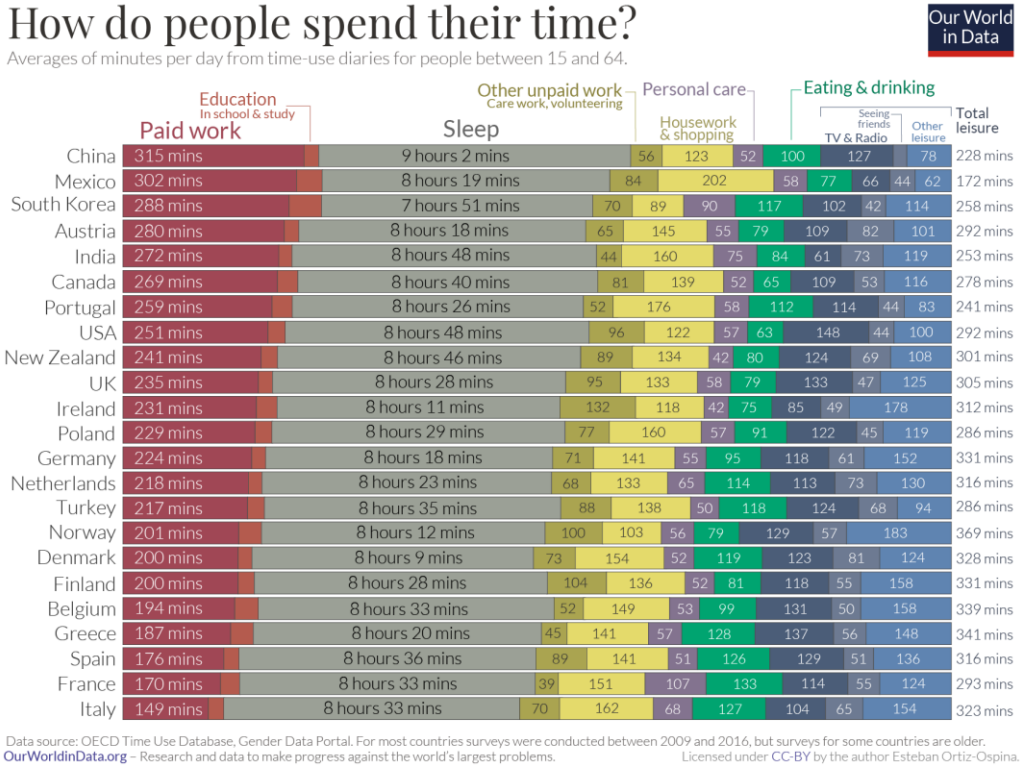
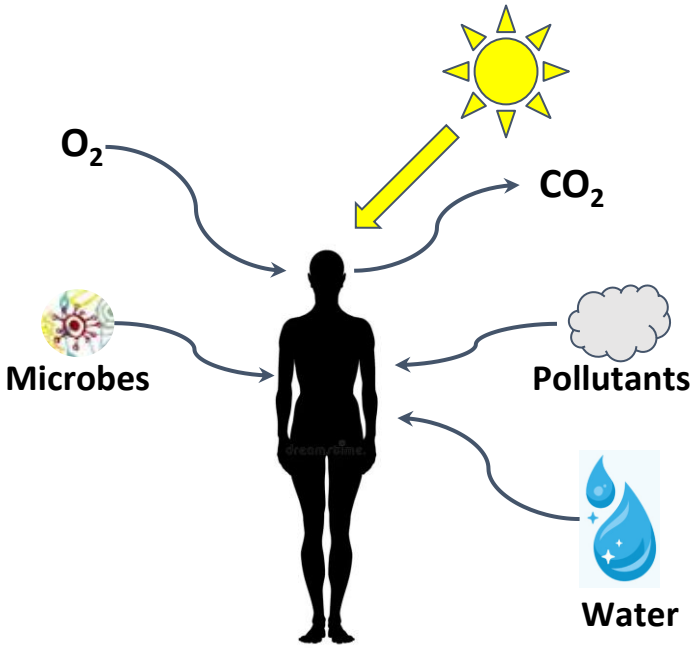
Key Factor 1:
We spend a lot of time indoors



We spend, on average, up to 87% of our time indoors in different enclosed buildings and an additional 6% in vehicles. This means IEQ has a major impact on our health, comfort, and productivity—and its importance will only grow over time due to several key trends, remote work that decreases outdoors commute, climate change that increases indoors time in hot summer, especially global south, global outdoor air quality issues that requires cleaner indoor air through proper filtration and ventilation to safeguard for public health, and an aging population tends to spend more time indoors.

Key Factor 2:
IEQ shapes us—Literally



Environmental Elements Can Become Physically Part of Our Bodies

Indoor air elements—water vapor, oxygen, CO_2, microbial particles, and contaminants—can become part of our bodies, affecting everything from cellular health to hormone balance.The indoor environment influences our biology both in the short and long term.

Short-term responses include sweating, shrinking of blood vessels, and altitude acclimation, long-term adaptations can include changes to lung capacity, nasal passage size, and even skin tone.

Key Factor 3:
Health Impacts *(Page 1 of 2)*

Physical

- **General Safety**: Poor lighting contributes to over 1,000,000 emergency room visits per year—many due to staircase accidents in poorly lit environments.
- **Respiratory Health:** Poor IAQ can increase the likelihood of respiratory conditions by up to 78% in children and 50% in the general population. Conditions impacted include asthma, bronchitis, allergies, COPD (Chronic Obstructive Pulmonary Disease), lung cancer and respiratory infections.
- **Allergies:** Over 50% of all allergic diseases are linked to indoor allergens, especially from dust mites, pet dander, and mold.
- **Obesity & Type 2 Diabetes:** Certain indoor pollutants are associated with a 114% increased risk of being overweight. Up to 17.9% of type 2 diabetes cases may be attributed to environmental exposures such as indoor air pollutants.
- **Building-Related Illness (BRI)**: Upgrading indoor air quality systems can reduce BRI symptoms by up to 50%.
- **Skin**: Dermatologic symptoms were approximately 2.6 times more prevalent among workers in low-humidity settings (RH 42% vs.16%).
- **Legionnaire's Disease:** 90% of legionnaire's diseases are preventable.
- **Cardiovascular:** 25% of all heart disease deaths were caused by air pollution.

Key Factor 3
Health Impacts *(Page 2 of 2)*

Health Impacts

- **Mental:** IEQ can significantly increase the risk of anxiety, depression, mood and neurodevelopmental disorders by affecting brain function, emotional well-being, and cognitive performance.
- **Diseases transmission:** Improving IEQ elements, such as airflow rates, air quality, lighting, and thermal conditions, can significantly reduce the transmission of infectious diseases by minimizing airborne pathogen spread, with ventilation alone linked to up to an 80% reduction in student infections.
- **Sleeping Quality:** Poor indoor environmental quality, such as elevated temperature, CO_2, $PM_{2.5}$, noise, and humidity, can reduce sleep efficiency, e.g. elevated noise level can reduce sleep efficiency by up to 4.7%.
- **Premature death and DALY:** Poor indoor environmental quality—including noise, lighting, and air pollution—contributes significantly impact premature death rate, with environmental noise causing 1.6 million lost healthy life years annually in Western Europe, bright night light increasing premature death risk by up to 34%, and indoor air pollution responsible for 3.2 million of deaths and a 10–20% higher risk of respiratory mortality.

Key Factor 4
Productivity & Performance *(Page 1 of 3)*

Performance Impacts

- **Staffing costs** can be a major component of building operations—ranging from under 30% in manufacturing to nearly 90% in selected organizations—with service industries typically seeing the highest labor-related expenses, highlighting the importance of productivity and performance.

- **IAQ:** Can lead to substantial benefits, including up to 60x return on investment, a 13.7% increase in task performance speed, 16.1% reduction in error rates, 8–11% boost in office performance, and a potential $410/m² annual gain from just a 5% productivity improvement, with 61% of employees expressing concern about IAQ.

- **Thermal Comfort:** Suboptimal temperatures increase mistakes by up to 44%, individual temperature control improves cognitive and typing tasks by 3–7%, and dynamic thermal environments may enhance comfort and reduce stress compared to constant temperatures.

- **Visual/Light:** Access to natural light and views significantly enhances well-being and performance—boosting mental function by up to 25%, increasing sleep duration by 46 minutes, reducing fatigue and gloominess.

- **Acoustic:** Environmental noise negatively impacts cognitive performance, with even a 1 dB increase reducing reading and language ability, up to a 66% drop in memory tasks, each 10dB increases, inrelates to 1.9% decline in well-being above 50 dB, and significant effects on concentration and creativity depending on noise levels.

- **Absenteeism**: Improved indoor environmental quality can reduce sick leave up to 35%, value up to $400 per employee annually, and significantly lower absenteeism costs.

Key Factor 4
Productivity & Performance *(Page 2 of 3)*

- **Student Performance:** Improved indoor environmental quality in schools—including better lighting, ventilation, acoustics, and thermal comfort—can enhance student performance up to 26%, reduce absenteeism and suspension rates, and significantly narrow achievement gaps, with benefits seen in test scores, learning outcomes, and classroom behavior.

- **Sales:** IEQ can significantly boost sales, with daylighting increasing retail sales by up to 40% and thermal comfort improvements raising real estate sale prices by an average of 2.22%.

- **Healing/Recovery Time:** Healing outcomes can be significantly improved, with studies showing reduced hospital stays by up to 41%, a 20% drop in mortality, and faster recovery times up to 37% through interventions like nature sounds and radiant cooling.

- **Financial Performance:** Neglecting indoor environmental quality (IEQ) can lead to costly legal and insurance liabilities, while investing in improvements can yield $700–$800 in productivity gains per employee annually and a $2–$3 return for every $1 spent.

- **Property Value:** Studies showing IAQ improvements yielding up to a 78.56% ROI and increasing office building values by 1.28% to 3.85%, while green-certified buildings with IEQ features can command 13.3% higher sale prices and 5-10% increase in occupancy.

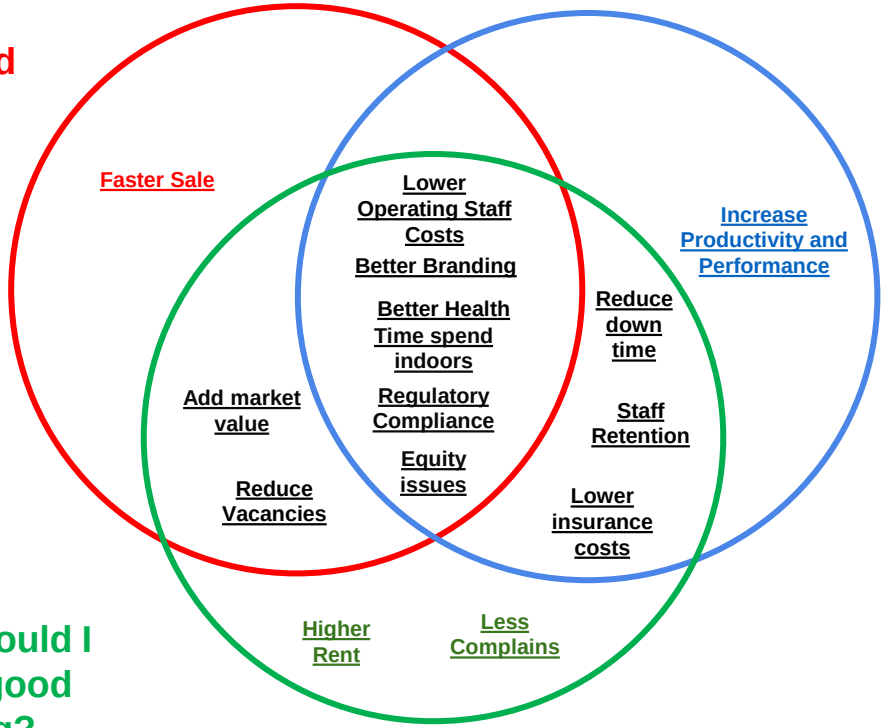
- **Rent:** LEED-certified buildings with IEQ features command a rent premium of 2.5% to 4%, though this has slightly declined to 3% since the COVID-19 pandemic.

- **Sell Faster:** green buildings, at least for residential, can sell faster. Certified green homes take only 52.8 - 57% of time to sell compared to non-certified homes.

Key Factor 4
Productivity & Performance *(Page 3 of 3)*

Developer: Why would I want to build good IEQ building?

Tenant: Why would I want to lease good IEQ building?



Owner: Why would I want to own good IEQ building?

Key Factor 5
Regulatory/Certification Compliance

Global IAQ Guidelines

Credit: https://www.sciencedirect.com/science/article/pii/S0160412023004002

Regulatory/Certification Compliance:

Over 50 organizations in at least 38 countries have established IAQ guidelines addressing pollutants, mold, moisture, and temperature. A study of 31 green building certifications across 30 countries found that all included IAQ requirements, contributing an average of 7.5% to certification criteria.

Key Factor 6
Equity Concerns *(Page 1 of 2)*

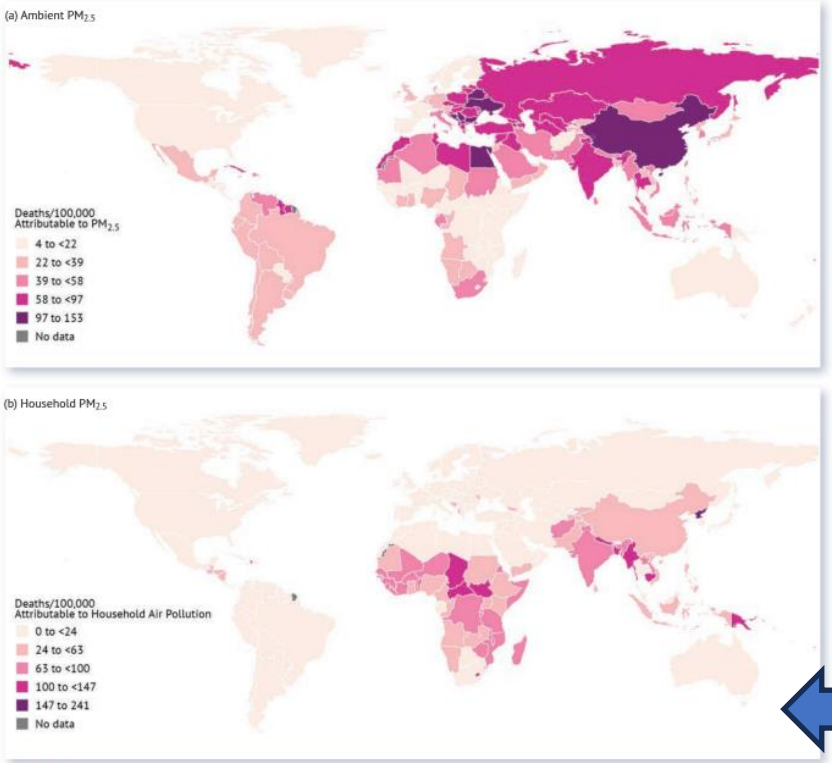


FIGURE 12. Global map of age-standardized rates of death attributable to (a) ambient and (b) household air pollution in 2021.
Visit *stateofglobalair.org* to explore the data for your country or region.

Equity Concerns:

Global: Air pollution causes 89% of the 4.2 million premature deaths in low- and middle-income countries, where poor indoor air quality ranks among the top global health risks, but interventions like cleaner fuels, better ventilation, and electrification can reduce PM2.5 by 66% and lower childhood respiratory infections by 8–14 percentage points.

Social Economical and Disadvantaged Communities: Air pollution disproportionately impacts disadvantaged communities, particularly communities of color and low-income individuals, with higher risks of premature death, while access to clean energy reduces mortality related to indoor air pollution, with higher income households having 22% lower odds of mortality.

Global air quality is also an equity issue, with global south countries facing more premature deaths. See more in the *State of Global Air 2024.*

Key Factor 6
Equity Concerns *(Page 2 of 2)*

Vulnerable: Children, Elderly, and Preexisting Conditions:

IEQ solutions, to be equitable, may not be "one size fits all:

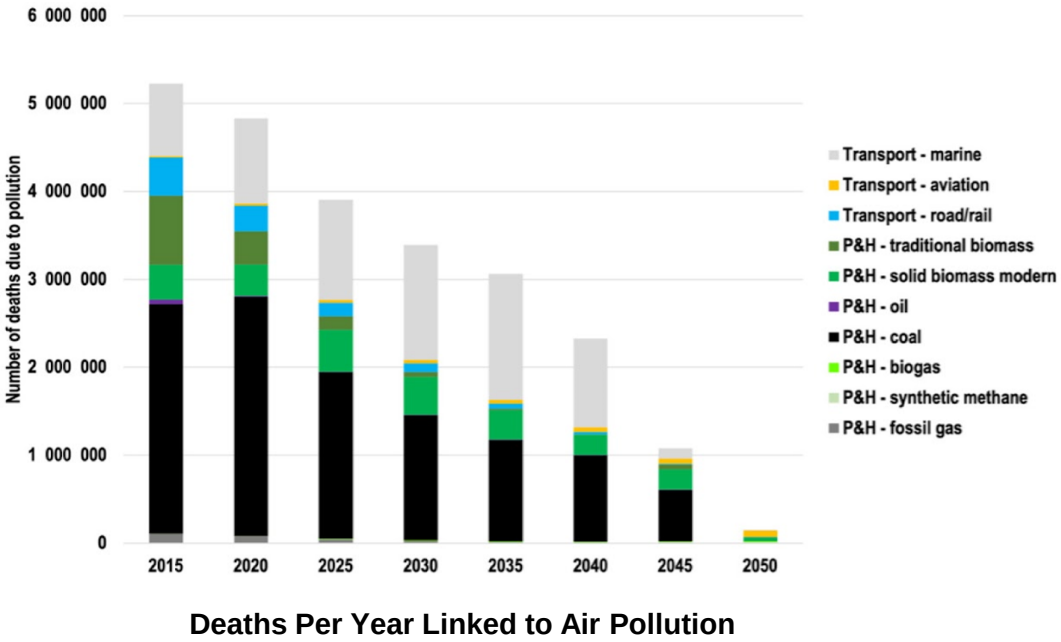
- **Air quality:** Children, especially those from lower socioeconomic and minority communities, and the elderly, are more vulnerable to the health impacts of air pollution, including respiratory issues, severe illness, and death from conditions like COVID-19 and the flu. Selected countries have different air quality standards tailored to address these vulnerabilities.

- **Visual/Lighting:** As people age, their lighting needs increase to support vision, circadian rhythms, and overall health, and it is essential to design environments that meet these needs, while also considering the impact of light exposure on children and pregnant women.

- **Thermal Comfort:** Cold housing significantly impacts children's respiratory health, emotional well-being, and educational attainment, while heat exposure during pregnancy increases risks of complications like preterm birth and placental abruption, and older adults are also vulnerable to higher mortality and health issues due to cold housing.

- **Acoustic:** Equity is crucial in creating environments that improve speech privacy, sound clarity, and reduce background noise, particularly in workplaces, elderly healthcare facilities, and public spaces, to address the needs of vulnerable groups like children, the elderly, and pregnant individuals.

Key Factor 7
IEQ and Climate Change Alignments



Deaths Per Year Linked to Air Pollution

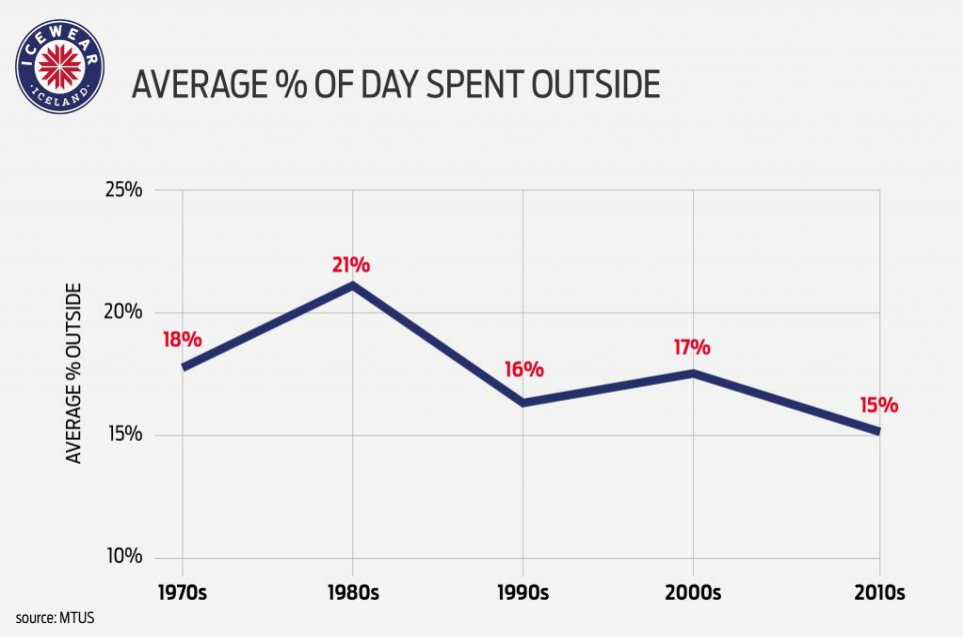
Credit:
https://www.sciencedirect.com/science/article/pii/S235248472202279X#:~:text=In%20this%20energy%20transition%2C%20total%20emissions%20from,2015%20to%20150%20thousand%20deaths%20by%202050.

IEQ and Climate Change Alignments:

Improving IEQ aligns with climate action through strategies like clean energy use, natural ventilation, low-VOC materials, and green design, while a global transition to 100% renewable energy by 2050 could reduce premature deaths by 97%, or about 5 million people annually and save global environment cost of about $5,000 billion US dollars.

Content

Key Factor 1 *(Page 1 of 6)*
More Indoor Time



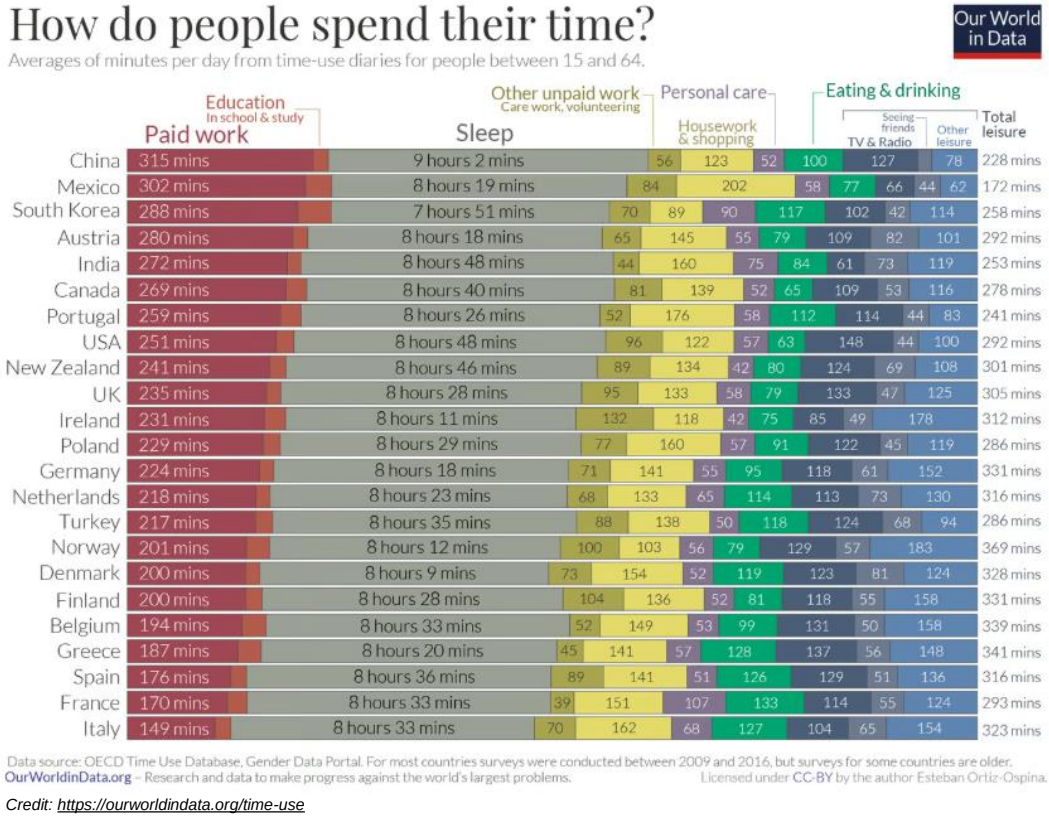
We are spending significantly more time indoors than outdoors:

Outdoor vs. Indoor: Spending time in outdoor environments with more nature is commonly linked to lower stress and better mental health, but much of our time is spent indoors or in transit. It is more likely to catch infectious diseases indoors rather than outdoors, for example, catching COVID-19 was almost 19 times higher indoors than outdoors. It seems likely that we will continue to spend even more time indoors in the future.

University College London Study - Average % of Day Spent Outside

Credit: https://www.icewear.is/us/blog/time-outdoors-the-inside-epidemic/

Key Factor 1 *(Page 2 of 6)*
How We Spend Our Time



Credit: https://ourworldindata.org/time-use

Before the Pandemic

In this older study, self reported data of 87% of time in average in enclosed buildings and about 6% of the time in enclosed vehicles, at least in US. Similar numbers in the US EPA website put the number at 90%. Note "indoors" represents a variety of spaces, including but not limited to "residences".

Key Factor 1 – *(Page 3 of 6)*
The “Great Indoor Shift”

After the Pandemic

Various factors suggest we're spending even more time indoors. With more companies shifting to remote or hybrid work models, many individuals are staying home rather than commuting to an office. The “Great Indoor Shift” seems to have become a lasting trend, with research showing that people in the US are now spending **51** minutes fewer outdoors per day compared to pre-COVID times.

https://www.insidenova.com/news/national/americans-spend-less-time-outside-home-post-covid-19-ucla-study-reveals/collection_8fbb9660-a787-5975-8583-c5ad8ab41906.html#1

Key Factor 1- *(Page 4 of 6)*
Rising Summer Temperatures

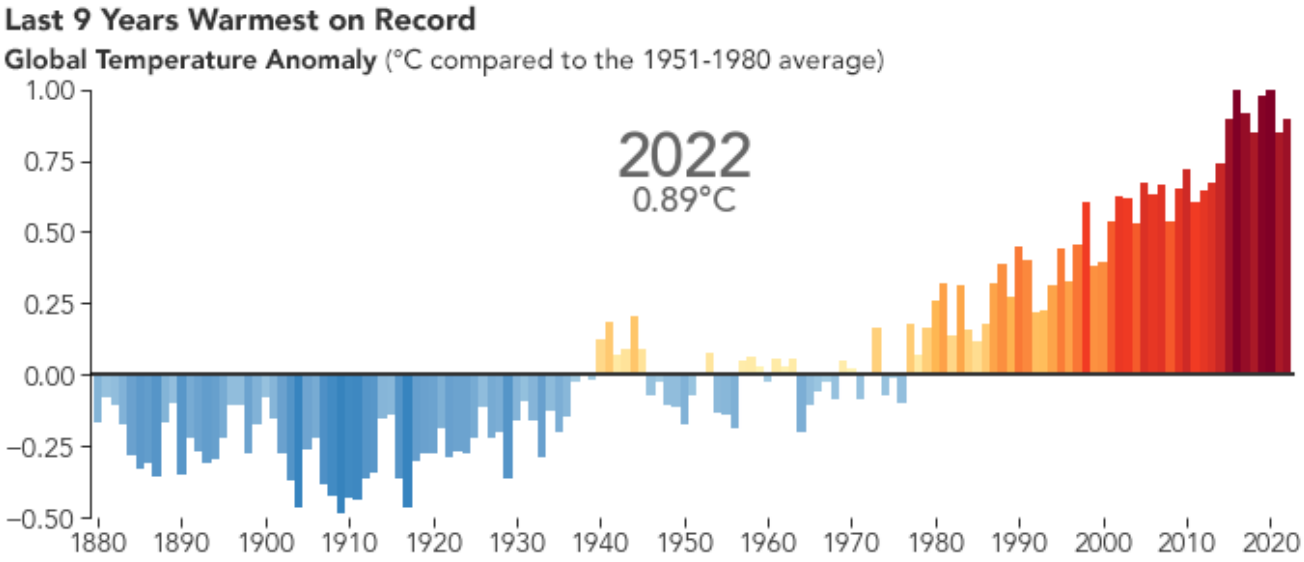
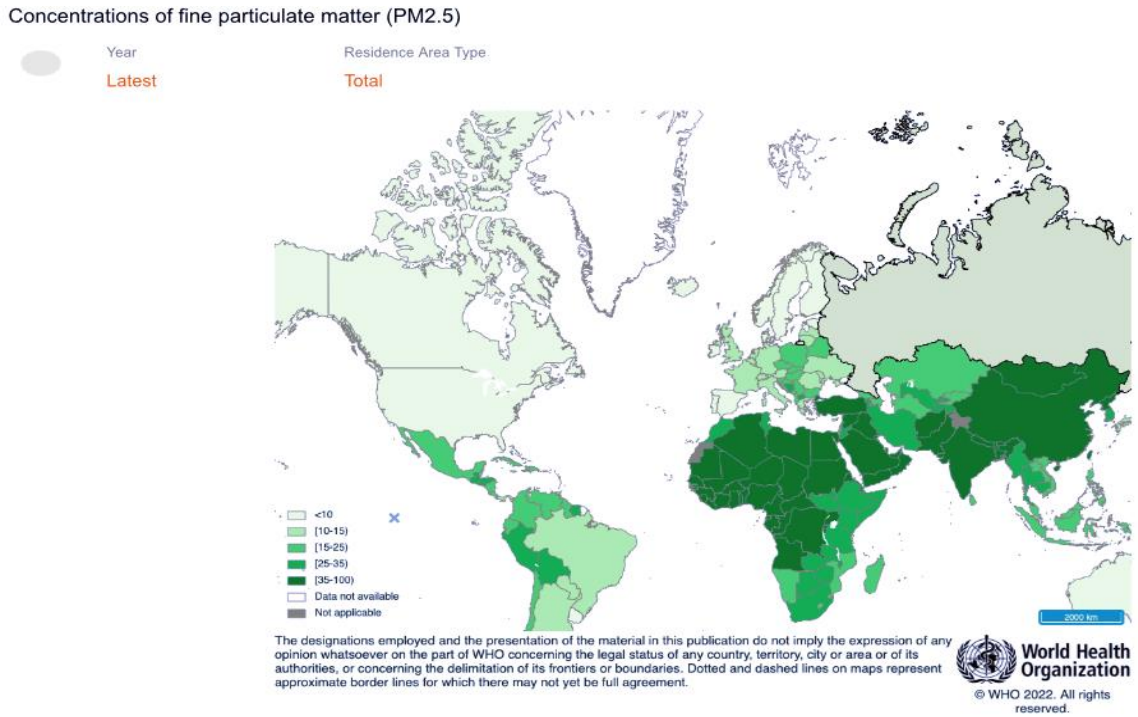


Image Credit, NASA Earth Observatory https://earthobservatory.nasa.gov/world-of-change/global-temperatures

Global Trends: Rising summer temperatures by climate change are one of the key reasons why people in certain cities choose to stay indoors to avoid the heat. As global development shifts toward the Global South, many countries in this region lack sufficient green space for outdoor cooling, leading to an increase in indoor time.

