TRANE TECHNOLOGIES™

Life Indoors

Understanding Indoor Environmental Quality

As Trane Technologies, we are climate innovators facing global challenges with daring optimism and a bold strategy to redefine what's possible for a more sustainable future.

For decades, we've experimented and innovated to create cleaner, more comfortable and energy efficient indoor environments for people — in homes, schools, offices, public transit and other dynamic spaces. Collectively with our brands, Trane® and Thermo King®, we bring a deep understanding of the science of indoor environments together with advanced systems and connected technology. We work shoulder to shoulder with businesses and communities to find solutions that progress their goals for a more sustainable tomorrow — while also addressing the challenges they face today.

Through the Trane Technologies Center for Healthy & Efficient Spaces (CHES), we work collaboratively with leading experts to advance indoor environmental quality (IEQ) policy, strategies and solutions. Together, we are taking action to build more resilient communities — and secure more sustainable futures.

www.tranetechnologies.com

TRANE TECHNOLOGIES™

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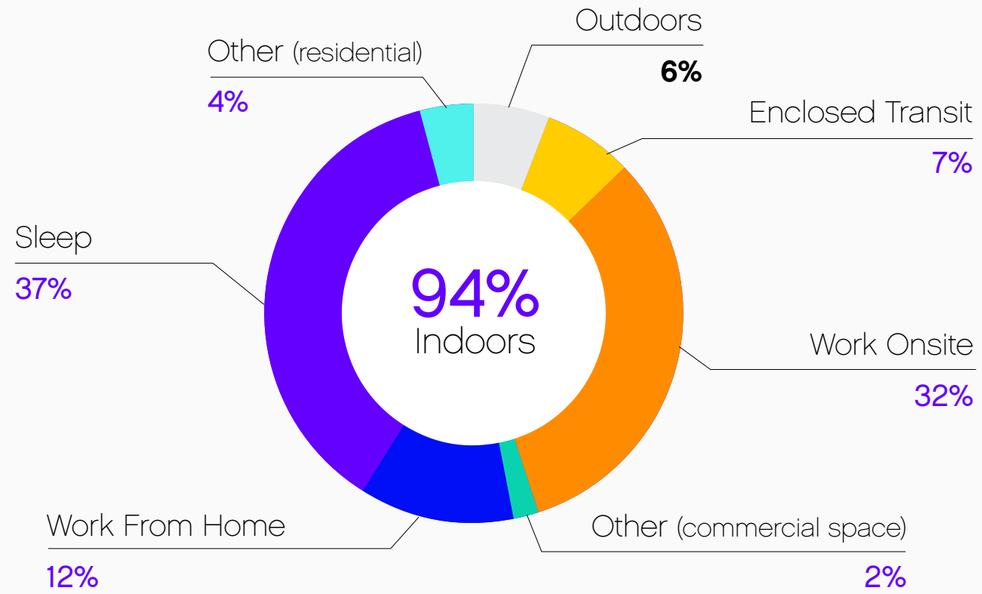
Introduction

Consider a typical day in many modern cities. You wake up, grab breakfast, put children on a bus to school, go to your workplace, go home, eat dinner, and go to bed. Of course, there are many other steps in between and variations of routines, but through it all — you have spent most of your day inside. In fact, people spend roughly 95% of their time inside enclosed spaces, so much that many studies have sought to understand exactly how that time is used, and how it affects human health and performance.[1]