Key Factor 1- *(Page 5 of 6)*
Global Levels of Fine Particulate Matter

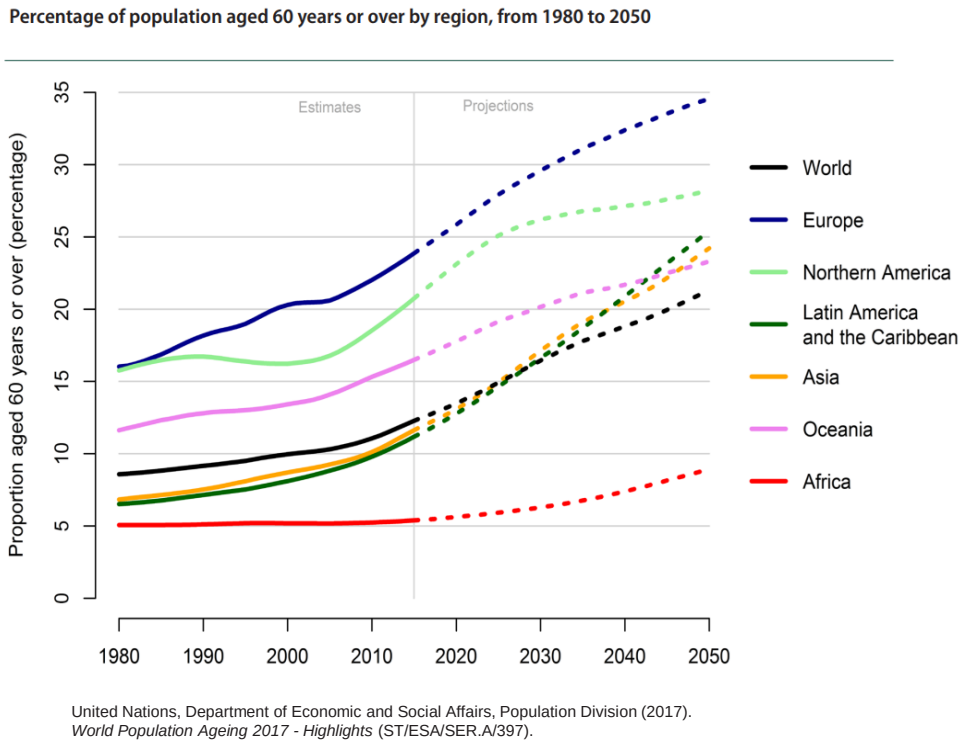


Indicator 11.6.2: Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)

WHO. WHO Ambient Air Quality Database (update 2024). Version 6.1. Geneva, World Health Organization, 2024. https://www.who.int/data/gho/data/themes/air-pollution/who-air-quality-database

Global Trends: Furthermore, per UN WHO, 99% of the global population is living in areas that exceed the annual PM 2.5 of 5 µg/M^3, which is air standard that is difficult to achieve in many cities without indoor air quality treatments.

Key Factor 1 *(Page 6 of 6)*
Population Over 60 Years Old

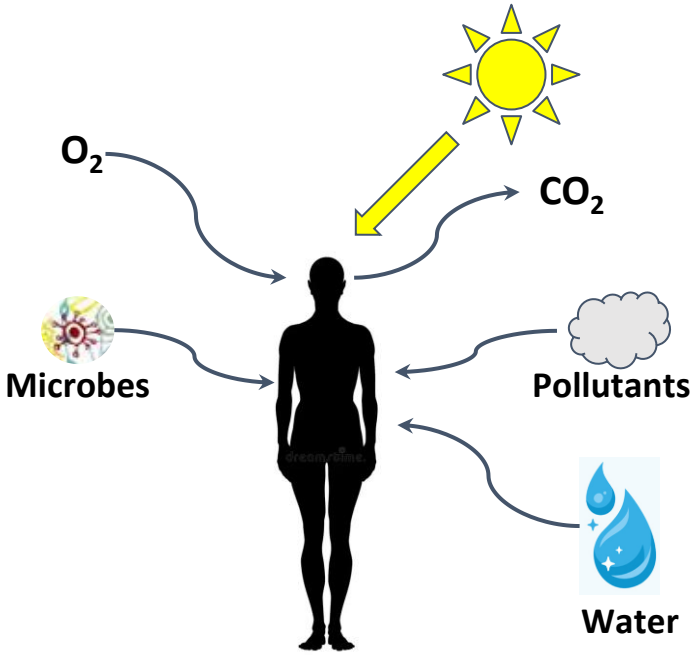


United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Ageing 2017 - Highlights* (ST/ESA/SER.A/397).

Global Trends: Global population is aging and older people tend to stay indoors more often: While "homebound" is obvious, elderly people also spend time in other indoor spaces rather than home.

- Approximately 19.6% of older adults are considered homebound, meaning they rarely or never leave their homes. Homebound individuals often experience higher healthcare utilization and expenditures. PubMed.
- Statistics show that adults 65 and older are more likely to volunteer than younger adults, often due to having more free time. The Guardian

Key Factor 2 *(Page 1 of 2)*
IEQ Can Become Part of Our Bodies



Environmental Elements Can Become Physically Part of Our Bodies

We are shaped by our environment and some environmental elements can actually become part of us.

Light:

Sunlight (Vitamin D): Sunlight is a direct environmental influence on our bodies. When our skin is exposed to sunlight, it synthesizes vitamin D, which is necessary for calcium absorption and bone health.

Air:

- **Oxygen**: We inhale oxygen from the air around us, and our cells use it to produce energy. The oxygen from the environment is literally incorporated into our bloodstream and used by our cells.
- **Carbon Dioxide**: As a waste product of cellular processes, we exhale carbon dioxide back into the environment, completing the cycle.
- **Microbes:** The microbes we breathe can become part of our body, especially as they colonize our respiratory system or contribute to the body's microbiome. Most microbes we inhale are harmless and may even help us maintain a healthy balance in our immune system and overall health
- **Pollutants**: Pollutants or toxins in the air can enter the body and affect our health, whether through respiratory systems or even through skin absorption.

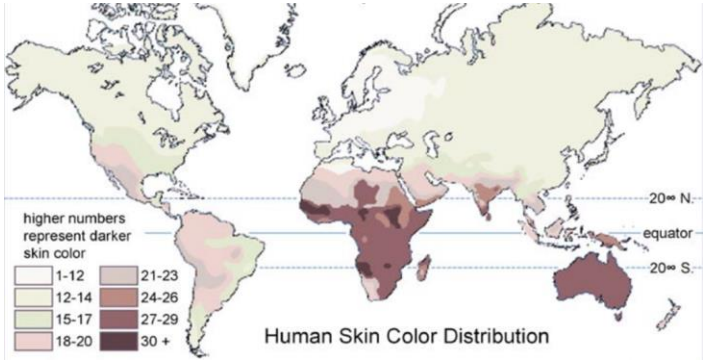
Water:

- .**Water**: The water we drink, as well as droplets and moisture in the air can become a part of our bodies.

Key Factor 2 *(Page 2 of 2)*
Long and Short-Term Acclimations

Acclimation (Short Term):
Heat
Cold
Altitude

Acclimation (Long Term):
Skin Color
Lung Capacity
Adaptation of nasal passages



Barsh GSWhat controls variation in human skin color? PLoS Biol 1:E27 - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Relationship-of-Skin-Color-to-Latitude-A-A-traditional-skin-color-map-by-Biasutti_fig1_9055512 [accessed 1 May 2025]

Acclimatization (Short-Term Adjustments) - These are temporary or short-term changes that occur in response to environmental conditions, typically within hours to weeks.

- **Heat**: When exposed to high temperatures, the body sweats more to cool.
- **Cold**: In cold environments, the body restricts blood flow to the skin to conserve heat, and shivering increases to generate warmth. Over time, the body becomes better at regulating temperature in colder environments.
- **Altitude**: In high-altitude environments, where oxygen is thinner, the body responds by increasing the production of red blood cells (which carry oxygen), improving lung capacity, and increasing the efficiency of oxygen utilization in the blood. This adaptation can take days to weeks to fully develop.

Physical Adaptations (Long-Term Changes) - These are more permanent, evolutionary changes that occur over many generations due to environmental pressures.

- **Skin Color**: In areas with high sun exposure (like near the equator), people tend to have darker skin, which provides more protection against harmful ultraviolet (UV) radiation. In areas with less sunlight (like northern latitudes), people tend to have lighter skin, which allows for more efficient production of vitamin D in response to the limited sunlight
- **Lung Capacity**: People living at high altitudes tend to have larger lung capacities and higher hemoglobin levels in their blood, which helps compensate for the lower oxygen levels in the air.
- **Nasal Passages**:Humans adapted to cold-dry environments exhibit turbinate morphologies that enhance contact between respired air and nasal
- mucosa to facilitate respiratory air conditioning.

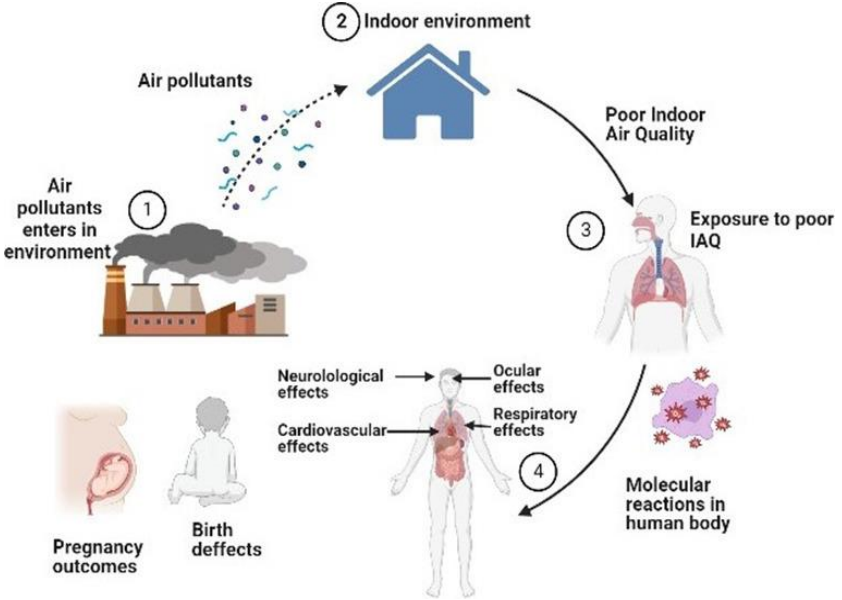
Key Factor 3 *(Page 1 of 13)*
Physical Health

Physical Health

General Safety - Thermal comfort helps maintain focus, posture, and reduces fatigue, preventing heat and cold stress-related hazards. Poor indoor air quality (IAQ) can lower productivity, distract individuals, and pose safety risks, including emergency situations like high CO concentrations. Inadequate lighting and high noise levels increase the risk of accidents, including falls and injuries, by impairing visibility and masking danger alerts. 1,000,000 emergency room visits per year are related to poor lit staircase accidents. (See link)

- **7%** higher injury risk indoor with days above 95 degrees than days in the low 60s. (See link)

Key Factor 3 *(Page 2 of 13)*
Physical Health



Air Pollution Impacts to Human Physical Health

Pradeep Kumar, A.B. Singh, Taruna Arora, Sevaram Singh, Rajeev Singh, Critical review on emerging health effects associated with the indoor air quality and its sustainable management, Science of The Total Environment, Volume 872, 2023, 162163, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2023.162163. (https://www.sciencedirect.com/science/article/pii/S0048969723007799)

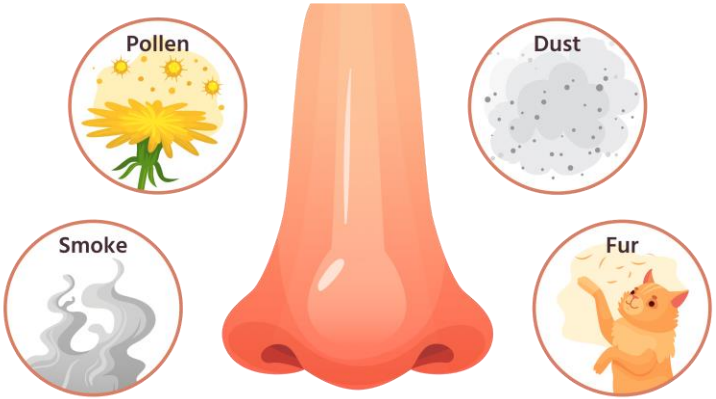
Physical Health

Respiratory Issues

Poor indoor air quality can significantly affect respiratory health, exacerbating conditions like asthma, allergies, bronchitis, and Chronic Obstructive Pulmonary Diseases (COPD). Exposure to pollutants such as PM2.5, NO2, radon, lead, and carbon monoxide can increase risk of long-term health issues, including poisoning, lung cancer, and respiratory infections, particularly in children and vulnerable populations.

- **50%** more likely for children living in a home with damp or mold to have asthma or wheezing. (See link)
- **78%** Increase in risk of acute lower respiratory infections in children under 5. HouseFresh+1R.S. Andrews+1
- Impact of Dampness and Mold: The U.S. Environmental Protection Agency reports that dampness and mold in indoor environments can increase the risk of respiratory issues by **30% to 50%.** Wikipedia
- Contribution to Chronic Obstructive Pulmonary Disease (COPD): Indoor air pollution is a significant risk factor for COPD, particularly in never-smokers, contributing to **20–25%** of cases. PMC

Key Factor 3 *(Page 3 of 13)*
Physical Health



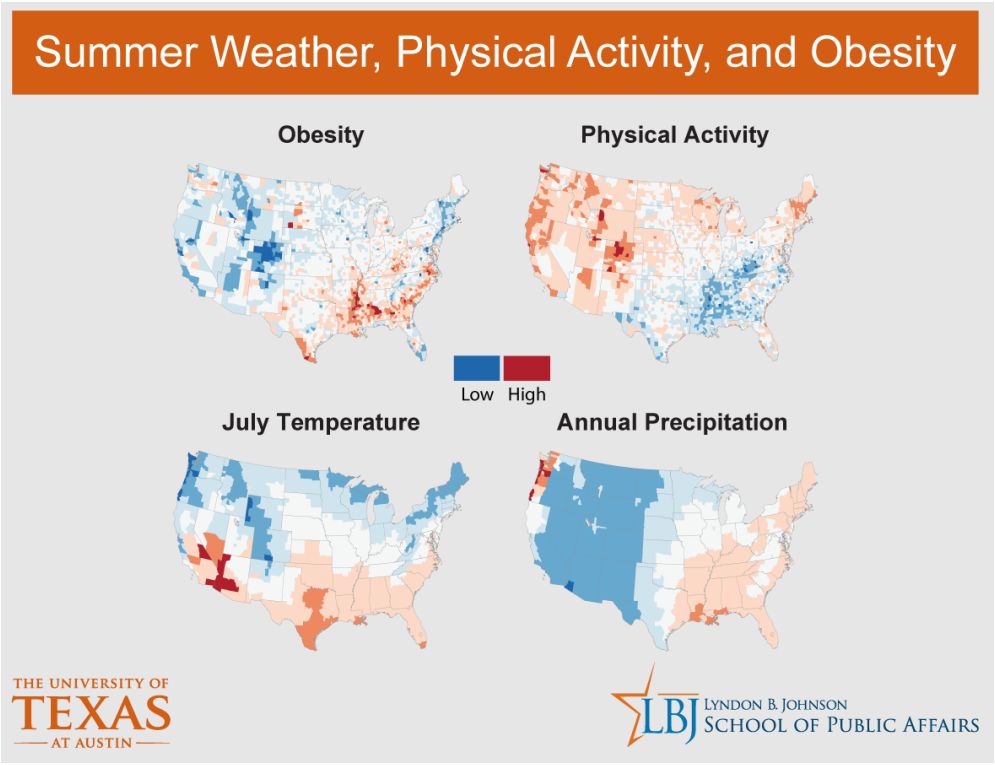
Allergens

Physical Health: Allergies and Autoimmune Disorder

Poor Indoor Environmental Quality (IEQ) can worsen allergies by increasing exposure to airborne allergens like dust mites, mold, and pet dander. Insufficient ventilation and high humidity can promote mold growth and allergen buildup, triggering symptoms like sneezing and wheezing (See link). In individuals with autoimmune disorders, poor IEQ may contribute to chronic inflammation and immune system dysregulation, potentially worsening symptoms. Toxins, allergens, and pollutants in the indoor environment can stress the body, exacerbating both allergic and autoimmune conditions.

- **80%** of people in the United States are exposed to dust mites which can be improved with better ventilation. (See link).
- Overall Indoor Allergens: More than **50%** of all allergic diseases are caused by indoor allergens, with significant contributors being cats, dust mites, and molds. PubMed

Key Factor 3 *(Page 4 of 13)*
Obesity and Type 2 Diabetes



Credit: Too hot to exercise? New research links obesity to temperature and humidity https://medicalxpress.com/news/2014-06-hot-links-obesity-temperature-humidity.html

Physical Health: [Obesity and Type 2 Diabetes]

- Mild cold and heat exposure can aid in combating obesity and type 2 diabetes by increasing metabolism and improving insulin sensitivity. Additionally, environmental factors like PM2.5 and noise pollution can contribute to the development or worsening of type 2 diabetes.
- 6.3% of the obesity and 17.9% of the Type 2 Diabetes, can be explained with an elevated level of PM2.5.
- An observational study involving 60 households found that exposure to indoor gaseous pollutants, such as carbon monoxide (CO), carbon dioxide (CO_2), and total volatile organic compounds (TVOCs), was associated with increased risks of obesity indicators. For instance, every interquartile range (IQR) increase in CO exposure was linked to a 71% higher risk of overweight (BMI ≥ 25 kg/m²) and a 92% higher risk of high body fat percentage. Similarly, each IQR increase in CO_2 exposure corresponded to a 77% higher risk of overweight, a 61% higher risk of abdominal obesity, and a 51% higher risk of high body fat percentage. TVOCs showed even stronger associations, with a 114% higher risk of overweight and a 97% higher risk of abdominal obesity per IQR increase. [PMCMDPI]

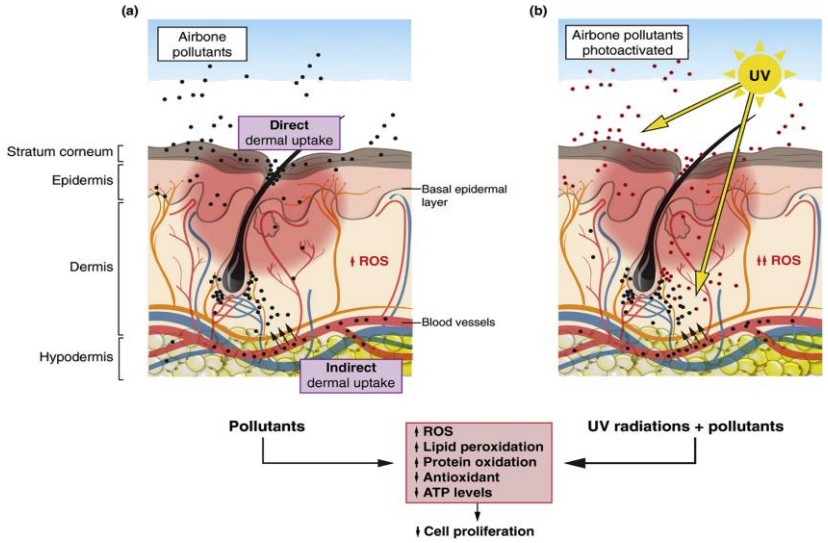
Key Factor 3 *(Page 5 of 13)*
Building-Related Illness

Building-Related Illness Symptoms

Physical Health: Building-Related Illness

- Poor indoor environmental quality (IEQ) can lead to Building-Related Illness (BRI), causing symptoms like headaches, fatigue, and eye irritation, often relieved by improving ventilation and reducing pollutants. Factors like thermal environment, inadequate lighting, noise, and poor ergonomics can also contribute to BRI, with studies showing that higher ventilation rates help reduce symptoms in affected spaces.
  - **20%** to **30%** fewer occupants reported BRI symptoms in study spaces with higher level of ventilation.
  - A study published in *Occupational and Environmental Medicine* found that after workers moved into a building with an improved ventilation system, the prevalence of BRI symptoms decreased by 40% to 50% within six months. This reduction was maintained over a three-year period. PubMed+2PubMed+2AIVC+2.

Key Factor 3 *(Page 6 of 13)*
Skin and IEQ



Airborne Pollutants Impacts to Skin

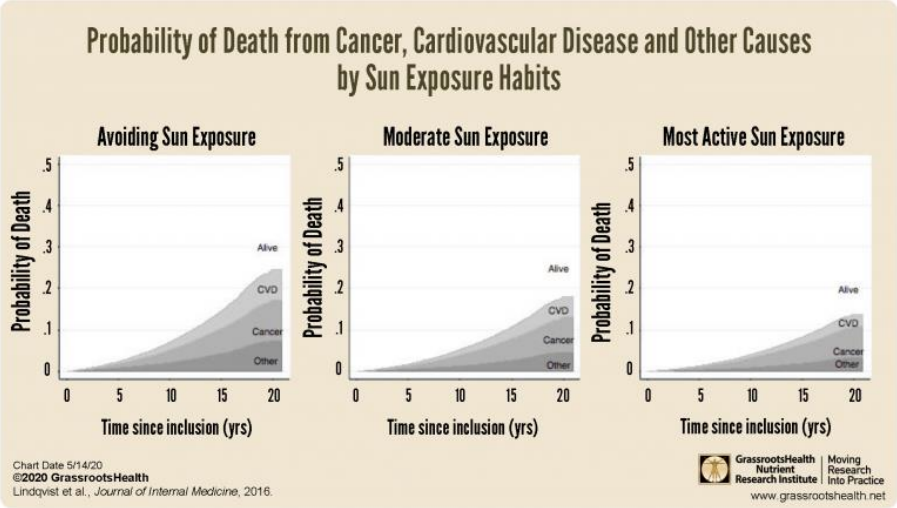
Araviiskaia, E., Berardesca, E., Bieber, T., Gontijo, G., Sanchez Viera, M., Marrot, L., Chuberre, B. and Dreno, B. (2019), The impact of airborne pollution on skin. J Eur Acad Dermatol Venereol, 33: 1496-1505. https://doi.org/10.1111/jdv.15583 from, https://www.sciencedirect.com/science/article/pii/S0891584919314984

Physical Health: Skin and IEQ

Exposure to indoor pollutants like VOCs, chemicals, and low humidity can lead to skin irritation, dryness, and conditions like eczema, hives, and premature aging. Long-term exposure to pollutants, including PM2.5 and UV radiation, can damage the skin's barrier function, increase inflammation, and exacerbate dermatological issues, such as acne and sensitivity.

- 20% increase in pigment spots on the forehead and cheeks due to traffic-related air pollution of PM 2.5 (See link**)**
- A study comparing cleanroom workers in ultra-low humidity (relative humidity less than 2.5%) to those in general environments (40–70% humidity) found that dermatologic symptoms were approximately **2.6 times more prevalent** among workers in low-humidity settings (42% vs. 16%). Additionally, the prevalence of atopic dermatitis was significantly higher in the low-humidity group (33% vs. 6%). NCBI

Key Factor 3 *(Page 7 of 13)*
Building-Related Illness



https://www.grassrootshealth.net/blog/research-shows-lifetime-sunshine-exposure-can-help-live-longer/

Physical Health: Increased Risk of Illness

Poor indoor environmental quality (IEQ) can weaken the immune system, increasing susceptibility to infections and respiratory issues. Factors like inadequate ventilation, not achieving thermal comfort, and lack of daylight exposure contribute to health risks, while maintaining relative humidity between 30-60% can help minimize microbial growth.

- 94% less likely for individuals with household sunlight exposure to be diagnosed with tuberculosis than those without. (See link)

Key Factor 3 *(Page 8 of 13)*
Legionnaires' Disease

Legionnaire Disease Transmission Paths

Credit: Image publically available for free at CDC.gov, https://www.cdc.gov/legionella/causes/index.html

Physical Health: Legionnaires' Disease

Spread of Legionnaires' disease can be through fostering the growth of *Legionella* bacteria in warm, stagnant water systems like cooling towers and plumbing. Inadequate ventilation, improper temperature regulation, and high humidity can allow aerosolized droplets containing the bacteria to spread indoors, increasing the risk of inhalation.

- 5.5 times growth in legionnaire diseases from 2000 - 2017 (See link)
- 90% of legionnaire diseases are preventable per CDC (See link)
- Research indicated that implementing copper-silver ionization and ultraviolet light treatments led to a 95% and 97% reduction, respectively, in Legionella positivity in environmental samples.
  American Journal of Infection Control

Key Factor 3 *(Page 9 of 13)*
Cardiovascular Issues

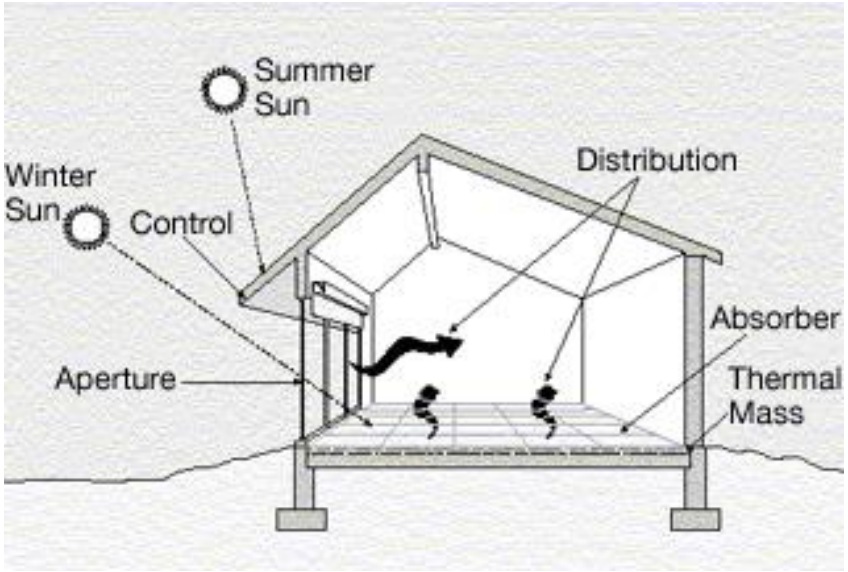
Air Quality Responsible for 25% Death of All Heart Disease

Physical Health: Cardiovascular Issues

Poor indoor air quality, extreme temperatures, humidity imbalances, and noise pollution can all increase stress on the cardiovascular system, leading to higher blood pressure and a greater risk of heart disease and stroke. Prolonged exposure to indoor pollutants and inflammation also contributes to the development of conditions like atherosclerosis, further elevating cardiovascular risks.

- **25%** of all heart disease deaths were caused by air pollution (See link)
- **0.5%** to 1.5% increases in risk of cardiovascular diseases for every 5~6 μg/m^3 increase in PM 2.5. (See link)
- **69%** increase in cardiovascular deaths after acute exposure to particulate air pollution. (See link)

Key Factor 3 *(Page 9 of 13)*
Legionnaires' Disease



Passive Survivability Elements

https://en.wikipedia.org/wiki/Passive_survivability, public domain.

Physical Health: Passive Survivability

During prolonged utilities outages, the ability to maintain minimum IEQ can mean survivability passively, especially in extreme climates.

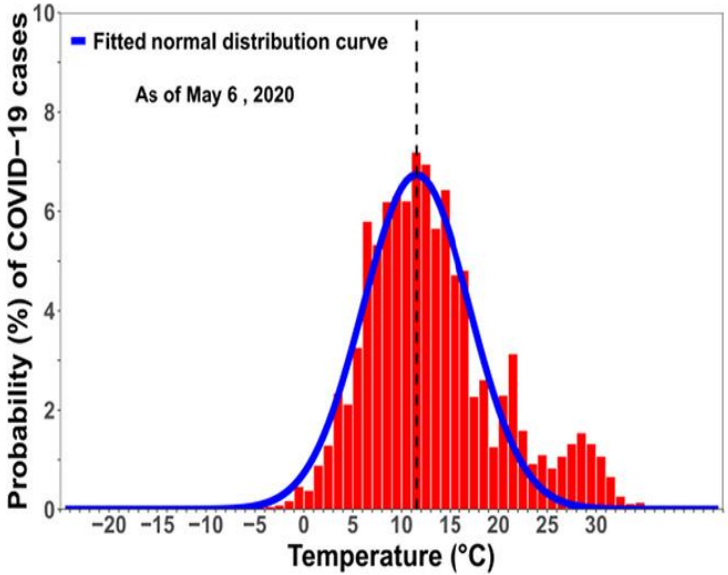
Key Factor 3 *(Page 10 of 13)*
Mental Health

IEQ Impacts Employees' Mental Health

Mental Health

- **Anxiety disorder** - Air pollution and inadequate IEQ, such as in dormitories, can increase the risk of anxiety and depressive disorders, influencing individuals' mental well-being and emotions. See link.
- **Mood disorder** - Air quality, thermal comfort, acoustic, natural light, and lighting, can significantly influence mood disorders such as depression and anxiety. Studies show that exposure to natural light, views of nature, and appropriate lighting can improve mood, alleviate stress, and enhance performance, while artificial light at night is linked to depressive symptoms and conditions like Seasonal Affective Disorder. See link
- **Neurodevelopmental disorder** - Poor indoor air quality, particularly exposure to air pollution, is linked to mental health issues like depression and anxiety, as it affects brain regions such as the hippocampus and prefrontal cortex, leading to inflammation and neurotransmitter changes. Noise pollution also exacerbates stress, memory impairment, and cognitive issues, while music therapy has shown potential in treating neurological conditions like Alzheimer's and Parkinson's disease. Thermal comfort significantly impacts mental health, with extreme temperatures—whether hot or cold—contributing to stress, anxiety, depression, social isolation, and physical discomfort, while a comfortable thermal environment promotes better sleep, mood, and cognitive function. See link

Key Factor 3 *(Page 11 of 13)*
Disease Spread in Indoor Spaces



Air Temperature Impacts to COVID-19 Infection Probability

Zhongwei Huang, Jianping Huang, Qianqing Gu, Pengyue Du, Hongbin Liang, Qing Dong, Optimal temperature zone for the dispersal of COVID-19, Science of The Total Environment, Volume 736, 2020, 139487, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2020.139487. (https://www.sciencedirect.com/science/article/pii/S0048969720330047)

Disease Transmissions

Air Flow Rates - Air flow rates, including dilution with outdoor air, filtration, airflow patterns, and disinfection technologies, are essential for reducing the risk of infectious aerosol transmission, with the ASHRAE Equivalent Clean Airflow Rate (ECAi) metric helping to quantify the necessary pathogen-free air to minimize disease spread in indoor spaces. See link

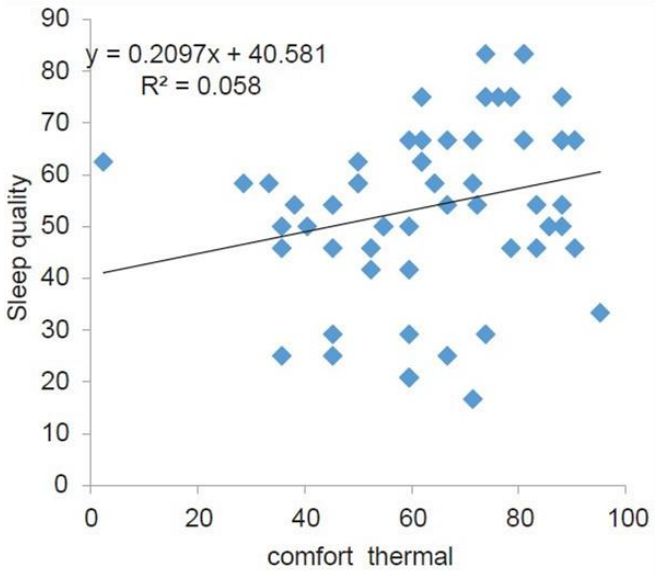
IAQ - Pollutants in the air, e.g. PM 10, PM 2.5 and carry viruses to travel longer distances. Evidence supports a clear association between air concentrations of some pollutants and human respiratory viruses interacting to adversely affect the respiratory system. See link

Light - UV light can play a role in reducing the risk of virus spread indoors. Additionally, natural light exposure can help boost immune function and regulate circadian rhythms, supporting overall health, and also reduce the active time of viruses. See link

Thermal Conditions - The thermal environment, including temperature, humidity, and airflow, can influence the spread of infectious diseases, with studies showing that airflow velocity and direction can cause pathogens to travel much further, potentially exceeding 2 meters in selected cases. See link

Improving Indoor Environmental Quality (IEQ) elements—such as ventilation, humidity control, and air filtration—can significantly reduce the transmission of infectious diseases; for instance, increasing ventilation rates in classrooms has been associated with up to an **80%** reduction in student infections. However, precise percentage impacts vary across different settings and pathogens, and comprehensive data quantifying the effects of all IEQ components on disease transmission are limited. arXiv

Key Factor 3 *(Page 12 of 13)*
IEQ and Sleep Quality



Air Temperature Impacts Sleep Quality

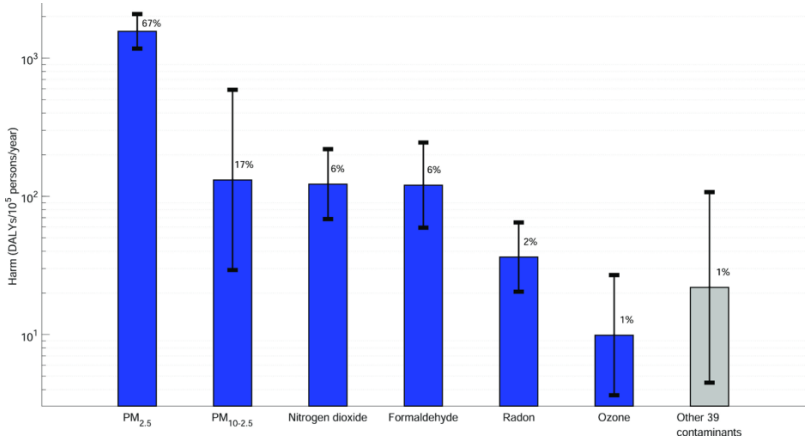
Figure from https://www.researchgate.net/figure/Scatter-plot-between-state-anxiety-and-eye-fatigue-in-shift-work-nurses_fig1_264393500, available viaCreative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported

Sleep Quality

Optimal temperature, humidity, air quality, and light exposure contributing to restful sleep, while poor conditions like excessive noise or improper thermal comfort can disrupt sleep patterns and lead to mental and physical health issues. Disruptive sounds and environmental factors like temperature extremes can negatively affect sleep, whereas calming sounds or white noise can improve sleep by reducing disturbances and promoting relaxation. See link, also refer to ASHRAE Position Document on "Ventilation, IEQ and Sleep Quality in Bedrooms"

- **Temperature**: A 1°C increase in bedroom temperature is associated with a 0.16% reduction in sleep efficiency. ScienceDirect
- **Carbon Dioxide (CO_2)**: An increase of 100 ppm in CO_2 concentration correlates with a 0.29% decline in sleep quality. ScienceDirect
- **Particulate Matter ($PM_{2.5}$)**: Higher levels of $PM_{2.5}$ are linked to a 3.2% decrease in sleep efficiency. Penn Medicine+2Daily Medical News+2Sleep Review+2
- **Noise**: Elevated noise levels contribute to a 4.7% reduction in sleep efficiency. Penn Medicine+2Daily Medical News+2Sleep Review+2
- **Humidity**: Increased humidity is associated with lower self-reported sleep quality and more daytime sleepiness.

Key Factor 3 *(Page 13 of 13)*
Long Term Health Impacts



Different Contaminants and Impacts to DALY

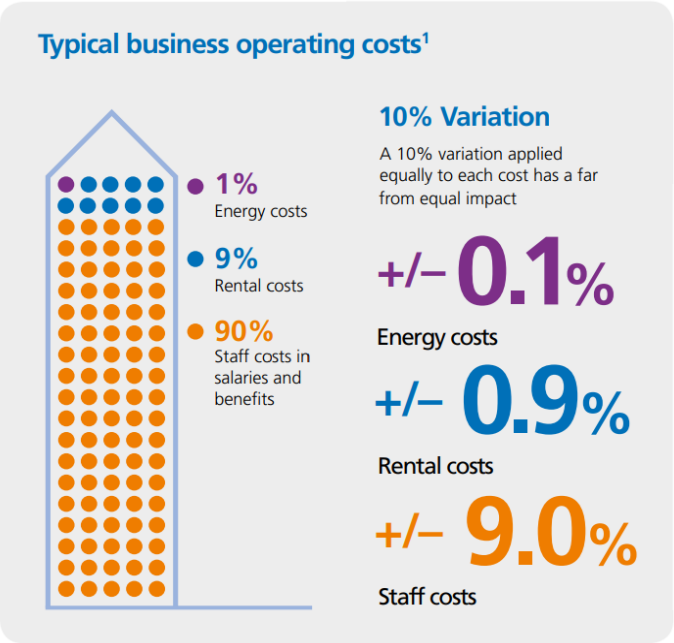
Disability-Adjusted Life Years (DALY) and long term health issues

Acoustics - The World Health Organization estimates that environmental noise results in the loss of at least 1.6 million healthy life years annually in Western Europe, with significant impacts including 61,000 DALYs lost to heart disease, 45,000 to cognitive impairment in children, and 903,000 to sleep disturbance. See link.

Light - Exposure to brighter daylight is associated with lower all-cause mortality risk, while brighter night light and disrupted circadian rhythms are linked to higher mortality risk, particularly for cardiometabolic health. Exposure to light at night, particularly brighter nights, has been linked to a 21% to 34% higher risk of premature death compared to those who experience darker nights, while brighter days are associated with a 17% to 34% lower mortality risk. See link.

IAQ - Exposure to indoor air pollution, such as from cooking with solid fuels, causes significant health impacts, including 1,000 premature deaths and 5,000 cases of chronic respiratory diseases in a population. Annually, 3.2 million people die prematurely from household air pollution, with long-term exposure increasing the risk of respiratory disease mortality by 10-20%. In 2016, ambient air pollution was responsible for 4.2 million deaths worldwide, contributing to 16% of lung cancer deaths, 25% of COPD deaths, and other respiratory and cardiovascular conditions. A study by Lawrence Berkeley National Lab, estimated population averaged annual cost, in DALYs, of chronic air contaminant inhalation in U.S. residences (AIVC, 2016) in below figure below. Also see link.

Key Factor 4 *(Page 1 of 19)*
Staffing Costs



Importance of Staffing Cost

Staffing costs while varied, can be significant in operating a building. It can be up to 90% of the operating cost of an organization. Productivity and performance increases are very important.

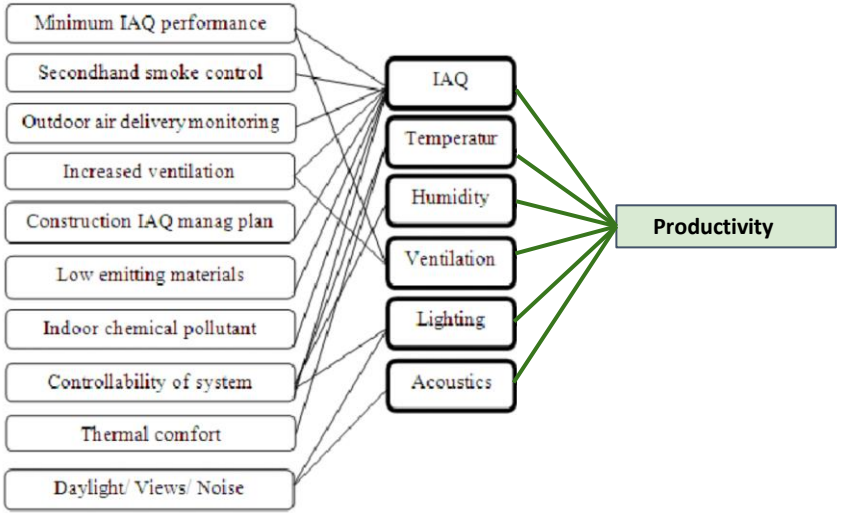
In the healthcare industry, the American Hospital Association reported that labor costs accounted for nearly 60% of total expenses for the average hospital in 2023. jobgraze.com.

For other sectors, for example, in service businesses like restaurants, labor costs can represent 22% to 40% of sales, and in some cases, even higher. (See link)

In contrast, manufacturing firms usually maintain labor costs below 30% of gross sales. (See link)

Clements-Croome, Derek & Yang, Tong. (2018). Research Roadmap for Intelligent and Responsive Buildings. https://www.researchgate.net/figure/Typical-business-operating-costs-regarding-energy-renting-and-staff-Source-Health_fig3_328225337

Key Factor 4 *(Page 2 of 19)*
Staffing Costs



IEQ Impacts on Productivity

Green Buildings Impacts on Occupants' Health and Productivity - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/EQ-occupant-wellbeing-and-productivity-structure_fig2_276948696 [accessed 29 Apr 2025] https://www.researchgate.net/figure/GBI-Point-Allocation-CBRE-2010_fig1_276948696

Overall IEQ

- Enhanced indoor environmental quality improves cognitive function by between 61% to 101%, depending on the extent of building improvements.
- Better ventilation, lighting, and environmental quality results in an NPV of $37 to $55 per square foot as a result of productivity gains from less sick time and greater worker productivity.
- Green buildings reduce day-to-day costs year-over-year. LEED buildings have reported almost 20 percent lower maintenance costs than typical commercial buildings, and green building retrofits typically decrease operation costs by almost 10 percent in just one year. Investing in IEQ improvements can yield substantial returns. Research from the U.S. Green Building Council shows that every dollar invested in green building features often results in an average ROI of **$2 to $3** due to savings in energy, operational costs, and enhanced productivity.

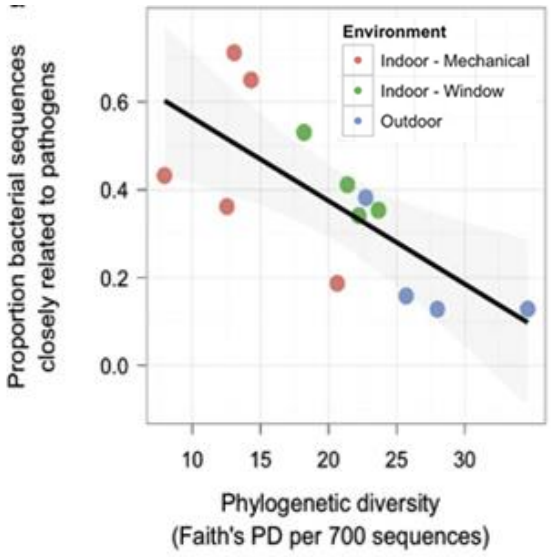
Key Factor 4 *(Page 3 of 19)*
Staffing Costs

Graphic from State of Indoor Air Quality in 2023: Market Landscape, Trends and Opportunities, and Global Data Benchmarks, p.13
https://learn.kaiterra.com/en/resources/iaq-in-2023-insights-from-325-industry-professionals

IAQ

- 61% of the employees and occupants concern about IAQ
- 2020 study: 3–6 times returns for increased ventilation, 8 times returns for increased filtration, and up to 60 times returns when all improvements and related benefits are combined.
- Improve outdoor air rates with better delivery can provide 8% to 11% improved office performance. The World Green Building Council estimates that if staff productivity improves by even a conservative 5% because of improved IAQ, that alone would be worth $410 per sq m.(See 2011 lab test, 2003 study, 2006 study)
- A meta-analysis of five studies involving 3,679 participants found that higher ventilation rates improved task performance speed by 13.7% in arithmetic tasks and reduced error rates by 16.1%. See link PubMed

Key Factor 4 *(Page 4 of 19)*
Natural Ventilation



Window Brings in More Diverse Microbes with Less Pathogens

Figure from Architectural design influences the diversity and structure of the built environment microbiome
https://www.nature.com/articles/ismej2011211

Natural Ventilation

- A comprehensive analysis by Carnegie Mellon concluded that natural ventilation or mixed-mode conditioning could achieve 0.8 - 1.3% savings on health costs, 3 - 18% productivity gains, and 47 - 79% in HVAC energy savings, for an average ROI of at least 120%.
- Natural ventilated buildings through windows tend to have a more diverse microbiome and less pathogens.
- This article suggests according to 12 independent studies, productivity could be increased by up to 18% in the built environment, just by incorporating natural and mixed mode ventilation in comparison to purely mechanical systems. Though the average increase in productivity is 8%.

Key Factor 4 *(Page 5 of 19)*
Thermal Comfort

Thermal Comfort

- Employees made 44% more mistakes at low temperature than at optimal room temperature.
- “Personal Environment” - individual control over temperature (in a 4°C range) led to an increase of about 3% in logical thinking performance and 7% in typing performance. Another suggests up to 3% gains in overall productivity as a result of personal control of workspace temperature.
- 2006 study indicated 10% reduction in performance at both 30C and 15C compared with a baseline between 21C and 23C.
- A study in controlled setting indicated a reduction in performance of 4% at cooler temperatures, and a reduction of 6% at warmer ones.
- The concept of dynamic thermal comfort/Alliesthesia suggests that non-steady-state environments can enhance comfort. A study on temperature fluctuations showed that cyclic fluctuating air temperatures between 26°C–28°C can lead to lower thermal dissatisfaction compared to constant temperatures at 26°C, while also using less energy. Moreover, fluctuating temperatures potentially can result in similar or even lower stress and fatigue levels compared to constant temperatures. See link.
- In this study, team from LBNL suggested relative performance follows an inverted bell curve with temperatures.

Key Factor 4 *(Page 5 of 19)*
Lighting Considerations

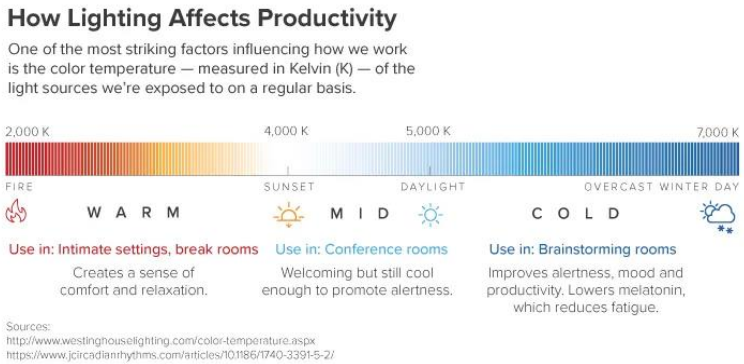
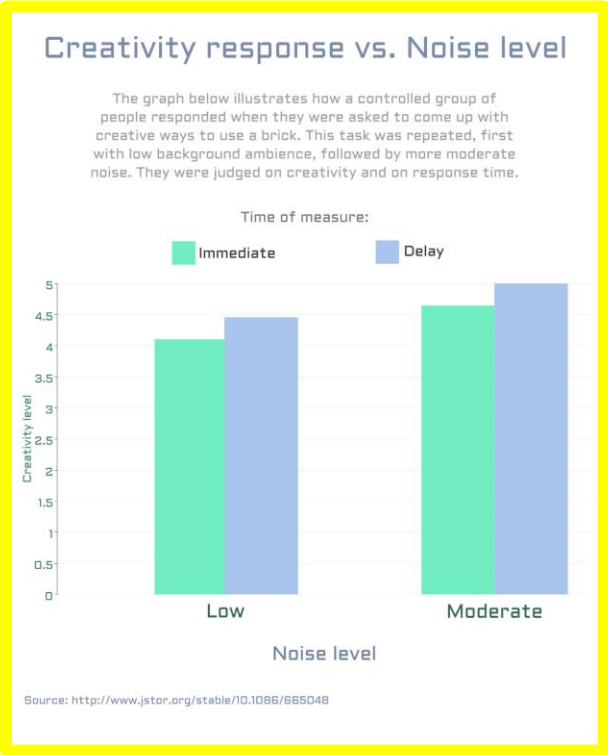


Figure from MBA@UNC, UNC Kenan-Flagler's online MBA program
https://onlinemba.unc.edu/news/how-lighting-affects-productivity/

Visual/Light

- Best possible view of natural light performed between 10% and 25% better on mental function and memory recall.
- 47% of employees admit they feel tired or very tired from the absence of natural light or a window at their office, and 43% report feeling gloomy because of the lack of light.
- A study by neuroscientists suggested that office workers with windows received 173 percent more white light exposure during work hours, and slept an average of 46 minutes more per night.
- A comprehensive study conducted measurements of the physical environment and occupant satisfaction for 779 workstations in 9 different buildings, and suggested that lack of access to a window was the biggest risk factor for dissatisfaction with lighting.
- Different color of light, per this study, can affect productivity in different environments.
- Visual of urban greenery with trees on a city block has notable psychological benefits, equivalent to the impacts of $10,000/year/person or 7 years younger. See link.

Key Factor 4 *(Page 6 of 19)*
Effects of Noise Level

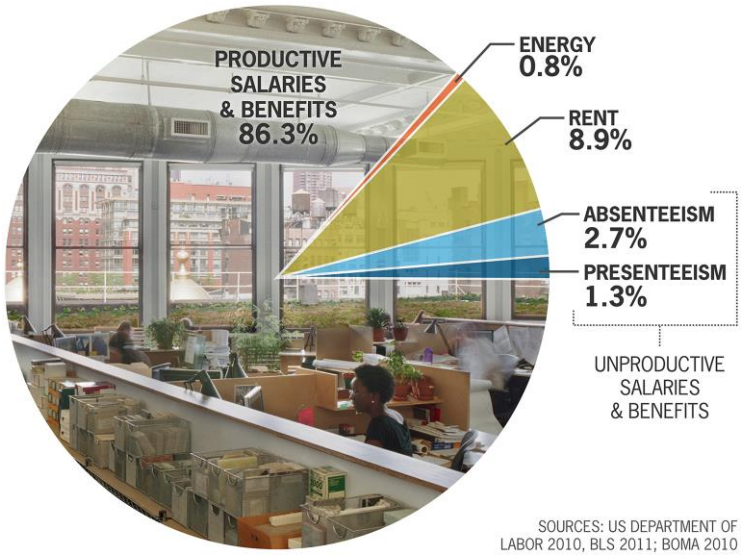


Acoustic:

- Meta-analysis of the impact of 1 dB (dB) increase in environmental noise on reading and language abilities decreases performances.
- There was up to a 66% drop in performance for a ‘memory for prose’ task when participants were exposed to different types of background noise. A follow-up study by the same authors in 2005 found that 99% of people surveyed reported that their concentration was impaired by office noise such as unanswered phones and background speech.
- when a worker's environmental sound level was above 50 decibels, each 10-decibel increase was related to a 1.9% decrease in physiological well-being. But when office sound was lower than 50 decibels, each 10-decibel increase related to a 5.4% increase in physiological well-being
- In this paper, a group’s creativity in relation to surrounding noise level is tested. The group was asked to come up with as many ‘*creative uses of a brick*‘ as possible, and then judged on their immediate and delayed response times. The graph to the left shows how background noise affected their performance:

https://www.agencycentral.co.uk/articles/is-silence-golden-how-office-noise-affects-productivity/

Key Factor 4 *(Page 7 of 19)*
Absenteeism



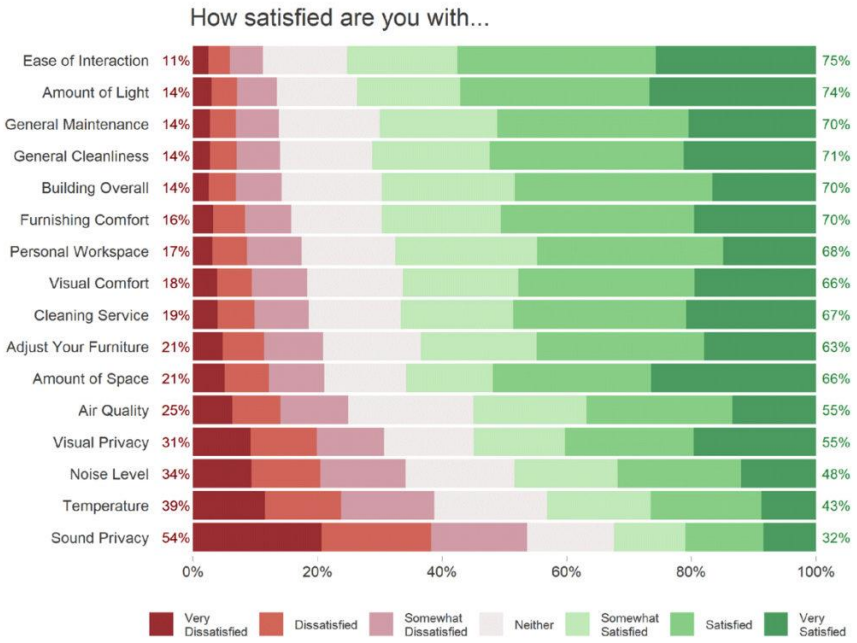
Absenteeism and Presenteeism Impacts

Image from The Economics of Biophilia, https://www.terrapinbrightgreen.com/reports/the-economics-of-biophilia/, Terrapin Bright Green, LLC

Absenteeism:

- IAQ: Short term sick leave was found to be 35% lower in offices ventilated by an outdoor air supply rate of 24 l/s compared to buildings with rates of 12 l/s in a 2000 study . The same study estimated the value of increased ventilation to be $400 per employee per year.
- While enhanced productivity solely as a function of improved health is still to be quantified, studies have calculated that employees tend to take 30% fewer sick leaves as a result of improved IAQ.
- Increased ventilation and higher grade air filtration (MERV-13 filters or higher) have been shown to result in a 9-20% annual reduction in sick leave. When implemented appropriately, these improvements can result in up to 60x return on investment in the form of worker reliability and productivity. See link
- Lighting and View: A study in 2011 investigated the relationship between view quality, daylighting and sick leave of employees in administration offices. Taken together, the two variables explained 6.5% of the variation in sick leave, which was statistically significant.
- World Green Building Council Report in 2015:
  - Absenteeism in US is 3% per employee in the private sector and 4% in the public sector, costing employers $2.074 and $2,502 per employee per year.
  - Poor mental health specifically costs UK employers £30 billion a year through lost production, recruitment and absence.
  - Absenteeism in Australia is estimated at A$7 billion per year, while the cost of “presenteeism” (not functioning at work because of medical conditions) is estimated to be A$26 billion

Key Factor 4 *(Page 8 of 19)*
Improved IEQ Boosts Job Satisfaction



https://cbe.berkeley.edu/centerline/lessons-learned-from-20-years-of-cbe-occupant-surveys/

Well Being and Employee Retention

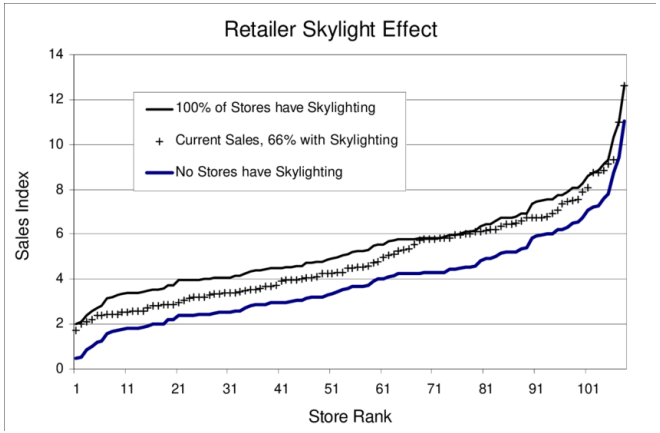
- IEQ Survey: U of California, CBE Survey Database reviewed IEQ issues are top of the list in terms of dissatisfactions.IEQ Survey: U of California, CBE Survey Database reviewed IEQ issues are top of the list in terms of dissatisfactions. See link.
- Improving environmental quality (IEQ) boosts job satisfaction, aids in attracting and retaining talent by aligning with sustainability efforts, and enhances cognitive performance and psychological well-being through exposure to nature. Interface Inc. found that 71% of full-time workers consider a company's commitment to sustainability an important criterion when evaluating a new workplace. Research also suggests that natural sounds in offices can improve mood, cognitive abilities, and provide privacy.