A Snapshot in Time

Full-Time Employee



1 https://www.bls.gov/news.release/pdf/atus.pdf

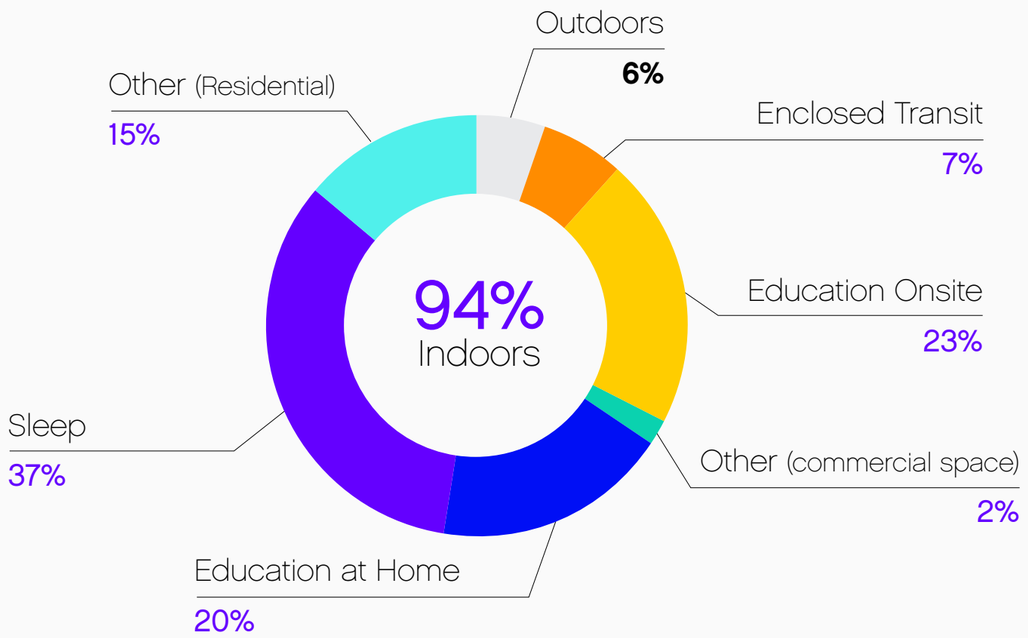
https://www.nature.com/articles/7500165

https://snowbrains.com/brain-post-much-time-average-american-spend-outdoors/

https://www2.deloitte.com/us/en/insights/economy/issues-by-the-numbers/decoding-american-time-use.html

https://ww2.arb.ca.gov/sites/default/files/2020-05/board-presentation-03-17-05.pdf

Full-Time Student



While the type of indoor time can vary slightly from country to country or occupation to occupation, the situation is still that people in both emerging and mature economies spend much more of their time inside than outside.

In a world now dealing with a health crisis, we do not yet know if the dramatic shift towards time spent in residential spaces will continue or if a different mix of indoor time will emerge, with a transition towards hybrid or part-time remote or virtual work environments.

No matter the breakdown of how time inside is spent, the fact remains — it is significant. Therefore, it also makes sense that considerable focus and investments be made on creating environments designed to maximize productivity and performance. To do that, it is critical to understand the elements of and the need for high quality indoor environments — and what achieving those environments means to the overall sustainability and efficiency of the built world we occupy.

What is Indoor Environmental Quality?

Indoor Environmental Quality (IEQ) encompasses the quality of conditions inside a building; air quality, lighting, thermal conditions, acoustics, ergonomics/architecture — and their effects on occupants.

Strategies for addressing IEQ include those that protect human health, improve quality of life, and reduce stress and potential injuries. By focusing on the occupant experience, elements of indoor environmental quality are combined and dynamically optimized to meet the unique needs of each individual. While these interactions create a complex and inter-dependent system, it is important to not focus on a single element at the expense of others. Tactics like increasing ventilation or filtration as a solution to a healthy indoor environment have been widely touted during the COVID-19 pandemic; these strategies alone may not be the best or only solution.

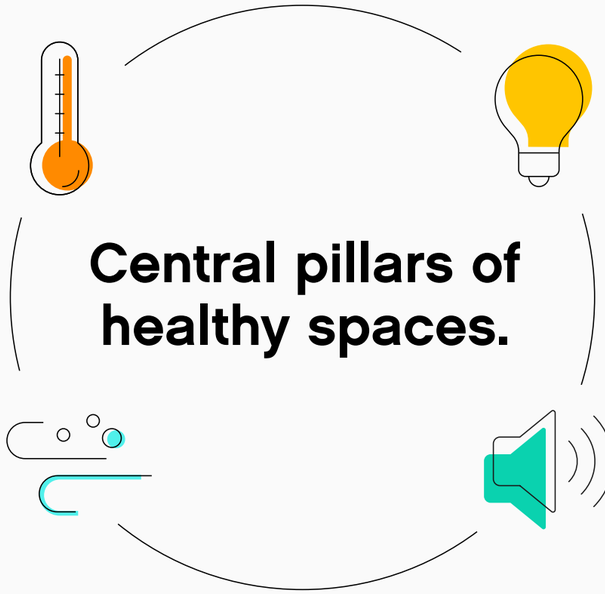
For example, there are highly effective lighting solutions that can reduce the risk of pathogen propagation. By focusing on the occupant, the right strategies can improve quality without compromising long-term health or energy efficiency.