Key Factor 4 *(Page 9 of 19)*
IEQ Impacts on Student Performance

Student Performance

- Lighting
  - Three studies collectively underscore the positive impact of daylighting on student learning, with improvements ranging from 7% to 26% in various academic assessments. See PUPN Magazine+3Academia+3Building Enclosure Online+3; Make Great Light; PUPN Magazine+5Academia+5Make Great Light+5
- IAQ
  - Ventilation systems led to a 2 percent reduction in absenteeism and a seven percent drop in suspension rates.
  - In this study, an association of increased student performance with increased ventilation rates from a few percent to as much as 15%. See link
- Acoustic
  - Quiet classrooms were 0.80 points higher than children in noisier classrooms.
- Thermal comfort
  - In California, without air conditioning, a 1°F hotter school year reduces that year's learning by 1 percent. Hot school days disproportionately impact minority students, accounting for roughly 5 percent of the racial achievement gap, according to UCLA research
  - Cooling system replacements boosted math scores by 3 percent of a standard deviation while heating system replacements led to a rise of 4 percent

Key Factor 4 *(Page 10 of 19)*
Increased Sales



Sales Increase with Skylight

Image from Mahone, Douglas & Kuttaiah, Kalpana & Chappell, Cathy & Mchugh, Jon & Heschong, Lisa. (1999). Skylighting and Retail Sales An Investigation into the Relationship Between Daylighting and Human Performance Condensed Report for PG&E by the Heschong Mahone Group. 1999. 10.13140/RG.2.2.28809.29288. https://www.researchgate.net/publication/328965592_Skylighting_and_Retail_Sales_An_Investigation_into_the_Relationship_Between_Daylighting_and_Human_Performance_Condensed_Report_for_PGE_by_the_Heschong_Mahone_Group_1999

Sales Performance

- **Lighting:**
  - Enhancing lighting in retail environments has been shown to positively influence sales performance. For example, implementing effective strategies in lighting showrooms can increase sales by an average of 15-20%. FinModelsLab
  - Integrating daylighting—the strategic use of natural light—into retail environments has been shown to significantly boost sales performance. Studies indicate that stores incorporating daylighting can experience sales increases ranging from 10% to 40%.retailbiz+1vtechskylights.com+
  - At a Target store, sales during periods with uncovered skylights were 15% to 20% higher compared to periods when the skylights were covered, highlighting the influence of daylighting on sales performance. vtechskylights.com

- **Thermal Comfort:**
  - Residential Thermal Comfort and Sales: A study on high-rise apartments in hot and humid climates found that implementing thermal comfort-based pricing strategies led to a mean increase of 2.22% in total sale prices. This indicates that prioritizing thermal comfort can directly enhance sales revenue in the real estate sector. ASCE Library

Key Factor 4 *(Page 11 of 19)*
IEQ Impacts on Patient Recovery Time

Natural light in patient rooms

Healing and Recovery Time

- **Acoustic:**
  In this paper, half-life SCL (the half time required to recover measured by reflecting the action of sweat glands and nervous system) recovery was 9−37% faster during the nature sound than during the noises.
- **Thermal Comfort:**
  - Radiant Cooling Systems: A study compared patients with radiant cooling found a median hospital stay of 6 days, while those without had 9 days, indicating that improved thermal comfort may expedite recovery
  - For burn patients, maintaining ambient temperatures around 33°C (91.4°F) and relative humidity near 80% is recommended. This environment reduces energy demands and evaporative heat losses, potentially aiding recovery. See link
- **IAQ:**
  Implementing advanced air purification systems has been associated with a substantial decrease in airborne pathogens, leading to a reduction in HAIs. This improvement can indirectly contribute to shorter recovery times by minimizing infection risks. See NCBI
- **Lighting:**
  - A study involving 3,964 high-risk surgery patients found that rooms with natural light reduced mortality rates by 20%.
  - Mental Patients in sunny rooms had an average stay of 16.9 days, while those in dull rooms stayed an average of 19.5 days.
  - Sleep Duration Improvement: Implementing enhanced daytime brightness and restricted nocturnal light exposure improved patients' sleep duration by approximately 29 minutes (a 7.3% increase) over a five-day hospitalization period.
  - Building and Environment reported findings that patients with direct access to morning light were seeing their stays were shortened by anywhere from 16% to 41%

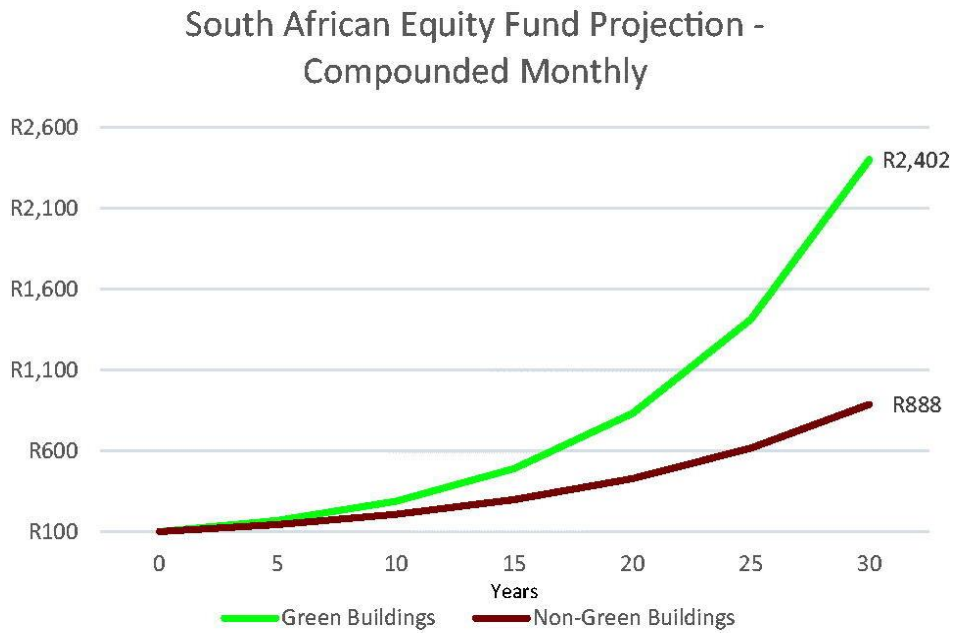
Key Factor 4 *(Page 12 of 19)*
Productivity & Financial Impacts

Financial Performance:

- **Legal Fee and Insurance Cost:**
  There is growing concern over the "silent crisis" of indoor air quality (IAQ), leading to significant legal and insurance costs, including health insurance claims, professional liability, and litigation, prompting insurers to adjust policies. As IAQ-related lawsuits increase, companies like Chevron, Samsung, and Boeing have faced millions of payouts for health issues linked to poor air quality, highlighting the financial risks of neglecting IAQ in the workplace. See link.

- **Productivity Loss and Upside:**
  A bottom-up approach considering IAQ identify different productivity loss and leads to an expected return on investment in the range of $750 to $800 per employee, with minimum of $700 per employee per year in the US.
  See the link.

Key Factor 4 *(Page 13 of 19)*
Green Buildings and Productivity



Organizational Productivity Performance

This study aimed to assess whether green buildings with IEQ focus provided any benefits in terms of organizational performance, as measured by annualized returns. The results suggested that organizations in green buildings generally achieved higher annualized returns compared to those in non-green buildings.

Nurick, S. (2022). Mind over Mortar: Examining IEQ Scores and Financial Services Companies Performance. *Journal of Sustainable Real Estate*, *14*(1), 42–56. https://doi.org/10.1080/19498276.2022.2102624
https://www.tandfonline.com/doi/full/10.1080/19498276.2022.2102624

Key Factor 4 *(Page 14 of 19)*
Economic Impacts

IEQ Impacts for US:

- Base line is 2000:
  - $6 to $14 billion productivity gain from reduced respiratory diseases
  - $1 to $4 billion from reduced allergies and asthma
  - $10 to $30 billion from reduced Building-Related Illness symptoms
  - Economizer Cycle: $20 to $160 billion from direct improvements in worker performance that are unrelated to health

- Baseline 2011, increase in ventilation from 17 to 32 cfm
  - 1.1% increase in productivity for 12.4 million workers
  - 18.8% decrease in Building-Related Illness symptoms
  - 10 million days of avoided absence

- A study on 100 office buildings suggested $0.2-1.1 billion annual economic benefit from improved particle filtration in US

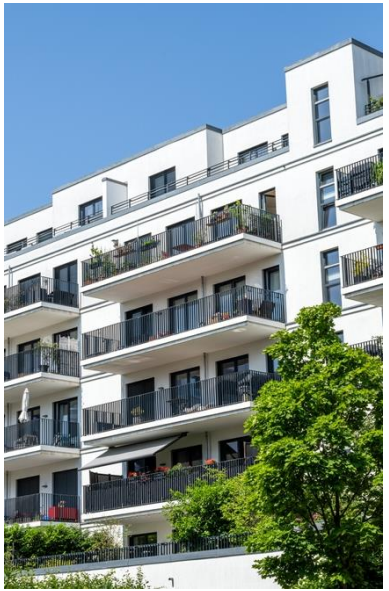
- LBL Study, regarding thermal comfort
  - $3.4 billion annual economic benefit, with $0.4 billion implementation costs, through integration of thermal occupant controls
  - Estimated $2 billion estimated annual value of work performance gains from avoiding high temperatures in the winter.

Key Factor 4 *(Page 15 of 19)*
Property Value

Property Value

Many researchers have found that indoor air quality (IAQ) effects tenant landlord relationships, workers' health and productivity, and building elements and systems. This may imply that IAQ could affect, positively or negatively, the value of buildings. This paper examines the impact of IAQ on the value of office buildings in Singapore. The results show that the return on investment in IAQ could be substantial (78.56%) while property values could increase by 1.28% to 3.85%. Another study for green buildings in general suggests sales price can be 13.3% higher. Upfront investment in green building also makes properties more valuable, with a growing number of building owners seeing a 10 percent or greater increase in asset value. The percentage of owners reporting that level of growth has nearly doubled since 2012. Green buildings are for every market and every community. Green Buildings - Published in the September 2015 issue of the *Journal of Portfolio Management* analyzed financial data from the last 10 years for nearly 300 office properties in North America.

- 6% in tenant retention
- 5-10% increases in occupancy
- 8-10% increases in value



Key Factor 4 *(Page 16 of 19)*
Higher Rent

Higher Rent

When the effects of building location, age and renovation history of a building are accounted for, LEED-certified buildings (with IEQ components) still command an average 4% rent premium; however, since the start of the COVID-19 pandemic, this premium has fallen to just 3%. Another study on financial performance of green buildings suggested a rent increase of 2.5%. A report on the Los Angeles market indicated that while traditional (non-LEED certified) buildings receive an average of $2.16/ft2, tenants were willing to pay $2.91/ft2 for LEED certified space.

Key Factor 4 *(Page 17 of 19)*
Return on Investment in Green Buildings

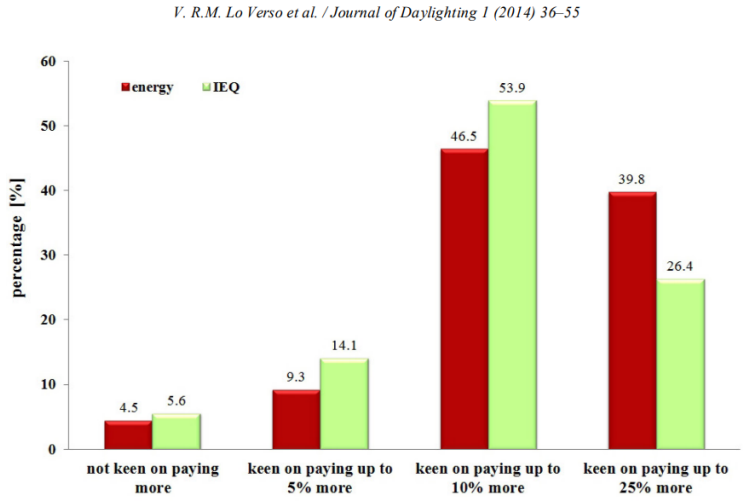
- **Green Buildings** - Published in the September 2015 issue of the *Journal of Portfolio Management* analyzed financial data from the last 10 years for nearly 300 office properties in North America. 3.7% increase in rent

- Upfront investment in green building also makes properties more valuable, with a growing number of building owners seeing a 10 percent or greater increase in asset value. The percentage of owners reporting that level of growth has nearly doubled since 2012.

Key Factor 4 *(Page 18 of 19)*
Sales of Residential Green Buildings

Sell Faster - green buildings, at least for residential, can sell faster. Certified green homes take only 52.8 - 57% of time to sell compared to non-certified homes.

Key Factor 4 *(Page 19 of 19)*
IEQ and Home Value



Willingness of the People To Pay Extra When Buying a New Home for IEQ vs. Energy Performance Technologies.

Homes

The University of Texas at Austin looked at resale value on homes in the Austin-Round Rock Metropolitan Statistical Area and found that homes built to LEED standards between 2008-2016 showed an eight percent boost in value, while homes built to a wider range of green standards saw a 6 percent increase in value.

In this paper, it was found that majority of the people are willing to pay extra when buying a new home for IEQ vs. energy performance technologies.

Lo Verso, Valerio Roberto Maria & Fregonara, Elena & Caffaro, Federica & Morisano, Caterina & Peiretti, Gian. (2014). Daylighting as the Driving Force of the Design Process: From the Results of a Survey to the Implementation into an Advanced Daylighting Project. Journal of Daylighting. 1. 36-55. 10.15627/jd.2014.5. https://www.researchgate.net/publication/273169438_Daylighting_as_the_Driving_Force_of_the_Design_Process_From_the_Results_of_a_Survey_to_the_Implementation_into_an_Advanced_Daylighting_Project

Key Factor 5 *(Slide 1 of 8)*
Global IAQ Standards

Global IAQ Guidelines

IAQ Standards Requirements

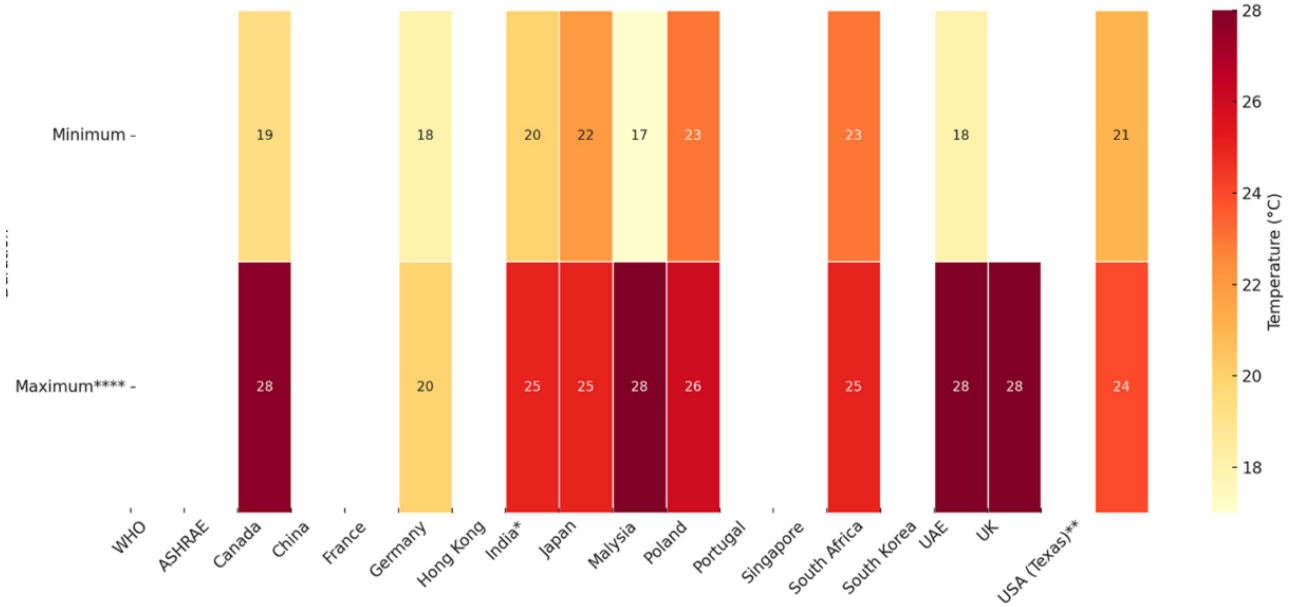
More than 50 organizations across at least 38 countries have established IAQ guidelines in occupational, commercial, or residential settings. Guidelines cover pollutants and other risks such as mold, moisture, and temperature. Although general pollutant information and source control measures are important, guidelines that include health-based numerical pollutant exposure limits are the most informative for assessing IAQ. While there is no global IAQ standard applicable to all countries, this paper appraises limit values for selected indoor pollutants reported in the scientific literature, and to present how they are handled in international and national guidelines and standards. The database is coordinated by the Scientific and Technical Committee (STC) 34, as part of ISIAQ, the International Society of Indoor Air Quality and Climate.

2015 study reviewed 31 green building certifications from 30 countries and found that 100% of these programs incorporated indoor air quality (IAQ) requirements, with an average IAQ contribution of 7.5% to the overall certification criteria. The most commonly addressed pollutants were volatile organic compounds (VOCs), formaldehyde, and carbon dioxide (CO_2), while ozone and semi-volatile organic compounds (SVOCs) were less frequently included. Key IAQ management strategies across these certifications included emission source control (77%), ventilation (100%), and indoor air measurement (65%) HERO.

Sani Dimitroulopoulou, Marzenna R. Dudzińska, Lars Gunnarsen, Linda Hägerhed, Henna Maula, Raja Singh, Oluyemi Toyinbo, Ulla Haverinen-Shaughnessy, Indoor air quality guidelines from across the world: An appraisal considering energy saving, health, productivity, and comfort, Environment International, Volume 178, 2023, 108127, ISSN 0160-4120, https://doi.org/10.1016/j.envint.2023.108127. https://www.sciencedirect.com/science/article/pii/S0160412023004002

Key Factor 5 *(Slide 2 of 8)*
*W*idely Accepted IAQ Guidelines & Standards

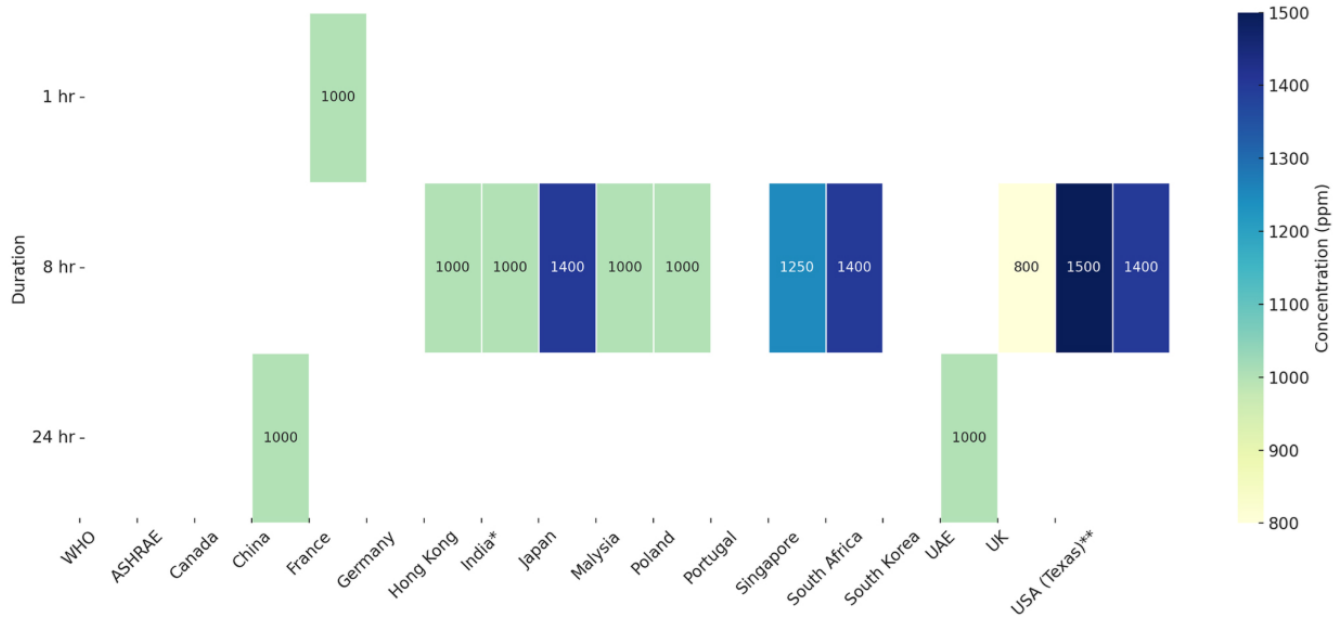
Thermal and IAQ International Standard: This paper comprehensively synthesize the current status of widely accepted IAQ guidelines and standards. It analyzes their global implementation and effectiveness to offer insights into challenges and disparities in IAQ policies and practices. See below for summary diagram:



Recommended Exposure of Dry Bulb Temperatures in Various Countries

Siddique, Azhar, Al-Shamlan, Maryam Y. M., Al-Romaihi, Hamad E. and Khwaja, Haider A.. "Beyond the outdoors: indoor air quality guidelines and standards – challenges, inequalities, and the path forward" Reviews on Environmental Health, vol. 40, no. 1, 2025, pp. 21-35. https://doi.org/10.1515/reveh-2023-0150
https://www.degruyter.com/document/doi/10.1515/reveh-2023-0150/html

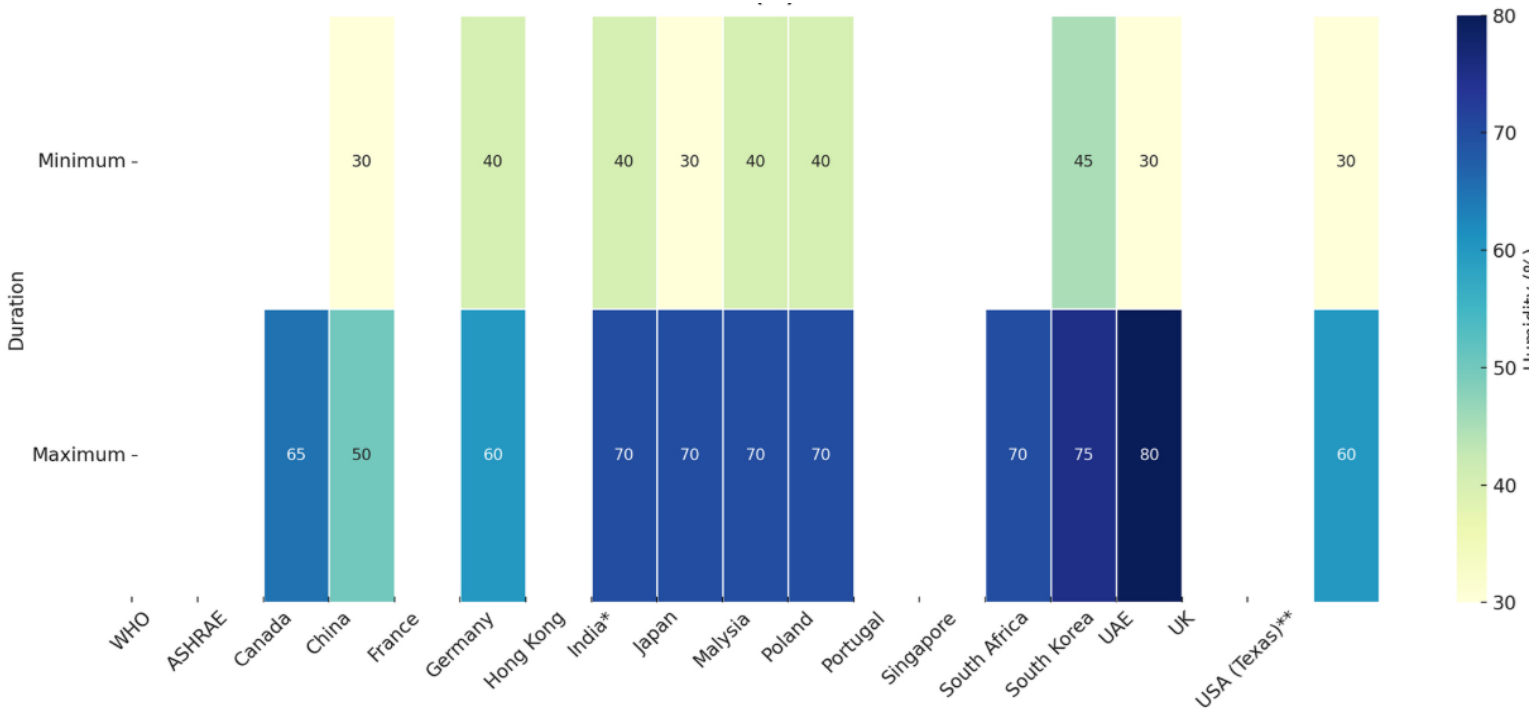
Key Factor 5 *(Slide 3 of 8)*
Carbon Dioxide Exposure



Recommended Exposure of CO2 in Various Countries with Different Exposure Duration
(value of 1,400 derived from ambient + 700)

Siddique, Azhar, Al-Shamlan, Maryam Y. M., Al-Romaihi, Hamad E. and Khwaja, Haider A.. "Beyond the outdoors: indoor air quality guidelines and standards – challenges, inequalities, and the path forward" Reviews on Environmental Health, vol. 40, no. 1, 2025, pp. 21-35. https://doi.org/10.1515/reveh-2023-0150

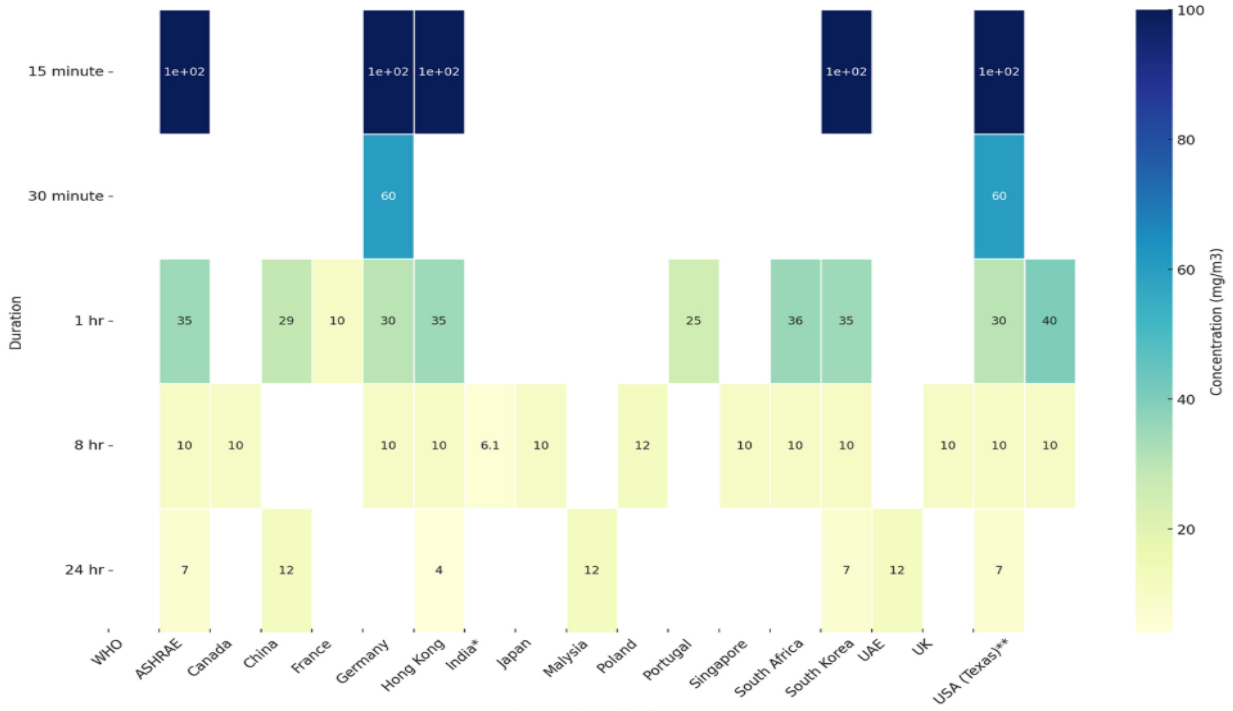
Key Factor 5 *(Slide 3 of 8)*
Recommended Exposure of RH



Recommended Exposure of RH in Various Countries

Siddique, Azhar, Al-Shamlan, Maryam Y. M., Al-Romaihi, Hamad E. and Khwaja, Haider A.. "Beyond the outdoors: indoor air quality guidelines and standards – challenges, inequalities, and the path forward" Reviews on Environmental Health, vol. 40, no. 1, 2025, pp. 21-35. https://doi.org/10.1515/reveh-2023-0150

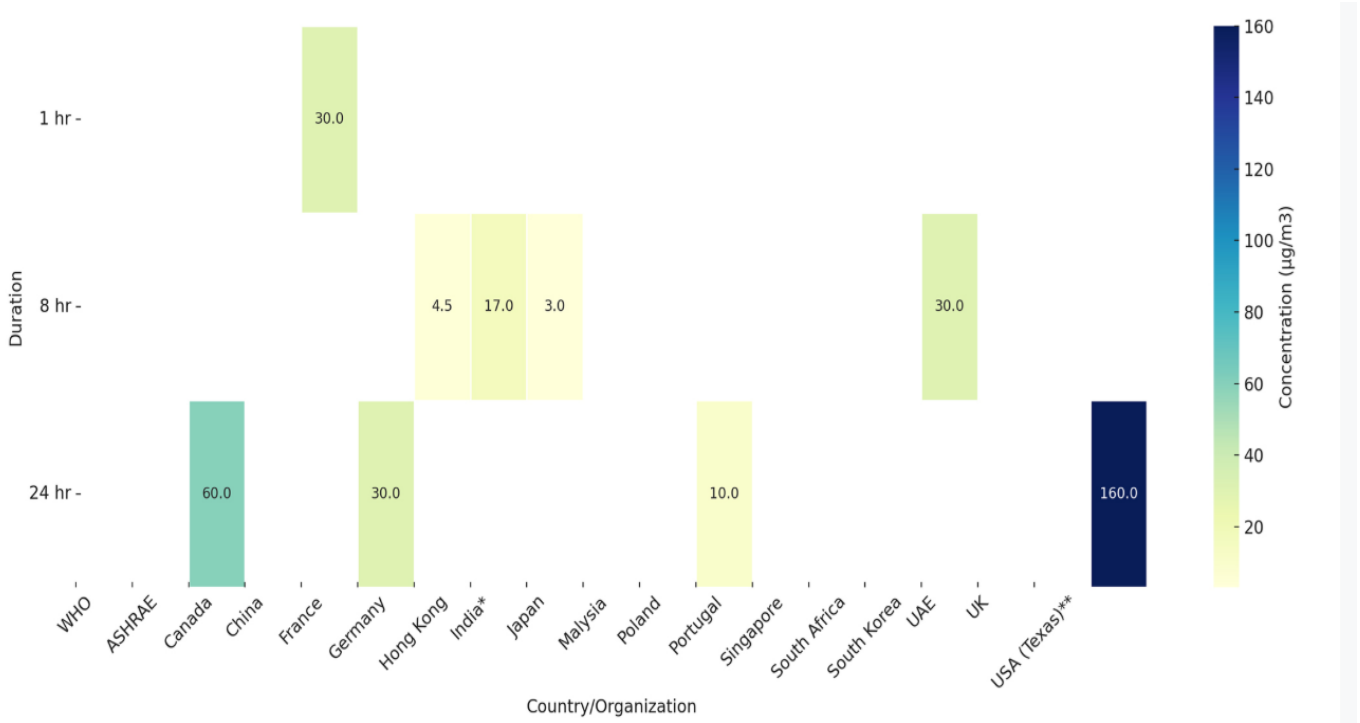
Key Factor 5 *(Slide 4 of 8)*
Recommended Exposure of CO



Recommended Exposure of CO in Various Countries with Different Exposure Duration

Siddique, Azhar, Al-Shamlan, Maryam Y. M., Al-Romaihi, Hamad E. and Khwaja, Haider A.. "Beyond the outdoors: indoor air quality guidelines and standards – challenges, inequalities, and the path forward" Reviews on Environmental Health, vol. 40, no. 1, 2025, pp. 21-35. https://doi.org/10.1515/reveh-2023-0150

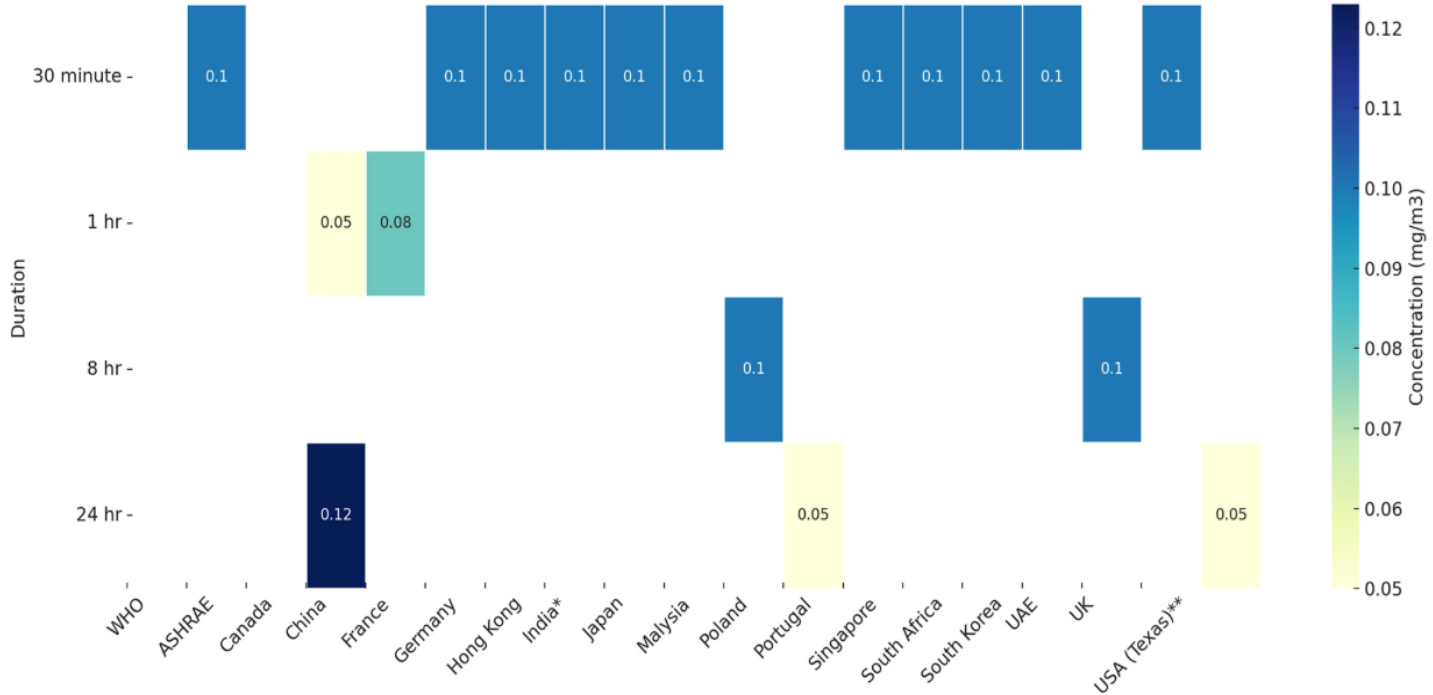
Key Factor 5 *(Slide 5 of 8)*
Recommended Exposure of Benzene



Recommended Exposure of Benzene in Various Countries with Different Exposure Duration

Siddique, Azhar, Al-Shamlan, Maryam Y. M., Al-Romaihi, Hamad E. and Khwaja, Haider A.. "Beyond the outdoors: indoor air quality guidelines and standards – challenges, inequalities, and the path forward" Reviews on Environmental Health, vol. 40, no. 1, 2025, pp. 21-35. https://doi.org/10.1515/reveh-2023-0150

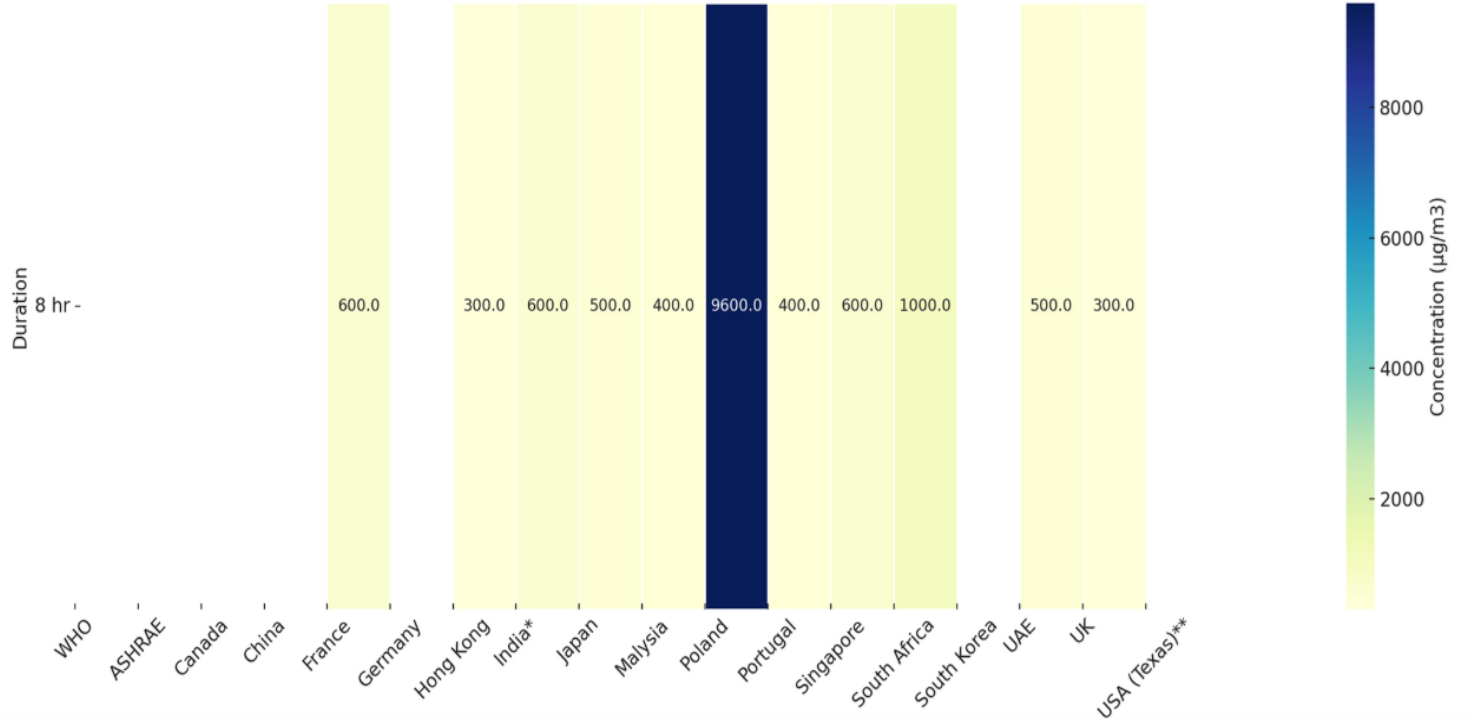
Key Factor 5 *(Slide 6 of 8)*
Recommended Exposure of Formaldehyde



Recommended Exposure of Formaldehyde in Various Countries with Different Exposure Duration

Siddique, Azhar, Al-Shamlan, Maryam Y. M., Al-Romaihi, Hamad E. and Khwaja, Haider A.. "Beyond the outdoors: indoor air quality guidelines and standards – challenges, inequalities, and the path forward" Reviews on Environmental Health, vol. 40, no. 1, 2025, pp. 21-35. https://doi.org/10.1515/reveh-2023-0150

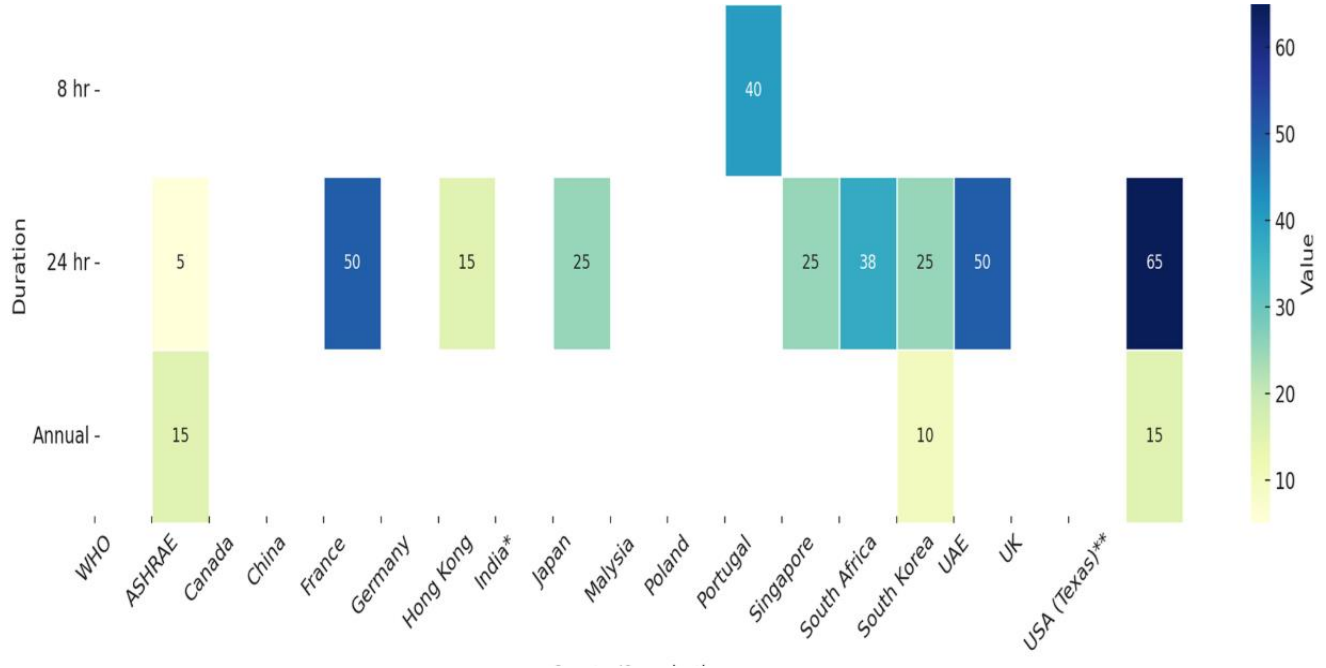
Key Factor 5 *(Slide 7 of 8)*
Recommended Exposure of VOCs



Recommended Exposure of VOC in Various Countries with Different Exposure Duration

Siddique, Azhar, Al-Shamlan, Maryam Y. M., Al-Romaihi, Hamad E. and Khwaja, Haider A.. "Beyond the outdoors: indoor air quality guidelines and standards – challenges, inequalities, and the path forward" Reviews on Environmental Health, vol. 40, no. 1, 2025, pp. 21-35. https://doi.org/10.1515/reveh-2023-0150

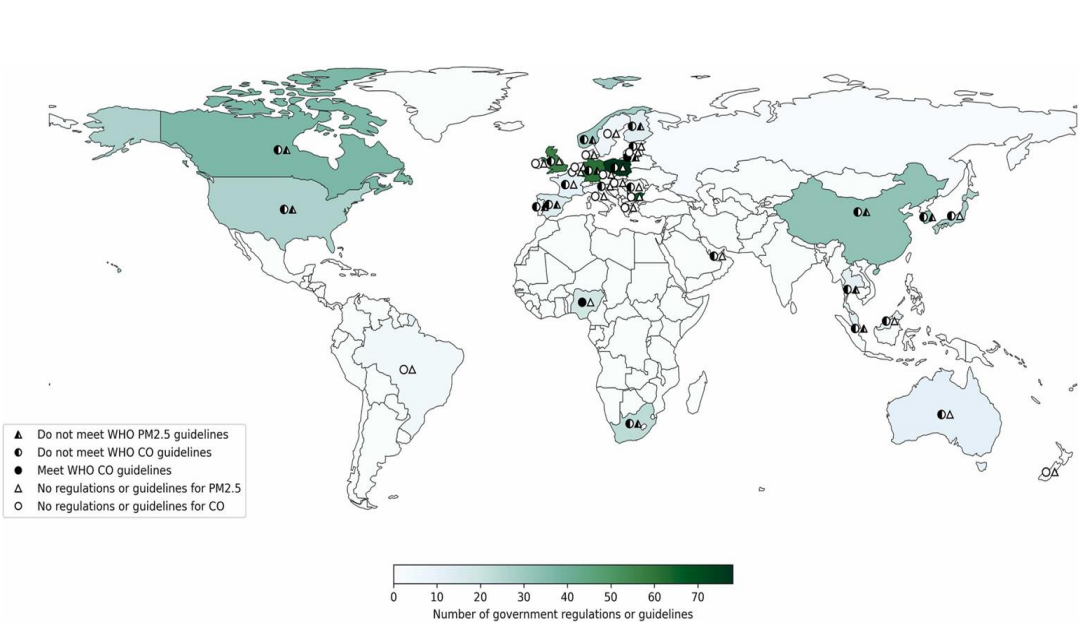
Key Factor 5 *(Slide 8 of 8)*
Recommended Exposure of PM 2.5



Recommended Exposure of PM 2.5 in Various Countries with Different Exposure Duration

Siddique, Azhar, Al-Shamlan, Maryam Y. M., Al-Romaihi, Hamad E. and Khwaja, Haider A.. "Beyond the outdoors: indoor air quality guidelines and standards – challenges, inequalities, and the path forward" Reviews on Environmental Health, vol. 40, no. 1, 2025, pp. 21-35. https://doi.org/10.1515/reveh-2023-0150

Key Factor 6 *(Page 1 of 8)*
Equity Concerns

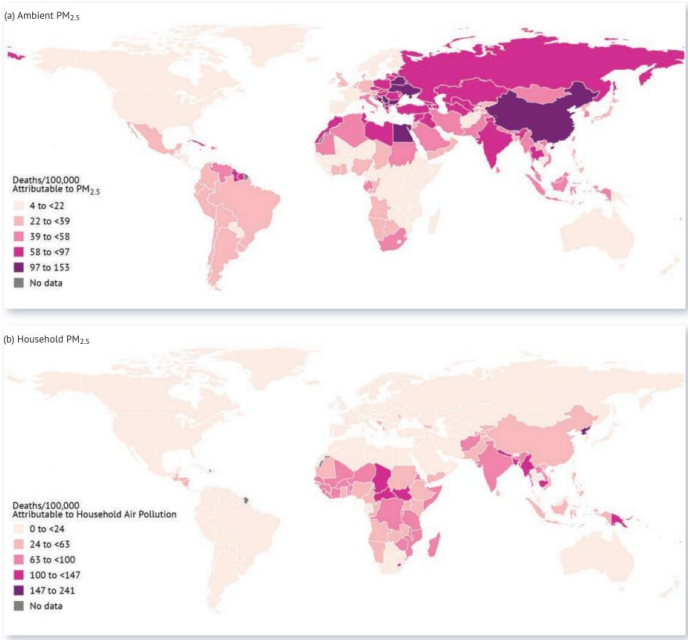


Number of Governmental Regulations or Guidelines by Country Included in the IEQ Database As of April 2024

There is no single universal IAQ standard. While UN WHO has air quality guidelines, they are applied differently in the world. Note that many Global South cities are behind regarding PM 2.5 regulations.

Ulla Haverinen-Shaughnessy, Marzenna R. Dudzinska, Samy Clinchard, Sani Dimitroulopoulou, Xiaojun Fan, Piet Jacobs, Henna Maula, Amelia Staszowska, Oluyemi Toyinbo, Ju-Hyeong Park, Towards equitable and sustainable indoor air quality guidelines − A perspective on mandating indoor air quality for public buildings, Indoor Environments, Volume 2, Issue 1, 2025, 100070, ISSN 2950-3620, https://doi.org/10.1016/j.indenv.2024.100070. (https://www.sciencedirect.com/science/article/pii/S2950362024000675)

Key Factor 6 *(Page 2 of 8)*
Air Quality and Developing Nations



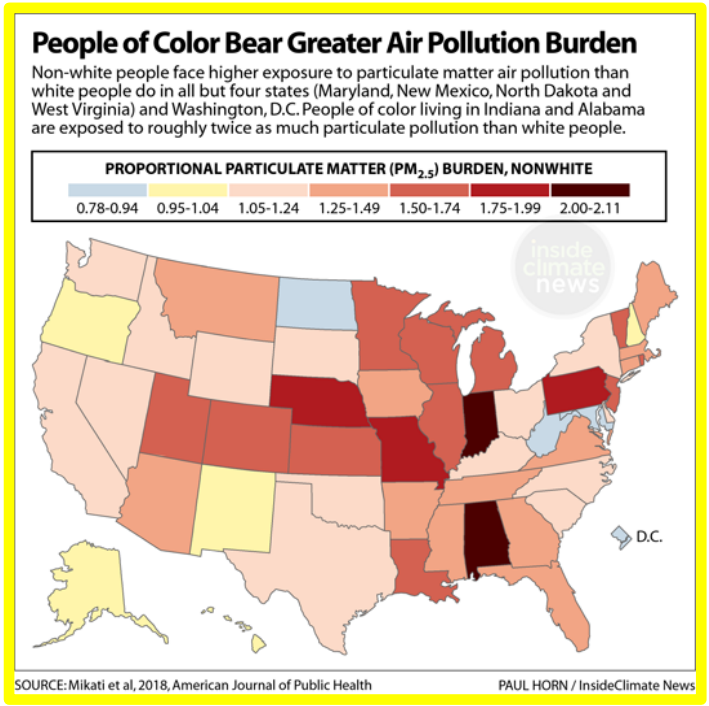
Global Air Quality Is Also An Equity Issue, with Global South Countries Facing More Premature Deaths

Health Effects Institute. 2024.State of Global Air 2024. Special Report. Boston, MA: Health Effects Institute. P16. https://issuu.com/ihme/docs/soga-2024-report

Air Quality and Developing Nations

World Health Organization (WHO) reports that 89% of the 4.2 million premature deaths due to outdoor air pollution occur in low- and middle-income countries, with the highest burden in South-East Asia and the Western Pacific. Air pollution is a significant contributor to cardiovascular illness and death in these regions. Household air pollution from solid cooking fuels is a major environmental health risk, particularly in developing countries. According to the ASHRAE Position Document, IAQ accounts for 4.3% of global Disability-Adjusted Life Years (DALYs) and is the third-largest risk factor globally. The greatest impacts are in South Asia and Sub-Saharan Africa, where it is among the top risk factors, and in Southeast and East Asia, where it ranks in the top five. Efforts to address this include promoting more efficient stoves, cleaner fuels, and improved ventilation. This study found that households in developing countries encouraged to connect to the electrical grid had 66% lower average overnight fine particulate matter (PM2.5) concentrations compared to those that were not. As a result, the prevalence of acute respiratory infections in children under six was 8-14 percentage points lower in these households. The reduction in kerosene use in developing countries appears to be a key factor driving these improvements in air quality and health outcomes.

Key Factor 6 *(Page 3 of 8)*
Equity Concerns



Air Quality and Socioeconomic Disadvantaged Communities

Recent studies, at least in US, have shown that air pollution disproportionately affects communities of color, with higher risks of premature death from particle pollution, which often times associated with lower income. Additionally, the disadvantage communities tend to live in areas with greater exposure to air pollution due to historical residential segregation. Socioeconomic status also plays a significant role, with low-income individuals, regardless of race, facing higher risks of premature death from air pollution. Several studies indicate that communities with higher African American populations, lower incomes, and higher unemployment rates are more vulnerable to the health impacts of air pollution.

A multi-country study revealed that households in the highest income quartile had a 22% lower odds of mortality related to indoor air pollution compared to those in the lowest income quartile, underscoring the protective effect of clean energy access. PubMed

Key Factor 6 *(Page 4 of 8)*
The Most Vulnerable Individuals

Vulnerable: Children, Elderly, and Preexisting Conditions:

Visual: Elderly become more dependent on their environment to compensate for sensory loss, frailty, and reduced mobility. In this paper, it discussed as people aged, they need higher light requirements in terms of % compared to when they were in teenager years. Lighting design standard often tailored around a 40 years old person. Lighting needs for older adults go beyond vision, impacting both their circadian rhythms (sleep/wake cycle) and overall health, including the synthesis of vitamin D for bone health. As the 65+ population grows, it's essential to design environments that meet the unique lighting needs of older adults. Research shows that children are particularly sensitive to light exposure, which can influence their sleep, activity, and overall health. Additionally, environmental light during pregnancy is crucial, as it impacts maternal circadian rhythms and the growth of the offspring. With the rise of shift work and jet travel, more pregnant women are exposed to disruptive light conditions, affecting both maternal and fetal health outcomes. Link

Key Factor 6 *(Page 5 of 8)*
The Most Vulnerable Individuals, *continued*

Table 2. Target values for indoor air quality.

		Unit	Indoor climate category Maximum values S1	S2	S3	Note
Radon	Rn	Bq/m³	100	100	200	(I)
Carbon dioxide	CO_2	ppm	700	900	1200	(II)
Carbon dioxide	CO_2	mg/m³	1300	1650	2200	
Ammonia and amines	NH_3	µg/m³	30	30	40	(III)
Formaldehyde	H_2CO	µg/m³	30	50	100	(IV)
Volatile organic compounds	TVOC	µg/m³	200	300	600	(V)
Carbon monoxide	CO	mg/m³	2	3	8	(VI)
Ozone	O_3	µg/m³	20	50	80	(VII)
Odor intensity (intensity scale)		-	3	4	5,5	(VIII)
Microbes			No maximum value			(IX)
Cigarette smoke in rooms for non-smokers			Not discernible			(X)
Mass concentration of airborne particulate matter	PM_{10}	µg/m³	20	40	50	(XI)

Target IAQ Values in Finland

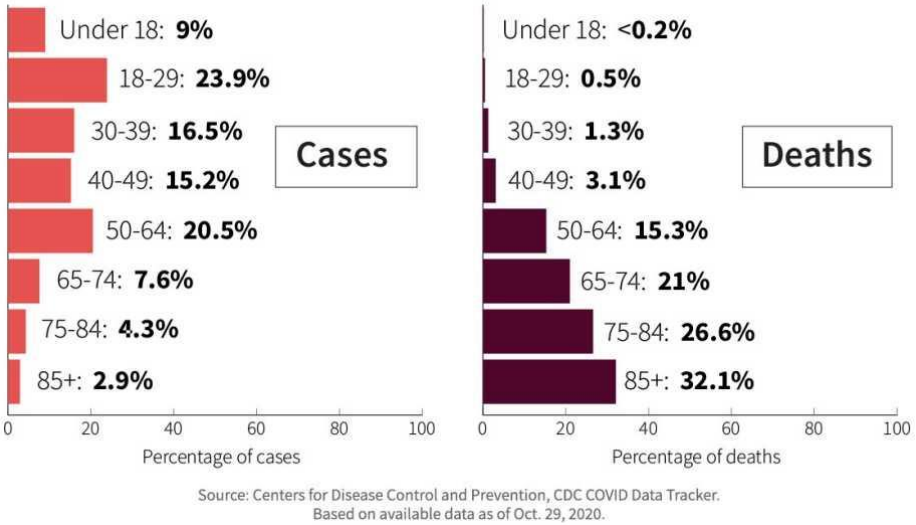
Figure from Proceedings, Indoor Air 2002, Finnish Classification of Indoor Climate 2000: Revised Target Values, by Jorma Säteri. https://www.irbnet.de/daten/iconda/CIB7264.pdf

Vulnerables: Children, Elderly, and Preexisting Conditions:

Vulnerable individuals are more susceptible to illness and should be given special consideration. To ensure equity in Indoor Environmental Quality (IEQ), solutions should be tailored rather than adopting a "one size fits all" approach.

Air Quality: Children, especially those from lower socioeconomic backgrounds and minority communities, are more vulnerable to air pollution, leading to increased asthma-related hospital visits and worsening respiratory symptoms. The elderly, particularly those over 75, are at a higher risk of severe illness and death from conditions such as COVID-19 and the flu. Air pollution also negatively impacts pregnancy by disrupting placental development, posing long-term risks to both maternal and fetal health. As a result, some countries, such as. Finland, have established different air quality standards based on the specific needs of various population groups. In the European Union, 30% of children are exposed to indoor climate hazards such as dampness, mold, noise, and inadequate daylight, leading to health issues like asthma and respiratory infections. RAND Corporation+1RAND Corporation+1

Key Factor 6 *(Page 6 of 8)*
Air Quality Impacts on the Elderly



Significant Amount of Deaths in COVID - 19 Were Elderly

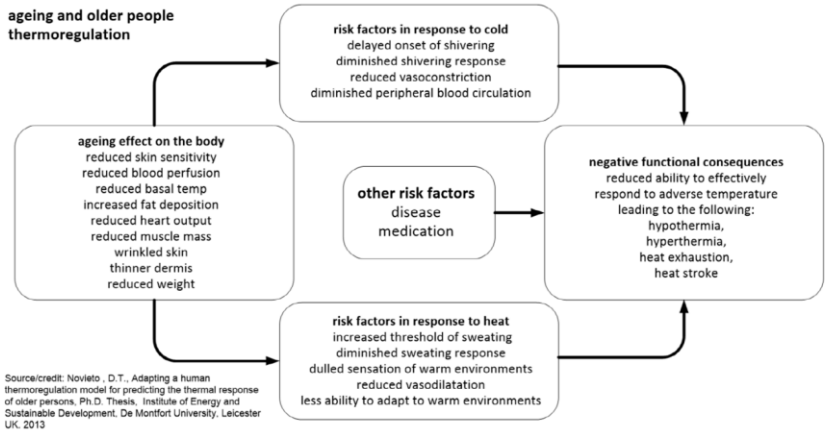
Image from AARP: https://www.aarp.org/health/conditions-treatments/coronavirus-deaths-older-adults/, 95 Percent of Americans Killed by COVID-19 Were 50 or Older

Air Quality Impacts on the Elderly

Elderly people tend to be vulnerable: Compared to people ages 18-39 years, people over age 75 are about 9 times as likely to die from COVID-19. *Link*. Each year, it is estimated that 100,000-150,000 older adults in the United States are hospitalized due to RSV infection. *Link* In recent years, it's estimated that between 70 percent and 85 percent of seasonal flu-related deaths in the United States have occurred among people 65 years and older, and between about 50 percent and 70 percent of seasonal flu-related hospitalizations have occurred among people in this age group. *Link*.

Key Factor 6 *(Page 7 of 8)*
Thermal Comfort

Designing systems for buildings people?



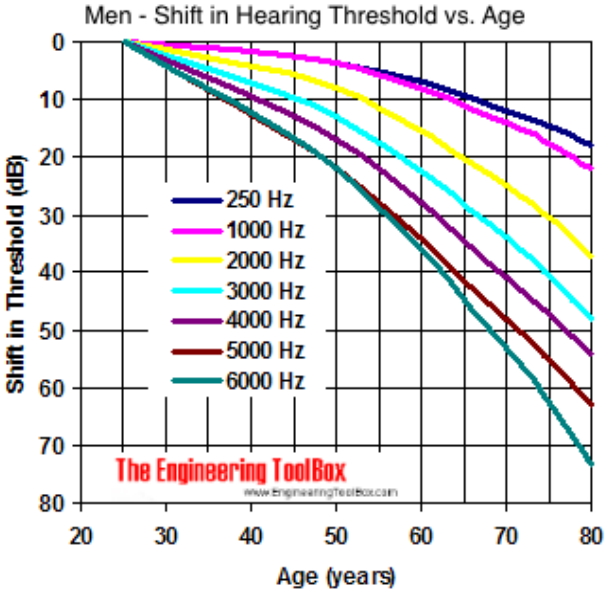
Source/credit: Novieto , D.T., Adapting a human thermoregulation model for predicting the thermal response of older persons, Ph.D. Thesis, Institute of Energy and Sustainable Development. De Montfort University, Leicester UK. 2013

Thermal comfort:

- Children living in cold homes are more than twice as likely to suffer from a variety of respiratory problems than children living in warm homes.
- Cold housing negatively affects children's educational attainment, emotional well-being and resilience.
- During pregnancy the thermal comfort requirements can change. Negative heat-health outcomes for pregnant people include obstetric complications such as placental abruption and cardiovascular events, which are life-threatening emergencies. Heat exposure was also associated with increased rates of preterm birth, which impacts 1 out of every 10 babies born. In this paper, the conclusions is pregnant women's thermal preferences are different in the three trimesters. Pregnancy diseases can affect pregnant women's thermal preferences.
- For older people, effects of cold housing were evident in terms of higher mortality risk, physical health and mental health. See below for thermal design considerations for elderly:

Courtesy of Mr. Robert Bean

Key Factor 6 *(Page 8 of 8)*
Acoustics



The Engineering ToolBox (2009). Sound - Hearing Threshold vs. Age. [online] Available at: https://www.engineeringtoolbox.com/age-shift-in-threshold-d_1474.html [Accessed April 29, 2025].

Acoustics

It is important to create acoustic equity for all, particularly in the workplace, where acoustical design can significantly impact occupants. One key issue is speech privacy, which, according to surveys, is the top workplace complaint and is relevant in both private offices and open-plan environments. For the elderly, who often experience high-frequency hearing loss, equitable acoustic environments should be optimized to improve sound clarity by reducing background noise and using clearer speech reinforcement, especially in public spaces like elderly healthcare facilities and transportation systems. Additionally, children and the elderly may need lower frequency sounds for fire alarms to ensure they wake up. Loud noise exposure during pregnancy can increase the risk of hearing problems for the baby.

Key Factor 7 *(Page 1 of 3)*
IEQ and Climate Change Alignments

IEQ and Climate Change Alignments

A. **IEQ and Climate Change:** As climate change affects outdoor air quality, the need for better indoor air filtration and ventilation systems increases. More frequent temperature extremes and pollution spikes from climate events could result in compromised IAQ. Also both climate change and IEQ will prefer:
i. Use of economizer
ii. Use of more natural ventilation (when outdoor is appropriate) and use of adaptive comfort
iii. Use of low GWP, natural, or healthier refrigerant indoors.
iv. As ASHRAE 241 methodology of "Equivalent Clean Airflow Rate" use of relatively low energy impact devices, UV light and MERV13 filters, can create acceptable IAQ and minimize energy consumptions.

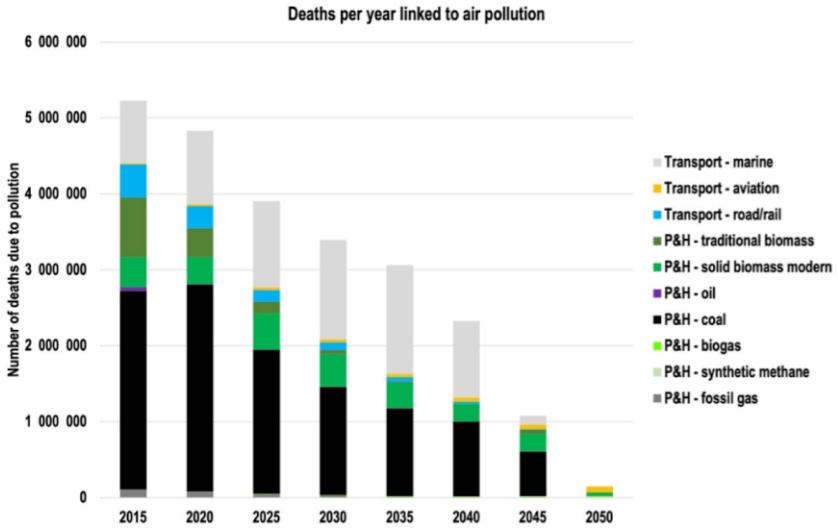
B. **Use of Sustainable Materials** - Climate change concerns often drive the choice of natural and sustainable materials in building design, which, in turn, affects indoor air quality with less chemicals. Materials that are low in volatile organic compounds (VOCs) and made from sustainable resources contribute to a healthier indoor environment.

C. **Health Impacts and Climate Adaptation** - Rising temperatures, extreme weather events, and changes in outdoor air quality directly impact public health. Designing buildings that maintain comfortable, healthy indoor environments can reduce the adverse health effects associated with climate change, such as heat stress, respiratory issues, and exposure to airborne toxins.

D. **Building Performance Monitoring and Data Use -** The use of building performance data is growing in both addressing IEQ and combating climate change. Sensors that monitor temperature, humidity, CO2 levels, and air quality can provide insights into indoor environmental conditions and also track the building's carbon footprint, energy usage, and resilience to climate change.

E. **Urbanization and Climate Resilience -** As urban areas grow and face climate impacts such as heat islands and air pollution, creating green, energy-efficient buildings with high IEQ is essential. Green spaces, green roofs, and other nature-based solutions within urban buildings contribute to improved air quality and help cities adapt to climate change.

Key Factor 7 *(Page 2 of 3)*
IEQ and Climate Change Alignments, *continued*



5.2 M → **150 k**

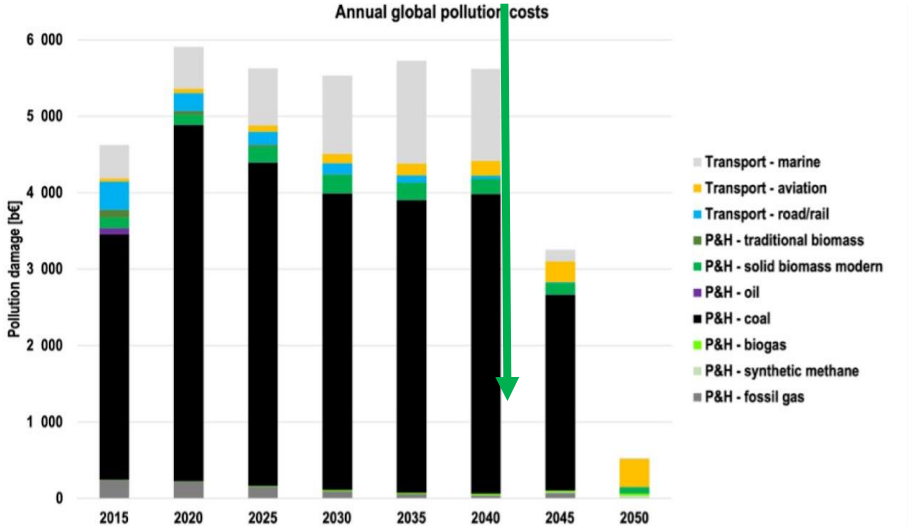
IEQ and climate change are aligned in using clean energy can improve air quality, using natural ventilation, incorporating air side economizer, and installing sustainable refrigerants to maintain indoor environmental quality (IEQ). Additionally, the use of low-VOC materials, health-focused building designs, performance monitoring, bio-based material and urban green spaces can improve IAQ and support climate resilience.

Global energy transition towards 100% renewable energy system by 2050 has great impacts to humanity. Reduction in premature death from 5.2 million today to about 150,000 in 2050, a reduction of 97%,

Tansu Galimova, Manish Ram, Christian Breyer, Mitigation of air pollution and corresponding impacts during a global energy transition towards 100% renewable energy system by 2050, Energy Reports, Volume 8, 2022, Pages 14124-14143, ISSN 2352-484https://doi.org/10.1016/j.egyr.2022.10.343. (https://www.sciencedirect.com/science/article/pii/S235248472202279X)

Key Factor 7 *(Page 3 of 3)*
IEQ and Climate Change Alignments, *continued*

88.5%



Global energy transition towards 100% renewable energy system by 2050, reduction in environmental damage cost of about US $5,750 billion today to about US $661 billion in 2050.

Tansu Galimova, Manish Ram, Christian Breyer, Mitigation of air pollution and corresponding impacts during a global energy transition towards 100% renewable energy system by 2050, Energy Reports, Volume 8, 2022, Pages 14124-14143, ISSN 2352-484https://doi.org/10.1016/j.egyr.2022.10.343. (https://www.sciencedirect.com/science/article/pii/S235248472202279X)

Content

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Support Information

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A. Physical Health

a. General Safety:

i. **Thermal Comfort:** Can avoid unnecessary heat and cold stress, provide better focus, maintain better posture, and reduce fatigue.ii.

ii. **IAQ: P**oor IAQ can reduce occupant comfort and productivity, leading to distraction or even the inability to work effectively. This could lead to situations where employees or residents are less aware of potential hazards, affecting overall safety. Also, IAQ can cause emergency evacuation, e.g. CO concentration is too high.

iii. **Lighting:** Proper lighting improves visibility, allowing individuals to see potential hazards like uneven surfaces, obstacles, or spills, minimizing the risk of falls or slips. The presence of natural light also associated with injuries. Falls are more likely with inadequate natural lighting in the home. Sufficient lighting ensures that workers can clearly see their surroundings, including potential hazards like machinery, equipment, or moving objects, enabling them to react appropriately and avoid accidents. Good quality lighting, reduces the chance of incidents and injuries from "momentary blindness" (momentary low field vision due to eyes adjusting from brighter to darker, or vice-versa, surroundings).

iv, **Acoustic:** Noise level, if too high, may mask the alert of danger from other colleagues. Unhealthy high level of ambient noises can cause hearing humming noise, or temporary hearing loss.

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A. Physical Health

b. Respiratory Issues: Ambient air quality and its deleterious effects on human health have been brought to the forefront in recent times. Air cleaning, as a comprehensive environmental intervention, decreases exposure to indoor pollutants. Poor air quality can cause or exacerbate respiratory problems including:

i. **Asthma**: Exposure to PM2.5 or NO2 air pollution during early childhood may play a role in the development of childhood asthma, especially in lower income families living in densely populated communities. Per ASHRAE "Limiting Indoor Mold and Dampness in Buildings" Position Document, "*..public health authorities have documented consistent associations between damp buildings and increased risks of adverse health effects, including exacerbation of existing asthma, new asthma, respiratory infections and allergic rhinitis (IOM 2004; WHO 2009). In addition, credible researchers have documented a causal link between damp buildings and exacerbations in children with asthma.*" A meta-analysis showed that children living in a home with damp or mould were 50% more likely to have asthma or wheezing.

ii. **Allergies**: Indoor air can have a lot of allergens, such as pollen, airborne pollutants produced by dust mites or cockroaches, and mold. These substances irritate the airways of people with allergies.

iii. **Bronchitis:** Childhood NO2 and PM10 exposures were associated with adult bronchitis symptoms.

iv. **Chronic Obstructive Pulmonary Diseases (COPD):** Indoor pollutant exposure, including PM 2.5 and NO2, was associated with increased respiratory symptoms and risk of COPD exacerbation, especially in developing nations.

v. **Poisoning:** Carbon monoxide can provoke direct poisoning when breathed in at high levels. Heavy metals such as lead, when absorbed into the human body, can lead to direct poisoning or chronic intoxication, depending on exposure. Per ASHRAE "Unvented Combustion Devices and Indoor Air Quality" Position Document, *"...unvented combustion appliances should never be used as the primary/sole source of heating…About 170 people in the United States die every year from carbon monoxide (CO) produced by non-automotive consumer products."*

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A. Physical Health

b. Respiratory Issues:

vi. Lung Cancer: PM2.5 has been is linked to the development of lung cancer. Radon gas and smoke from burning domestic fuels further elevate lung cancer risk when exposed over extended periods of time.

c. Obesity and Type 2 Diabetes: Mild cold exposure at temperatures between 12 °C and 22 °C and heat exposure at temperatures above 30 °C were regarded as anti-obesity and anti-diabetes treatments. PM2.5 can also contribute to Type 2 Diabetes. Mildly cold or warm environments, outside the standard comfort zone, increases metabolism and energy expenditure which may help to tackle obesity. For those with type 2 diabetes, exposure to mild coldness influences glucose metabolism and after 10 days of intermittent cold, patients had increased insulin sensitivity by more than 40%. Noise pollution can cause or exacerbate type 2 diabetes

d. **Building-Related Illness**:

i. Poor IEQ can lead to Building-Related Illness (BRI), which includes a cluster of symptoms such as headaches, fatigue, eye irritation, and respiratory discomfort. Improving ventilation and controlling indoor pollutants can significantly reduce these symptoms. Some health effects may show up shortly after a single exposure or repeated exposures to a pollutant. These include irritation of the eyes, nose, and throat, headaches, dizziness, and fatigue. Such immediate effects are usually short-term and treatable. Sometimes the treatment is simply eliminating the person's exposure to the source of the pollution, if it can be identified. The largest U.S. study of building characteristics and occupant symptoms is the EPA Building Assessment Survey and Evaluation (BASE) Study of 100 representative office buildings. Analyses of data from this study indicate a general decrease in BRI symptoms as study space ventilation rates increase from as low as 10 cfm (4.7 L/s) per person up to approximately 25 to 35 cfm (12 to 17 L/s) per person. 20% to 30% fewer occupants reported BRI symptoms in study spaces with ventilation rates above 20 to 25 cfm (9.4 to 11 L/s) per person, compared to study spaces with lower rates typically ranging between 10 and 20 cfm (4.7 and 9.4 L/s) per person.

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A. Physical Health

d. Building-related illness:

ii. The elements that can impact BRI potentially include:
- Particulate matter (PM2.5 & PM10)
- Chemicals
- Carbon monoxide (CO)
- Mold and mildew spores
- Radon (especially in basements)
- Allergens (pollen, pet dander, dust mites)
- Lead (Pb)
- Nitrogen Dioxide (NO2)
- Ozone (O3)
- Sulphur Dioxide (SO2)
- Formaldehyde
- Asbestos

iii. Thermal Environment: Thermal environment can impact Building-Related Illness

iv. Impacts on Lighting, Acoustics, and thermal comfort: Poor and inappropriate lighting with absence of sunlight, bad acoustics, poor ergonomics and humidity may also contribute to BRI. Too bright or flickering lights are elements that may cause BRI

e. Skin and IEQ: Exposure to indoor pollutants like VOCs, chemicals, or low humidity can lead to skin irritation, dryness, or rashes. Long-term exposure could increase the risk of dermatological issues.

i. **Premature Skin Aging -** UV exposure can cause permanent skin damage. In the last few decades, it has become increasingly clear that air pollution is also at fault for premature skin aging. Back in 2010, research revealed that an increase in particulate matter (PM) due to traffic-related air pollution was associated with a 20 percent increase in pigment spots on the forehead and cheeks. In less-trafficked areas, researchers found that moderate levels of "background" (non-traffic related) particulate matter was accelerating skin aging in similar ways. In 2017, a follow up study was done to examine the effects of indoor fine particle pollution (PM2.5) exposure on skin aging, higher indoor PM2.5 levels (associated with factors such as cooking with solid fuels and inadequate indoor ventilation) were linked to an increase in pigment spots and wrinkles.

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A. Physical Health

e. Skin and IEQ:

ii. **Eczema -** Eczema, also known as atopic dermatitis (AD), is a chronic skin condition that causes red, itchy patches on the skin that can periodically flare-up in response to environmental triggers. Although the primary risk factor for developing eczema is genetic (i.e. if you have a family history of allergies and skin conditions), research shows that environmental factors like air pollution, humidity, and temperature play a significant role in triggering and aggravating symptoms. Aside from family history, exposure to specific indoor pollutants such as airborne chemicals (VOCs) and PM2.5 may also increase your risk of developing eczema at a young age, through what's referred to as "gene-environment interactions". One study of primary school children in Seoul, Korea, found that eczema rates were significantly higher for children who had a family history of allergic diseases *and* had moved into a newly built house in their first year of life. Because harmful chemicals (VOCs) are emitted by many common building materials, fresh paint, and furniture, new houses tend to have higher levels of indoor chemical pollution. Additionally, newer houses are more airtight (to improve energy efficiency), which can cause air pollution to reach higher concentrations than outdoors. For these reasons, moving to a new home was considered an environmental trigger for the eczema gene. Even if you live in an older home, you may still be vulnerable to air quality related symptoms. In addition to building materials, routine household activities such as cooking and cleaning can increase airborne pollution levels and trigger eczema flare-ups.

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A. Physical Health

e. Skin and IEQ:

iii. **Hives -** Hives, also called urticaria, is a spontaneous skin reaction that occurs in response to specific allergens. Most people experience hives at least once in their lifetime, brought on by specific foods, medications, insect bites, sunlight, pet dander, or another (known or unknown) environmental trigger. For some people, an increase in airborne pollutants like PM2.5, VOCs, ozone (O3), and nitrogen dioxide (NO2) can trigger a hives outbreak. A study conducted in Windsor, Canada, found that emergency room visits for hives increased in relation to short-term spikes in ambient air pollution. Similar to eczema, another study noted an association between chronic cases of hives in children and living in a new residence.

iv. **Irritation, Breakouts, and Inflammation -** Even if you don't have an existing skin condition, airborne pollutants can cause everyday skin aggravation. Just as large particles such as dust and dirt collect on our skin, so do fine particles that are invisible to the naked eye. This microscopic build-up of pollution can trigger acne-like breakouts and disturb our skin's natural flora (the microbiome of bacteria that exist on the outermost layer of our skin). Many of the bacteria on our skin, such as *Staphylococcus epidermidis*, act as anti-inflammatories and help defend against potential pathogens. When air pollution upsets the natural balance of this ecosystem, it can decrease our skin's ability to combat dryness, humidity, sunlight, UV radiation, pathogens, and allergens.

v. **Decrease in Skin Barrier Function:** This paper concludes low humidity and low temperatures lead to a general decrease in skin barrier function and increased susceptible towards mechanical stress. Since pro-inflammatory cytokines and cortisol are released by keratinocytes, and the number of dermal mast cells increases, the skin also becomes more reactive towards skin irritants and allergens. Exposure to intense heat, UV radiation, pollution, and smoke can break down the skin's protective lipid coat, deplete skin antioxidants, and trigger oxidative stress

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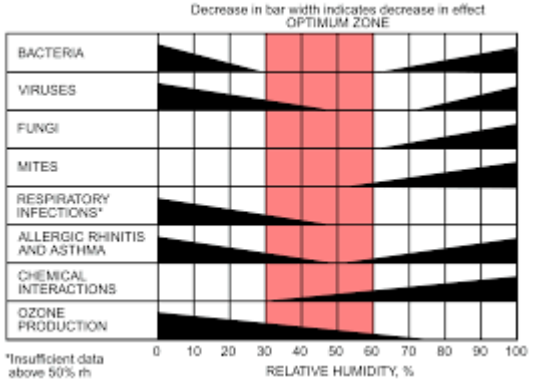
A. Physical Health

f. Increased Risk of Illness: Poor IEQ can affect the immune system, making individuals more susceptible to infections, colds, and flu. Contaminants like bacteria and viruses may thrive in certain relative humidity (see below), poorly ventilated indoor spaces, and temperatures.

i. **Relative Humidity -** The Sterling chart, from a 1986 research paper, suggests an optimum zone of 30 to 60 percent for relative humidity to minimize microbial activities. ASHRAE Handbooks updated 30 to 60 percent.



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A. Physical Health

f. Increased Risk of Illness:

ii. **Optimal Thermal Comfort Range**: Maintaining an appropriate environmental condition reflecting the requirements of the Standard 55.

iii. **Indoor Air Quality -** In renovations for better energy performance with tighter building envelope, evidence shows that certain retrofits increase the risk of health problems, particularly for airways, skin, and eyes.

iii. **Daylighting -** Individuals with household sunlight exposure were 94% less likely to be diagnosed with tuberculosis than those without. An increased risk of leprosy associated with insufficient natural light exposure.

g. Legionnaires' Disease: Between 2000 and 2017, the number of Legionnaires' Disease diagnoses grew by 5.5 times. Breathing in water droplets that is contaminated can contribute to this disease.

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A. Physical Health

h. Cardiovascular: Per ASHRAE "Environmental Tobacco Smoke" Position Document: "based on the preponderance of evidence, that exposure of nonsmokers to tobacco smoke causes specific diseases and other adverse effects to human health most significantly, cardiovascular disease and lung cancer." Research by EPA and others has found that exposure to increased concentrations of PM2.5 over a few hours to weeks can trigger cardiovascular disease-related heart attacks and death. Longer-term exposure can lead to increased risk of cardiovascular mortality and decreases in life expectancy." Noise pollution can cause or exacerbate cardiovascular disease.

i. Passive Survivability: Per DOE, Passive Survivability is "The ability to maintain safe indoor conditions in the event of extended energy outage or loss of energy supply. In practice, passive survivability enables safe indoor thermal conditions, relying on building design measures that require no energy." It is important that a building does not exceeds the survival temperatures (hot and cold) during prolonged power outage. Besides thermal autonomy, daylighting and ventilation autonomy are also important for prolong power outage and survivability.

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B. Mental Health

a. Stress and Mental Health: Poor IEQ is linked to mental health issues, such as increased stress, and mood disorders. The indoor environment is widely acknowledged as a non-pharmacological tool for regulating residents' mental health. It is widely accepted that elements of IEQ, such as daylighting, thermal comfort, acoustics, and indoor air quality can significantly influence people's mental health. These elements can either diminish feelings of well-being or convey positive and negative information, impacting individuals' self-esteem, sense of security, and identity.

i. Anxiety Disorder: Accumulating data suggest that air pollution increases the risk of internalizing psychopathology, including anxiety and depressive disorders. In another study, students' perceptions of dormitory IEQ significantly affected anxiety symptoms, explaining 40% of the variance

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B. Mental Health

a. Stress and Mental Health:

ii. Mood Disorder: Depression, bipolar, etc. mood disorder can be impacted by IEQ. Indoor air quality, exposure to natural light and adequate lighting can impact the mood of a person.

The impact of acoustic, or music therapy, can evoke memories in patients, to improve their mood and to alleviate stress.

Artificial light at night and depressions: Nine eligible studies were included in this review. Overall,moderate evidence of a positive association between light at night exposure and depressive symptoms and to a lesser extent other mental disorders.

Light Therapy and seasonal affective disorder and other types of depression: can be effectively reduced by both natural and artificial light therapy.

Daylight, happiness, and sadness: natural lighting conditions of housing significantly impact people's perceptions of happiness and sadness, with settings that have an increased amount of daylight entering the home leading to the greatest impacts.

Heat stress and its consequences on mental well-being - Chronic heat stress can lead to increased stress, anxiety, and cognitive impairment.

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B. Mental Health

a. Stress and Mental Health:

ii. Mood Disorder:

Lighting and view: A seminal study over 20 years ago showed that workers who had window views of nature felt less frustrated and more patient, and reported better health than those who did not have visual access to the outdoors or whose view consisted of built elements only. Various studies since then have suggested similar conclusions, and although from the healthcare sector. Another study of workers in a Californian call centre found that having a better view out of a window was consistently associated with better overall performance: workers were found to process calls 7% to 12% faster. Computer programmers with views spent 15% more time on their primary task, while equivalent workers without views spent 15% more time talking on the phone or to one another.

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B. Mental Health

a. **Indoor Air Quality**: The link between air pollution and poor mental health may relate to neurostructural (relationship between the nervous system and body structure) and neurofunctional (the relationship between the nervous system (neuro) and its function) changes. the majority of studies (73%) reported higher internalizing symptoms and behaviors with higher air pollution exposure. Air pollution was consistently associated (95% of articles reported significant findings) with neurostructural and neurofunctional effects (e.g., increased inflammation and oxidative stress, changes to neurotransmitters and neuromodulators and their metabolites) within multiple brain regions (24% of articles), or within the hippocampus (66%), PFC (7%), and amygdala (1%). The most studied exposure time frames were adulthood (48% and 59% for literature search) and the prenatal period (26% and 27% for literature). The extant literature suggests that air pollution is associated with increased depressive and anxiety symptoms and behaviors, and alterations in brain regions implicated in risk of psychopathology. Fire smoke may also contributes to memory loss in Alzheimer diseases.

b. **Acoustic:** noise pollution can cause or exacerbate stress; mental health and cognition problems, including memory impairment and attention deficits; childhood learning delays**.** Acoustic stimuli such as music or ambient noise can significantly affect physiological and psychological health in humans. Specifically, music therapy exhibits promising effects on treatment of neurological disorders such as Alzheimer's disease (AD) and Parkinson's disease (PD). Auditory intervention affects an organism, encompassing modulation of immune responses, gene expression, neurotransmitter regulation and neural circuitry. As a safe, cost-effective and non-invasive intervention, music therapy offers substantial potential in treating a variety of neurological conditions. More than 30% of research respondents considered their awareness of sounds when out and about in public spaces during darkness is important. People feel less secure wherever sensory input – such as vision – is restricted, through poor lighting or in cramped spaces.

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B. Mental Health

c. Thermal Comfort: Thermal comfort impacts:

i. **Increased stress and anxiety**: High temperatures can lead to discomfort, irritability, and frustration, which can increase stress levels.

Ii. **Depression and Seasonal Affective Disorder (SAD)**: Cold environments, especially during the winter months, are linked to depression, particularly in those with seasonal affective disorder. The lack of sunlight and extended darkness can disrupt circadian rhythms, reduce serotonin levels, and negatively affect mood.

iii. **Social isolation**: Cold weather often discourages outdoor activities and socializing, which can lead to loneliness and feelings of isolation. Lack of social interaction is a risk factor for mental health conditions like depression.

iv. **Physical discomfort**: Being exposed to cold can cause physical discomfort, such as numbness or shivering, which may contribute to heightened stress or anxiety levels. On the other hand, a comfortable and stable thermal environment can promote better mental health by improving sleep quality, reducing stress, and enhancing overall mood and cognitive function.

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B. Mental Health

c. Lighting: Lighting impacts:

i. **Natural Light**: Exposure to natural sunlight helps regulate our circadian rhythms, which play a key role in sleep-wake cycles and mood regulation. Sunlight triggers the production of serotonin, a neurotransmitter that improves mood and helps with focus. Lack of natural light, especially in winter, can lead to conditions like Seasonal Affective Disorder (SAD), which is a form of depression linked to changes in seasons and decreased sunlight exposure.

ii. **Artificial Light**: Poor or excessive artificial lighting can negatively affect mental health. For example, harsh, fluorescent lighting in workplaces or homes can cause eye strain, headaches, and irritability. On the other hand, dim lighting can sometimes promote relaxation but can also make people feel sluggish if it's too dark for extended periods.

iii. **Blue Light**: Exposure to blue light, especially from screens (phones, computers, TVs), in the evening can disrupt sleep by interfering with melatonin production. This can lead to poor sleep quality, which is strongly linked to mood disorders like anxiety and depression.

iv. **Light Temperature**: The color temperature of lighting also matters. Warm lighting (yellow or orange tones) tends to be more relaxing and is ideal for evening use. Cool lighting (blue or white tones) is often associated with alertness and productivity, making it suitable for daytime or work settings.

v. **Lighting in Environment**: The overall ambiance created by lighting in a space can influence how a person feels. Bright, well-lit spaces are often associated with positive energy and productivity, while dim or poorly lit spaces can feel isolating or depressing.

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C. Infectious Disease Transmission: Ventilation rate, indoor air quality, lighting, and thermal conditions can impact the spread of infectious diseases.

a. Ventilation rates: Per ASHRAE "Infectious Aerosols" Position Document, "Exposure to infectious aerosols is an important factor in the transmission of infections in indoor environments between a source and a susceptible individual. Engineering controls demonstrated to reduce the risk of exposure to infectious aerosols include dilution with outdoor air provided by mechanical or natural ventilation, filtration of indoor air, indoor airflow patterns, and disinfection by germicidal ultraviolet light and other technologies proven to be effective and safe." ASHRAE 241, "Control of Infectious Aerosols", has Equivalent Clean Air refers to a metric within the ASHRAE Standard 241, which defines the theoretical flow rate of pathogen-free air needed to significantly reduce the risk of disease transmission in a space, achieved by combining ventilation, filtration, and air cleaning technologies, essentially representing the "clean air" delivered to an occupied area considering all these factors; it is expressed as an "Equivalent Clean Airflow Rate" (ECAi) and is calculated based on the specific space and its occupancy level.

a. IAQ: Pollutants in the air, e.g. PM 10, PM 2.5 and carry viruses to travel longer distances. Evidence supports a clear association between air concentrations of some pollutants and human respiratory viruses interacting to adversely affect the respiratory system.

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c. **Light**: Sunlight played a significant role in infection control and preventing the spread of disease in buildings. Even today, forms of artificial light are effectively being used in hospital settings to reduce infection transmission. UVC is also used in different settings to mitigate contaminants.

d. **Thermal conditions:** Thermal environment, temperature and humidity can impact spread of infectious diseases, as in the Homeland Security "Estimated Airborne Decay of SARS-CoV-2 (virus that causes COVID-19)" calculator. Also, air flow speed and direction and can infectious diseases spread. In a Korean study, the researchers concluded that "droplet transmission can occur at a distance greater than 2 meters [6.5 feet] if there is direct airflow from an infected person. The default airflow velocity in Standard 55 is 20 fpm. With sufficient flow and buoyancy-driven by temperature and stack effects, pathogens could travel 10 ft in 30 seconds.

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D. Sleep Quality: IEQ can impact sleep quality. Per ASHRAE "Ventilation, IEQ and Sleep Quality in Bedrooms" Residential Issues Brief, "A 2018 review attempted to define environmental conditions in sleeping environments for optimal sleep quality and proposed temperature and humidity ranging generally between 17-28 °C and 40-60% RH, all forms of noise being less than 35 dB, complete darkness and avoidance of blue light immediately before and during sleep, ventilation using sea-level air quality, and passive design using architectural features to incorporate the above elements into bedroom design." Sleep serves as a critical indicator of an individual's physical, psychological and social health (Clement-Carbonell et al., 2021). Adequate sleep can regulate emotions, consolidate memory, enhance learning ability, and promote overall well-being (Rasch and Born, 2013; Papalambros et al., 2017; Ramar et al., 2021). Insufficient sleep not only increases the risk of obesity and cardiovascular diseases, but also triggers anxiety, depression and other mental disorders, leading to a decline in cognitive performance (Ward et al., 2014; Muto et al., 2016; Di Muzio et al., 2020; Scott et al., 2021). The Sleep Ambient Music Intervention can be an effective therapeutic measure for improving sleep quality and mental health (Loewy, 2020; Chen et al., 2021).

a. **IAQ and sleeping quality:** Per ASHRAE "Ventilation, IEQ and Sleep Quality in Bedrooms" Residential Issues Brief, "Good air quality, especially the reduction of pollutants (e.g., carbon dioxide, volatile organic compounds, particulate matter, odor, etc.), can help individuals sleep more soundly. Poor air quality can lead to symptoms like nasal congestion, coughing, and difficulty breathing, disrupting sleep".

a. **Light and sleeping quality:** Light plays an important role in the function of the nervous and endocrine systems and the secretion of hormones such as melatonin. Melatonin is released by the pineal gland in a 24-h cycle according to how much light is received, regulating the body's circadian rhythm. In regular sleep-wake cycles, the hormone is highest at night in the dark promoting healthy sleep and lowest during daylight promoting alertness. Disruption to these rhythms caused by a lack of daylight exposure during the day and exposure to bright lights during the night constitutes as improper light exposure which affects health.

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Sleep Quality:

c. **Thermal Comfort**

i. **Core body temperature**: During sleep, the body naturally cools down. A cooler environment supports this process, making it easier to fall asleep and maintain restful sleep throughout the night.

ii. **Hot environments**: When it's too warm, your body struggles to cool down. This can lead to tossing and turning, dehydration, and restlessness, which negatively affect sleep quality. It might also prevent you from entering deeper stages of sleep, like REM (rapid eye movement) sleep, which is important for restorative rest.

iii. **Cold environments**: While cooler temperatures might help you fall asleep initially, extreme cold can cause discomfort or awaken you during the night. If you're too cold, your body may expend energy warming itself, disrupting sleep cycles

d. **Acoustic**

i. **Disruptive Sounds (Negative Impact) -** Loud or sudden noises (e.g., traffic, barking dogs, construction sounds) can disrupt sleep cycles, causing you to wake up multiple times throughout the night or even prevent you from falling asleep entirely. Noise can cause micro-awakenings, breaking your sleep into fragmented cycles, preventing you from reaching deep, restorative sleep stages like REM.Noise that disrupts your sleep can raise stress levels, leading to the release of stress hormones (like cortisol), which can make it harder to relax and fall asleep the next night.

ii. **White Noise (Neutral or Positive Impact) -** White noise or background sounds, such as a fan, air purifier, or white noise machine, can mask disruptive environmental sounds, creating a more consistent sleep environment

iii. **Music or Nature Sounds (Positive Impact) -** Soft, calming music can promote relaxation and help the brain transition into a sleep-ready state. This is especially helpful if you struggle with racing thoughts or anxiety before bed. Sounds like rainfall, ocean waves, or gentle winds can also promote a sense of calm and help lower heart rates, making it easier to relax and fall into deep sleep

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E. Premature Death, and DALY, Mortality, and Long Term Issues:

a. Acoustic and DALY: The World Health Organization (WHO) estimates that at least 1.6 million healthy life years are lost every year in western European countries alone due to the environmental noise (Kempen et al., 2018). In an earlier publication from the (WHO, 2011), it was estimated that in western Europe, 61,000 disability adjusted life years (DALYs) were lost to noise-associated ischemic heart disease, 45,000 to cognitive impairment in children, 903,000 to sleep disturbance, 22,000 to tinnitus, and 587,000 to annoyance.

b. Light and Mortality Risk: This study predicted mortality risk from lighting. Individuals with brighter day light had incrementally lower all-cause mortality risk, and those with brighter night light had incrementally higher all-cause mortality risk, compared to individuals in darker environments. Individuals with lower circadian amplitude, or later circadian phase had higher all-cause mortality risks. Daylight, night light, and circadian amplitude predicted cardiometabolic mortality, with larger hazard ratios than for mortality by other causes. Findings were robust to adjustment for age, sex, ethnicity, photoperiod, and sociodemographic and lifestyle factors. Minimizing night light, maximizing day light, and keeping regular light-dark patterns that enhance circadian rhythms may promote cardiometabolic health and longevity. Exposure to light at night, particularly brighter nights, has been linked to a 21% to 34% higher risk of premature death compared to those who experience darker nights, while brighter days are associated with a 17% to 34% lower mortality risk.

c. Air Pollution: If a study shows that exposure to indoor air pollution (e.g., from cooking with solid fuels) causes 1,000 premature deaths and 5,000 cases of chronic respiratory diseases in a population. The total DALY would represent the health burden associated with this exposure. For premature deaths (YLL), if each death occurs at age 60 and the expected life expectancy is 80, this would contribute 20 YLL per death. For chronic diseases (YLD), each case of chronic respiratory disease would be assigned a disability weight based on the severity of the disease and the number of years the person lives with. Each year, 3.2 million people die prematurely from illnesses attributable to the household air pollution caused by the incomplete combustion of solid fuels and kerosene used for cooking (see household air pollution data for details). The *Environmental Protection Agency (EPA)* notes that long-term exposure to indoor air pollutants can increase the risk of mortality from respiratory diseases by 10-20%. In the year 2016, ambient air pollution was responsible for 4.2 million deaths. Worldwide, ambient air pollution is estimated to cause about 16% of the lung cancer deaths, 25% of chronic obstructive pulmonary disease (COPD) deaths, about 17% of ischaemic heart disease and stroke, and about 26% of respiratory infection deaths.

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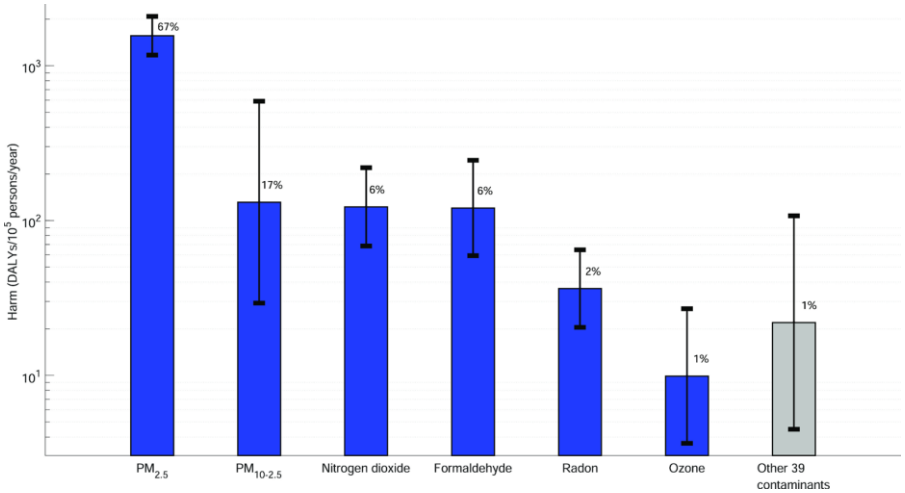
d. DALY and Long Term Health Issues

Air Pollution in Homes: In this study, estimated population DALYs of chronic air contaminant inhalation in U.S. residences are indicated in below figure:



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Support Information

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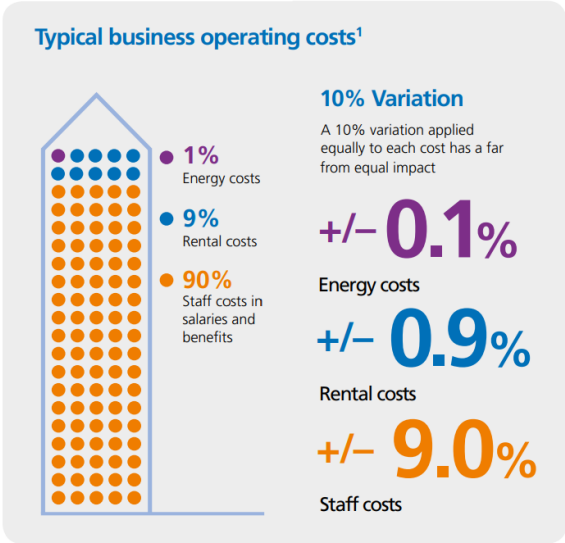
IEQ and productivity:

- Enhanced indoor environmental quality improves cognitive function by between 61% to 101%, depending on the extent of improvements.
- Better ventilation, lighting, and environmental quality results in an NPV of $37 to $55 per square foot as a result of productivity gains from less sick time and greater worker productivity.

Importance of Staffing Cost

Staffing cost is most significant in operating a building.



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Cognitive Function and Productivity:

a. A 2000 study suggested for the United States, the estimated potential annual savings and productivity gains are $6 to $14 billion from reduced respiratory disease, $1 to $4 billion from reduced allergies and asthma, $10 to $30 billion from reduced Building-Related Illness symptoms, and $20 to $160 billion from direct improvements in worker performance that are unrelated to health. Productivity gains that are quantified and demonstrated could serve as a strong stimulus for energy efficiency measures that simultaneously improve the indoor environment. The estimated benefits regarding US were a 1.1% average increase in performance in 12.4 million workers, an 18.8% average decrease in Building-Related Illness symptoms in 12.4 million workers, and 10 million days of avoided absence.$9-14 billion economic benefit associated with increasing ventilation rates to 32 cfm per person. Numerous studies have indicated that the physical environment of healthcare settings is closely tied to staff well-being, productivity, and satisfaction. Two studies have mentioned that offices with improved indoor environment can increase the productivity of occupants by more than 20%, which corresponds to more than GBP 130 billion per year in UK.

b. IAQ:

i. General ventilation can improve Staff Productivity => $410 per sq. m. Studies have pegged that improved IAQ could result in an 8 - 10% boost in employee productivity. The World Green Building Council estimates that if staff productivity improves by even a conservative 5% because of improved IAQ, that alone would be worth $410 per sq m. (₹ 26,185 per sq m)

ii. Another study by Harvard calculates the benefit to a company as a result of improved cognitive scores and decision-making performance. According to the study, when ventilation was increased from 20 cfm/person to 40 cfm/person, it corresponded to a $6500 change in a typical office worker's productivity. Possible ROI = 120%

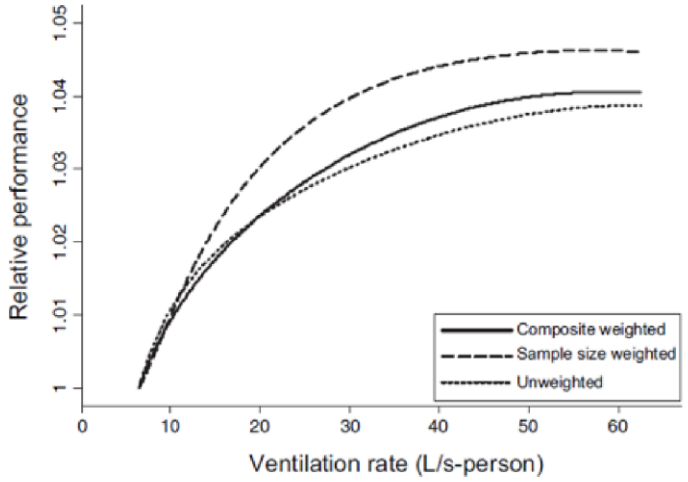
iii. The relationship between air pollution and the productivity of individuals at a large call center in China was studied. A 10-unit increase in the air pollution index decreases the number of daily calls handled by a worker by 0.35 percent. The analysis also suggests that these productivity losses are largely linearly increasing in pollution levels.

iv. Seminal research in 2003 identified 15 studies linking improved ventilation with up to 11% gains in productivity, as a result of increased outside air rates, dedicated delivery of fresh air to the workstation, and reduced levels of pollutants. A meta-analysis in 2006 of 24 studies – including 6 office studies – found that poor air quality (and elevated temperatures) consistently lowered performance by up to 10%, on measures such as typing speed and units output. This analysis appeared to demonstrate that the optimum ventilation rate is between 20 and 30 litres/second (l/s).

Key Factor 4 - Productivity and Performance Support Information *(Page 4 of 16)*

v. In a 2011 lab test which mimicked an office, a range of office-related tasks were carried out with the presence of airborne VOCs. Increasing ventilation from 5l/s to 20l/s improved performance by up to 8%. The same study estimated the value of increased ventilation to be $400 per employee per year

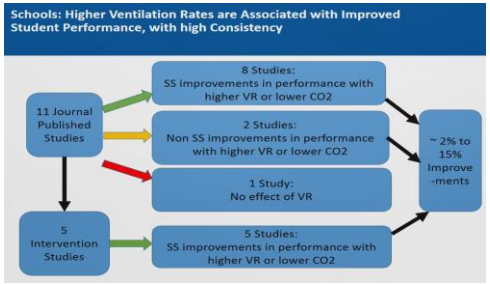
vi. "Ventilation and Performance in Office Work", suggested there is positive relative performances with increase ventilation rate:



Key Factor 4 - Productivity and Performance Support Information *(Page 5 of 16)*

xii. Another study based on ventilation, the scenarios include increasing ventilation rates when they are below 10 or 15 l/s per person, adding outdoor air economizers and controls when absent, eliminating winter indoor temperatures >23°C, and reducing dampness and mold problems. The estimated benefits of the scenarios analyzed are substantial in magnitude, including increased work performance, reduced Building-Related Illness symptoms, reduced absence, and improved thermal comfort for millions of office workers. The combined potential annual economic benefit of a set of nonoverlapping scenarios is approximately $20 billion.

xiii. In this study, from both cross sectional and intervention studies, of an association of increased student performance with increased ventilation rates. There is evidence that reduced respiratory health effects and reduced student absence are associated with increased ventilation rates.



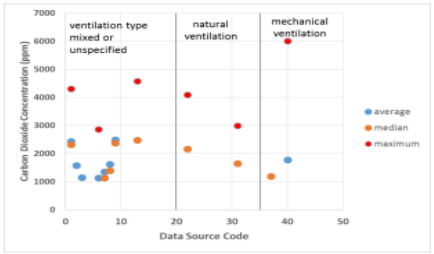


Figure 1. Peak carbon dioxide concentrations in classrooms.

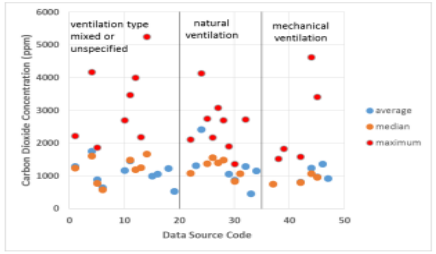


Figure 2. Time average carbon dioxide concentrations in classrooms.

Key Factor 4 - Productivity and Performance Support Information *(Page 6 of 16)*

c. Thermal Comfort:

i. When temperatures are low, employees made 44% more mistakes than at optimal room temperature.

ii. For US, in this LBL Study, estimated $3.4 billion annual economic benefit, with $0.4 billion implementation costs, through integration of thermal occupant controls

iii. For US, in this LBL study, estimated $2 billion estimated annual value of work performance gains from avoiding high temperatures in the winter.

iv. **Temperature Variations:** This temperature fluctuation study suggested by cyclic fluctuating air temperature demonstrates that the thermal dissatisfaction rate for cyclic fluctuating air temperature control between 26°C–28°C is lower than that for constant air temperature control at 26°C, while consuming less energy. Moreover, occupant stress levels measured by salivary alpha-amylase, and subjective fatigue levels under cyclic fluctuating air temperature show that similar or even lower distinct results can be achieved with fluctuating air temperature control compared with constant air temperature control.

v. **Dynamic Thermal Comfort/Alliesthesia:** The psychophysiological principle of thermal alliesthesia operates within the thermoneutral zone, making it equally relevant to quotidian indoor environments as it is to the extremes found in traditional physiological research. Non-steady-state built environments can potentially offer spatial alliesthesia through carefully managed contrasts between local and mean skin temperature trends. Transitional zones are suggested as design solutions. Intensity of thermal pleasure increases proportional to thermal load incurred

Key Factor 4 - Productivity and Performance Support Information *(Page 7 of 16)*

vi. "Personal Environment" - A 2006 study tested effectiveness of adjustable desk mounted personalized air supply devices on perceived air quality. Greater satisfaction with air quality was reported with desk-mounted devices despite ventilation rates being the same. Similarly, providing individuals with personal control over light levels with dimmers in offices can lead to improvements in satisfaction and mood. Subsequent research added comfort, improved motivation, and greater ease of task performance to this list of benefits"Personal Control", if an office worker has more control over their environment, they tend to be more satisfied as a result. One study found that individual control over temperature (in a 4°C range) led to an increase of about 3% in logical thinking performance and 7% in typing performance. Another suggests up to 3% gains in overall productivity as a result of personal control of workspace temperature.

vii. **Thermal Comfort:** An analysis in 2006 of 24 studies on the relationship between temperature and performance indicated a 10% reduction in performance at both 30C and 15C compared with a baseline between 21C and 23C, leaving little doubt as to the impact thermal comfort has on office occupants. A more recent study in a controlled setting indicated a reduction in performance of 4% at cooler temperatures, and a reduction of 6% at warmer ones.

Viii. In California, without air conditioning, a 1°F hotter school year reduces that year's learning by 1 percent. Hot school days disproportionately impact minority students, accounting for roughly 5 percent of the racial achievement gap, according to UCLA research.

ix. Cooling system replacements boosted math scores by 3 percent of a standard deviation while heating system replacements led to a rise of 4 percent.

Key Factor 4 - Productivity and Performance Support Information *(Page 8 of 16)*

d. Visual

i. **Lighting and Performance:** Studies of office worker performance have shown that those with the best possible view of natural light performed between 10% and 25%1 better on tests of mental function and memory recall. On the other hand, those with poor views or no view at all (think high cubicle partitions, heavy glare, basement offices etc.), reported increases in fatigue and decreases in overall speed of performance. These variables can be controlled with circadian lighting design. Incorporating daylighting in the architecture can boost not just the performance of a building, but of those who occupy it as well.

ii. A comprehensive study conducted measurements of the physical environment and occupant satisfaction for 779 workstations in 9 different buildings, and suggested that lack of access to a window was the biggest risk factor for dissatisfaction with lighting.

iii. A study by neuroscientists suggested that office workers with windows received 173 percent more white light exposure during work hours, and slept an average of 46 minutes more per night. Workers without windows reported poorer scores than their counterparts on quality of life measures related to physical problems and vitality, as well as poorer outcomes on measures of overall sleep quality, sleep efficiency, sleep disturbances and daytime dysfunction.

Key Factor 4 - Productivity and Performance Support Information *(Page 9 of 16)*

e. Acoustic

i. A meta analysis finds reading comprehension scores in quiet classrooms were 0.80 points higher than children in noisier classrooms. Meta-analysis of the impact of 1 dB (dB) increase in environmental noise on reading and language abilities decreases performances. A *meta*-analysis from 3 studies found higher odds of cognitive impairment in people aged 45 + with higher residential noise exposure. After qualitative synthesis of remaining studies, there was high quality evidence for an association between environmental noise and cognitive impairment in middle-to-older adults, moderate quality evidence for an association between aircraft noise and reading and language in children, and moderate quality evidence against an association between aircraft noise and executive functioning in children. Generally the literature was supportive for other cognitive outcomes, but with low or very low-quality evidence.

ii. A study in 1998 found that there was up to a 66% drop in performance for a 'memory for prose' task when participants were exposed to different types of background noise. A follow-up study by the same authors in 2005 found that 99% of people surveyed reported that their concentration was impaired by office noise such as unanswered phones and background speech.

iii. The detrimental effect of ambient noise on the short-term memory processes was commonly found in a workplace setting. It could lead to possible causes for reduced efficiency in performing cognitive tasks.

Key Factor 4 - Productivity and Performance Support Information *(Page 10 of 16)*

e. Acoustic

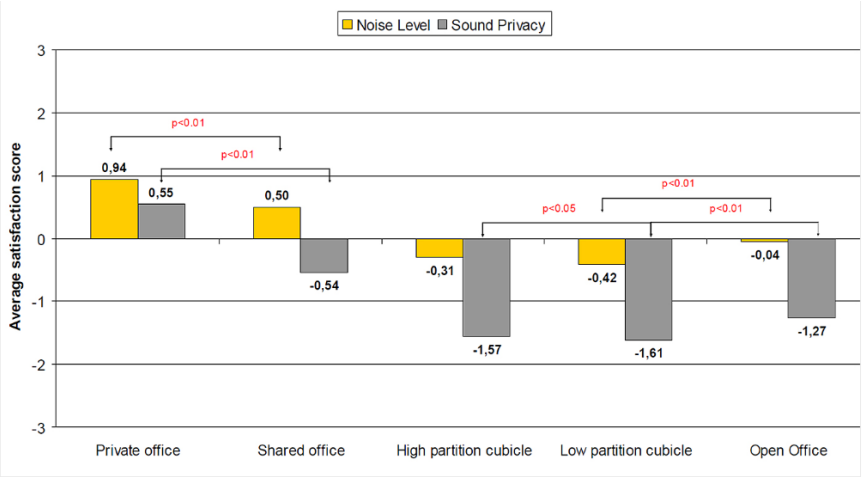
iv. A good acoustic environment ensures the occupants' psychological and physiological fitness and boosts concentration. In a 2011 laboratory experiment in Sweden, Jahncke et al. found increased performance on memory tasks and reduced tiredness in low-noise (39 dBA) work environments as compared to high-noise (51 dBA) work environments. Danielsson and Bodin identified that employees in individual closed offices reported higher health status, such as sleep quality and satisfaction rates, than those in open-plan offices. The types of offices, open or closed, and associated acoustic characteristics, such as privacy and noise disturbance, could have detrimental effects on occupants' wellbeing and impact occupants' job performance and subjective satisfaction.

v. In a research conducted by The University of Arizona -"The results showed that when a worker's environmental sound level was above 50 decibels, each 10-decibel increase was related to a 1.9% decrease in physiological well-being. But when office sound was lower than 50 decibels, each 10-decibel increase related to a 5.4% increase in physiological well-being."

Key Factor 4 - Productivity and Performance Support Information *(Page 11 of 16)*

e. Acoustic

v. Occupants' self-rated job performance shows that over 60% of occupants in cubicles think acoustics interfere with their ability to get their job done



Key Factor 4 - Productivity and Performance Support Information *(Page 12 of 16)*

b. **Job Satisfaction -** This research investigated and suggested that improving IEQ of offices is likely to have positive impact on job satisfaction and productivity of both professionals and academics.

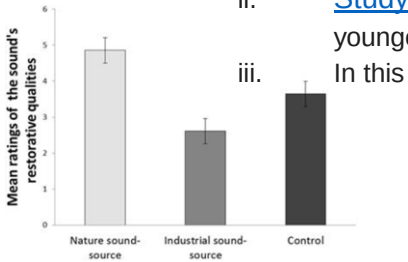
c. **Attracting and Retaining Tenants/ Differentiator -** Sustainability efforts which include improved IAQ increase employee satisfaction and thus improve retention as well as help attract talent. Interface Inc. found that 71% of full-time workers consider a company's commitment to sustainability an important criterion when evaluating a new workplace. In a survey of its employees. For more examples see SRER Report: Integrated Alternative Workplace Strategies (AWS), 2011; and SRER Report: More Sustainable Leased Space, 2011.

d. **Nature and IEQ:** Research shows that exposure to natural environments has substantial benefits for improving psychological well-being (e.g., positive effect) and cognitive performance (e.g., working memory), which have the potential to improve learning performance. A prior study suggested that exposure to nature sounds (e.g., the sounds of birds, rainfall, and waves) through a mobile application in daily life can reduce university students' mental fatigue and improve their cognitive performance.

i. Playing natural sounds such as flowing water in offices could boosts worker moods and improve cognitive abilities in addition to providing speech privacy, according to a new study from researchers at Rensselaer Polytechnic Institute.

ii. Study on trees in urban areas suggested it has the effect of making people feel $10,000 richer or similar effect to 7 years younger.

iii. In this paper below, natural sound was rated as more restorative than industrial noise.



Psychological Restoration Can Depend on Stimulus-Source Attribution: A Challenge for the Evolutionary Account
Andreas Haga, Niklas Halin, Mattias Holmgren and Patrik Sörqvist

Key Factor 4 - Productivity and Performance Support Information *(Page 13 of 16)*

C. **Absenteeism:** Cost of Absenteeism is estimated below in 2015

Costs of ill-health vary by sector and country, and are rarely comparable, but the impact is clear:

- The annual absenteeism rate in the US is 3% per employee in the private sector, and 4% in the public sector, costing employers $2,074 and $2,502 per employee per year respectively[2]
- Poor mental health specifically costs UK employers £30 billion a year through lost production, recruitment and absence[3]
- The aggregate cost to business of ill-health and absenteeism in Australia is estimated at $7 billion per year, while the cost of 'presenteeism' (not fully functioning at work because of medical conditions) is estimated to be A$26 billion[4].

Key Factor 4 - Productivity and Performance Support Information *(Page 14 of 16)*

a. In this study, the effects of improved indoor environmental quality (IEQ) on perceived health and productivity in occupants who moved from conventional to green (according to Leadership in Energy and Environmental Design ratings) office buildings. In 2 retrospective-prospective case studies we found that improved IEQ contributed to reductions in perceived absenteeism and work hours affected by asthma, respiratory allergies, depression, and stress and to self-reported improvements in productivity. These preliminary findings indicate that green buildings may positively affect public health.

b. **IEQ:** This study examined whether the combined effect of poor IEQ and self-reported psychosocial stressors (low social support from supervisors and experiences of injustice) increase the risk of employees' long-term sickness absence (more than 10 days) in comparison to employees who report only poor perceived IEQ and no psychosocial stressors. Results: After background variables were included in the model, employees who reported poor IEQ and low social support had higher rates of long-term absence than those who reported poor IEQ and high support. Similarly, employees who reported poor IEQ and experiences of injustice had higher rates of absence than those who reported poor IEQ and no injustice. Conclusions: Employees who reported poor perceived IEQ and a psychosocial stressor had higher rates of long-term sickness absence one to three years later, in comparison with those who report only poor perceived IEQ and no psychosocial stressors. These findings demonstrate the importance of taking account of psychosocial stressors as well, when resolving indoor environmental problems.

c. **IAQ:** Reduced absences may also be a key indicator of the benefits of good indoor air quality for businesses. Short term sick leave was found to be 35% lower in offices ventilated by an outdoor air supply rate of 24 l/s compared to buildings with rates of 12 l/s in a 2000 study . The same study estimated the value of increased ventilation to be $400 per employee per year.

d. **Lighting and View:** A study in 2011 investigated the relationship between view quality, daylighting and sick leave of employees in administration offices of Northwest University Campus. Taken together, the two variables explained 6.5% of the variation in sick leave, which was statistically significant.

e.

Key Factor 4 - Productivity and Performance Support Information *(Page 15 of 16)*

f. Filtration in this study, such as increased ventilation and higher grade air filtration (MERV-13 filters or higher) have been shown to result in a 9-20% annual reduction in sick leave. When implemented appropriately, these improvements can result in up to 60x return on investment in the form of worker reliability and productivity.

g. While enhanced productivity solely as a function of improved health is still to be quantified, studies have calculated that employees tend to take 30% fewer sick leaves as a result of improved IAQ.

Key Factor 4 - Productivity and Performance Support Information *(Page 16 of 16)*

D. Recovery Time:

a. In this study, circadian lighting has shown to have useful applications in the healthcare industry as well, benefiting patients and institutions alike by actually decreasing average length of patient stays. A recent study published in Building and Environment reported findings that patients with direct access to morning light were seeing their stays shortened by anywhere from 16% to 41%.

b. Florence Nightingale, renowned as the mother of nursing, advocated for care in environments with natural light, ventilation, cleanliness, and basic sanitation, believing that such conditions promote quicker recovery.

c. Researchers have uncovered a strong connection between health outcomes and the indoor environment where individuals live or receive treatment in hospitals. In 2012, it was estimated the economic benefits to the US of providing patients with views of nature to be US$93 million/year

Myth Busters

CO_2 Myth #1

CO_2 affects the perceived air quality

CO_2 Myth #1

CO_2 affects the perceived air quality

FALSE

CO_2 is a colorless and odorless gas

300,000 ppm (>30%) of CO_2 can activate trigeminal nociceptors to produce a burning sensation in our mucous membranes (sharp, acidic odor)

CO_2 levels, a quick recap

Outdoors: ca. 420 ppm (0.04%)

Indoors: up to 5,000 ppm (0.5%), usually less than 2,000 ppm (0.2%)

Exhaled: 40,000 ppm (4%) to 56,000 ppm (5.6%)

CO_2 Myth #2

CO_2 at levels typical in non-industrial buildings affects health

CO_2 Myth #2

CO_2 at levels typical in non-industrial buildings affects health

FALSE

The threshold limit value (occupational) is 5,000 ppm (0.5%) averaged over the 8-hour work shift

The short-term exposure limit is 30,000 ppm (3%), not to be exceeded during any 15-minute work period

CO_2 Myth #5

CO_2 then accumulates in the body which cause negative effects

CO_2 Myth #5

CO_2 then accumulates in the body which cause negative effects

FALSE

A body maintains acid-base homeostasis (pH 7.36-7.43). Enhanced respiration, and accumulation in bone marrow and extraction through kidneys remove CO_2 from the blood; the body can accumulate up to 120 L of CO_2.

CO_2 Myth #6

CO_2 must be removed from the air to improve perceived IAQ

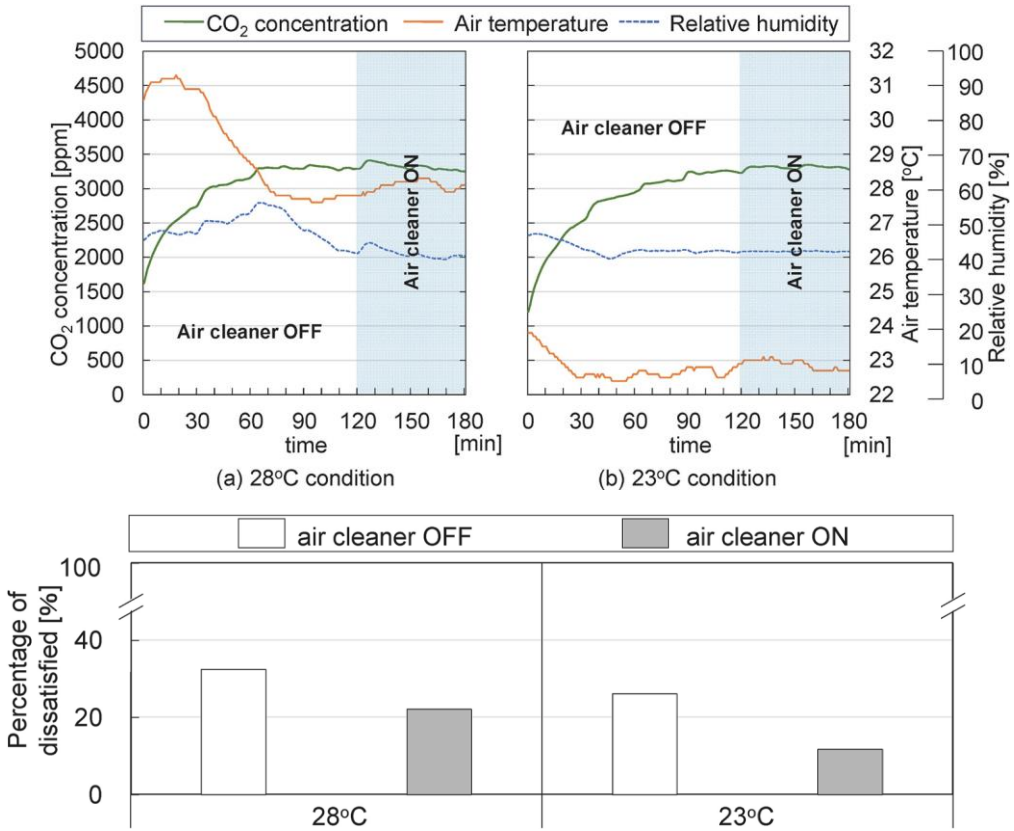
CO_2 Myth #6

CO_2 must be removed from the air to improve perceived IAQ

FALSE

A new study used activated carbon to remove human bioeffluents other than CO_2 and showed improved air quality with air cleaner even though CO_2 remained at 3,000 ppm

CO_2 Myth #6



Source: Akamatsu et al (2024)

CO_2 Myth #7

CO_2 is a marker of ventilation

CO_2 Myth #7

CO_2 is a marker of ventilation

TRUE

…. once we know all variables influencing ventilation estimation using CO_2 measurements, including emission rates of CO_2, whether the steady state level was obtained, mixing, etc. It is a crude estimate

CO_2 Myth #8

CO_2 is a marker of IAQ

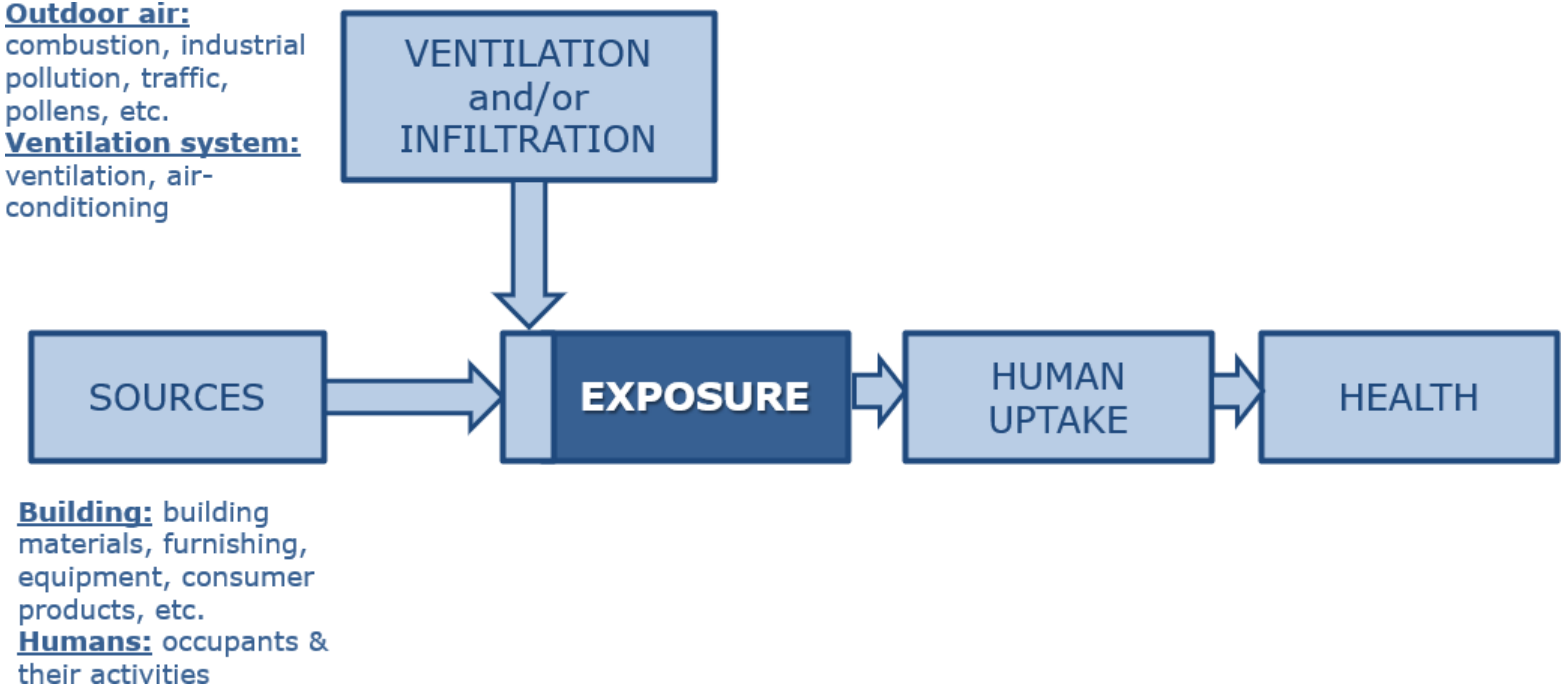
CO_2 Myth #8

CO_2 is a marker of IAQ

FALSE

CO_2 is, under specific conditions, a marker of ventilation, and is subject to the same restrictions as ventilation

CO_2 Myth #8


Outdoor air: combustion, industrial pollution, traffic, pollens, etc.
Ventilation system: ventilation, air-conditioning
VENTILATION and/or INFILTRATION
SOURCES
EXPOSURE
HUMAN UPTAKE
HEALTH
Building: building materials, furnishing, equipment, consumer products, etc.
Humans: occupants & their activities

CO_2 Myth #9

CO_2 is a marker of infection risk

CO_2 Myth #9

CO_2 is a marker of infection risk

FALSE

Emission rates of CO_2 does not correlate with vocal activities (breathing, talking, sneezing, coughing) and neither with the emission of infectious aerosols

CO_2 Myth #10

CO_2 should be kept at 1,000 ppm in buildings, also recommended by ASHRAE

CO_2 Myth #10

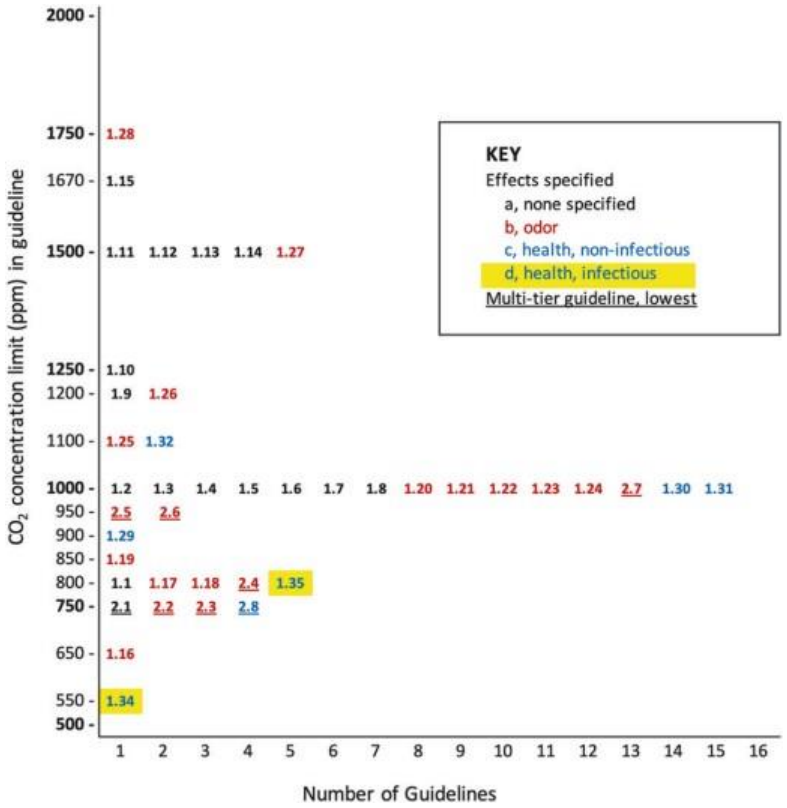
CO_2 should be kept at 1,000 ppm in buildings, also recommended by ASHRAE

FALSE

ASHRAE Standards do not recommend levels of CO_2 for achieving good indoor air quality.

Worldwide recommendations vary a lot with regard to CO_2

CO_2 Myth #10



Source: Mendell et al (2024)

CO_2 Myth #11

Ventilation with outdoor air should keep CO_2 in occupied spaces below 1,000 ppm

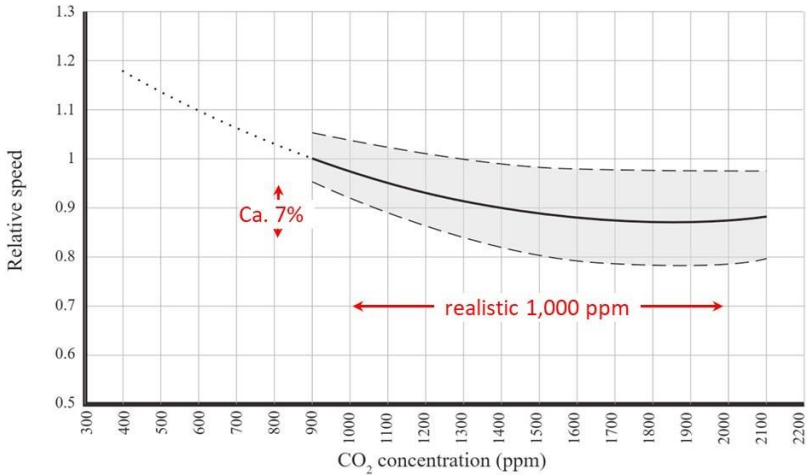
CO_2 Myth #11

Ventilation with outdoor air should keep CO_2 in occupied spaces below 1,000 ppm

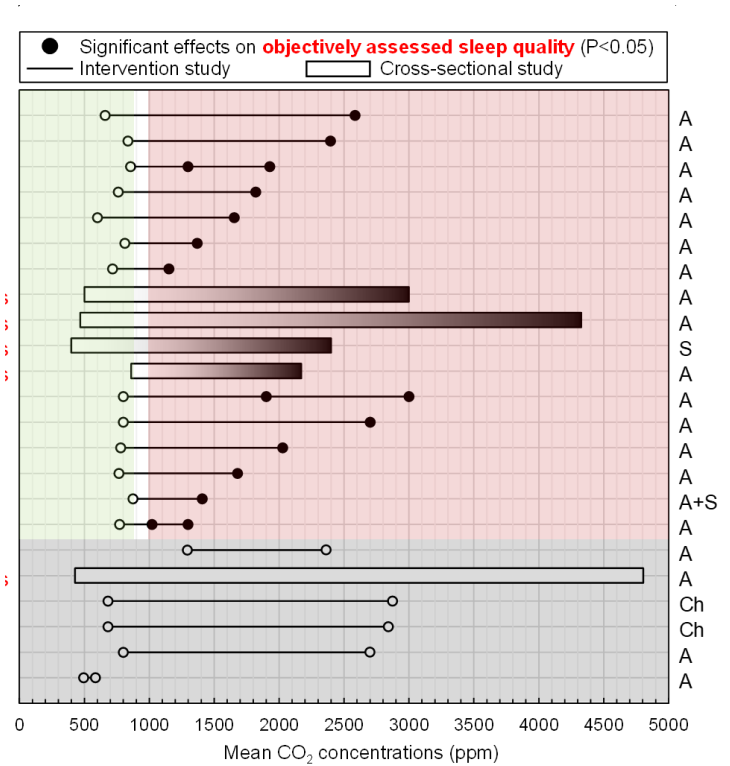
TRUE

Studies on learning in schools, sleep, and infection risk suggest that to avoid negative effects and risks the ventilation with outdoor air should be around 10 L/s per person to keep CO_2 levels (a marker of ventilation) around 800 ppm (0.08 ppm) or lower

CO_2 Myth #11



Source: Wargocki et al (2020)



Source: Wargocki at al (2023)

CO_2 Myth #12

CO_2 is easy to measure

CO_2 Myth #12

CO_2 is easy to measure

TRUE

With low-cost sensors that task is seemingly easy but the measurement is crude and interpretation depends on many factors such as the location of the sensor (usually on a wall so far away from a person), calibration (performance) of the sensor, mixing, and alike

CO_2 Myth #13

CO_2 sensors are the solution to IAQ problems in buildings

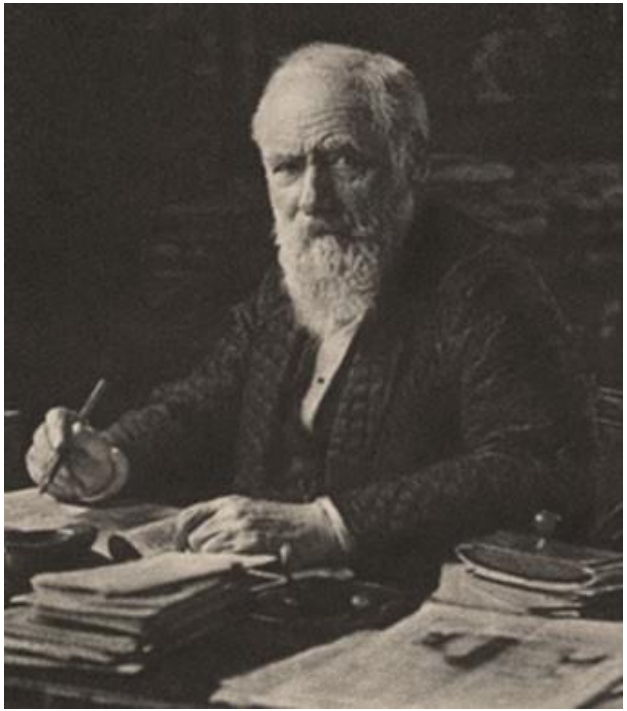
CO_2 Myth #13

CO_2 sensors are the solution to IAQ problems in buildings

FALSE

They will not indicate pollution penetrating from outdoors (PM2.5, NO_2) and neither correlate with the product of chemical reactions (with ozone and other reactants) as well as other pollutants of which emission rates do not correlate with CO_2

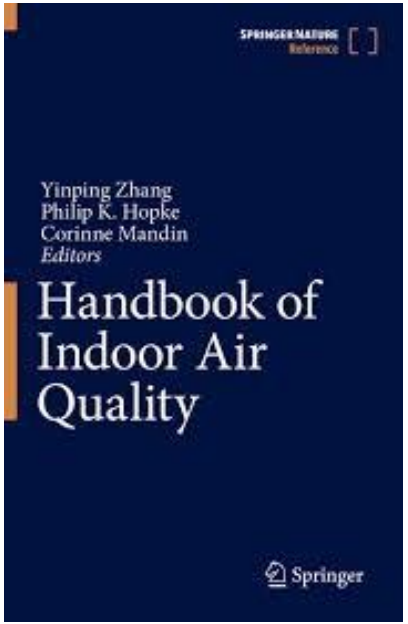
Summary - 1



"The corruption of the air is not caused solely by the carbon dioxide content; we simply use this as a benchmark from which we can then also estimate a higher or lower content of other (pollutant) substances..."

Summary - 2

		Pure CO_2	CO_2 with other bioeffluents
Cognitive impacts	 Office-like tasks	No adverse effects until 20,000 ppm, possibly higher. Incidental effects at 1,200 ppm and 3,000 ppm.	Adverse effects over 1,600 ppm.
	 Highly demanding tasks	Adverse effects at and over 1,000 ppm, but inconsistent.	Adverse effects at 950 ppm and over.
Physiological impacts	 End-tidal CO_2	Hypercapnic levels reached between 15,000 to 25,000 ppm and over.	Hypercapnic levels at 2,700 ppm.
	 Human neutrophils - *ex vivo*	Significant increase in inflammatory cytokines generation at 1,000 ppm and higher, above background levels.	No data.



Questions

Pawel

Wargocki

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MYTH 1
Not Addressing Health In IAQ Design Reduces Liability

5 MYTH 1

- Common objection to going beyond perceived air quality and safety
- Assumption that the professional is responsible for the outcome
- Actual responsibility is to comply with requirements
- Standard writer or adopting authority may have liability…possibly for not doing *enough*

MYTH 2

ASHRAE has an Accepted, Actionable Definition Of Health

7

MYTH 2

- "Health" appears in many ASHRAE documents
- At best, it is defined implicitly
- Absence of disease? More than that?
- A common but flawed definition from WHO:
  "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" – unattainable for most, maybe all
- *Actionable* – able to be done or acted on; having practical value
- We might feel differently about building to promote health if we knew what we meant

MYTH 3

ASHRAE's Mission and Vision Exclude Consideration Of Health in Standards

9 MY TH 3

- Mission

  To serve humanity by advancing the arts and sciences of heating, ventilation, air conditioning, refrigeration, and their allied fields

- Vision

  A *healthy* and *sustainable* world for all

MYTH 4

ASHRAE Policy Prohibits Consideration of Health in Standards

11

MYTH 4

- ASHRAE Code of Ethics (ROB 1.140.001.1.A) Efforts of the Society, its members, and its bodies shall be directed at all times to enhancing the public ***health***, safety and welfare.
- ROB 1.201.005 - ASHRAE standards shall consider **health** impacts where appropriate.
- ROB 1.201.006 - Consistent with the ASHRAE' Certificate of Consolidation, Bylaws and Code of Ethics,ASHRAE activities and publications including but not limited to position documents, handbooks, special publications, ***standards and guidelines***, technical and educational programs, and conferences shall consider ***health*** and safety impacts, where appropriate.
- ROB 1.201.012.1 - ASHRAE supports Building Sustainability as a means to provide a safe, ***healthy***, comfortable indoor environment while simultaneously limiting the impact on the Earth's natural resources.
- Environmental **Health** Committee (ROB 2.406.001) - This committee shall be responsible for identifying major environmental health trends impacting the practice of HVAC&R, informing the ASHRAE leadership and membership of these trends and their potential impacts, and making ***recommendations on new activities and policies*** in response to these trends.

12

MYTH 4

- ASHRAE Position Documents with Positions Related to Health
  - Indoor Air Quality
  - Limiting Indoor Mold and Dampness in Buildings
  - Combustion of Solid Fuels and Indoor Air Quality in Primarily Developing Countries
  - Environmental Tobacco Smoke
  - Filtration and Air Cleaning
  - Indoor Carbon Dioxide
  - Infectious Aerosols

MYTH 5

ASHRAE IAQ Standards do not Address Health

14

MYTH 5

- "…no known contaminants at harmful concentrations as determined by cognizant authorities…" – ASHRAE Standards 62.1, 62.2
- "…design requirements for odor control and asepsis…" ASHE/ASHRAE Standard170
- "The purpose of this standard is to provide minimum requirements for…high-performance green buildings to…*enhance building occupant health...This standard is intended to provide the technical basis of mandatory building codes and regulations…"* ASHRAE/ICC/USGBC/IES Standard 189.1
- "The purpose of this standard is to establish minimum requirements for control of infectious aerosols to reduce risk of disease transmission in the occupiable space…" ASHRAE Standard 241

15 CONCLUSION

- There is no prohibition against addressing health in ASHRAE standards
- It is *required* that health be addressed where appropriate
- Existing ASHRAE standards address health to some extent, but "health" is not well-defined
- An actionable definition of health is needed that goes beyond preventing disease
- ASHRAE should continue to develop standards based on the current state of knowledge with an expanded definition of acceptable indoor air quality that includes a current definition of health

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- ASHRAE Position Documents https://www.ashrae.org/about/position-documents
- ASHRAE Standards https://www.ashrae.org/technical-resources/standards-and-guidelines/read-only-versions-of-ashrae-standards
  - ASHRAE Standard 62.1-2022 *Ventilation and Acceptable Indoor Air Quality*
  - ASHRAE Standard 62.2-2022 *Ventilation and Acceptable Indoor Air Quality in Residential Buildings*
  - ASHRAE/ASHE Standard 170-2021 *Ventilation of Health Care Facilities*
  - ASHRAE Standard 241-2023 *Control of Infectious Aerosols*
  - ASHRAE/USGBC/IES Standard 189.1-2020 *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*