Core elements of IEQ

How a structure is built has significant bearing on how difficult or easy it is to design or redesign systems that produce high performance indoor environments. From construction materials and major systems, to how occupants use the space, these factors combine in a unique way to determine the indoor environmental experience of the occupant. Studies have shown that this overall experience can have a profound impact on the health and productivity of the occupant both consciously and subconsciously.[2]

Thermal Comfort
How cold am I?

Lighting
Is the lighting right for my task?



Indoor Air Quality
What's in the air I'm breathing?

Acoustics
Is noise disrupting my task?

2 Effects of Indoor Environmental Quality on Performance and Productivity

Architecture, ergonomics, and aesthetics of a space can have a significant impact on the occupant's perception. Their more profound impact however, is how they determine needs to ensure the other four dimensions of IEQ are realized.

> **Therefore, most of the science around indoor environmental quality focuses on thermal comfort, indoor air quality, lighting, and acoustics as the four main pillars of healthy spaces.**

The most challenging issue with these elements is that unless the environment is very bad, a lot of the impact goes unnoticed by the occupant, making it difficult to draw a connection between the negative effects of poor indoor environmental quality and root causes — especially since these changes tend to happen gradually over time with little noticeable signs.

For example, if you walk into a stale, smoke filled room, you will notice it at once.

What if the space "feels" fine?

You may not notice a carbon dioxide bubble forming between you and your computer screen making you sleepy and reducing your productivity.

You may also not notice fine dust particles in the air — and there is no way to know if the air contains pathogens.

It is the invisible nature of poor indoor environmental quality that makes it so difficult to convince occupants, or those responsible for the performance of the space, of the need for measures to enhance or invest in environmental quality solutions to protect and promote health. However, science shows that the need is there, regardless of our ability to physically detect the difference in the space around us.

Thermal Comfort

ASHRAE® & ISO® standards define thermal comfort as **“the state of mind that expresses satisfaction with the thermal environment in which it is located.”** Thermal comfort is the most important and easily defined element of IEQ. For occupants to work at their full capability, their space needs to be thermally comfortable. The human body tries to maintain a temperature of around 37°C/98°F; kept by heat exchange between the body and the environment through convection, radiation, and evaporation.

Six factors influence thermal comfort – four environmental and two personal:

Environment	Personal
Air temperature	Human metabolic rate
Mean radiant temperature	Insulation through clothing or other coverings
Air relative humidity	
Air velocity	

Several factors have a conditional impact on **perceived** thermal comfort such as occupant age, gender, climatic conditions, and the season.

> **While thermal comfort may be the most easily defined, because of these “personal” factors, it is the most difficult to reach and support across a broad spectrum of occupants.**

Historically thermal comfort has been managed in zones to balance the need for personal control and energy optimization. Recent advances in sensing devices and digital technologies are generating a lot of innovation in the space and enabling a focus on personal thermal comfort. By focusing on dynamic coupling of personal comfort with system optimization and using digital advances in artificial intelligence, better solutions that address both personal comfort and energy efficiency can be implemented.[3]

3 Artificial Intelligence for Efficient Thermal Comfort Systems: Requirements, Current Applications and Future Directions

Indoor Air Quality

Indoor air quality (IAQ) refers to the air quality within and around interior spaces, especially as it relates to the health and comfort of occupants.

Historically, indoor air quality has focused on understanding and controlling common pollutants to help reduce the risk of indoor health concerns. In addition, health effects from indoor air pollutants can be felt immediately or years later depending on the type and level of exposure to the pollutant. The major concerns with these pollutants are that they may or may not be detectable by our basic senses.

Common pollutants include:

- **Carbon dioxide**
- **Volatile Organic Compounds (VOCs)** such as those produced by paint, fabric, foam, hairspray, air fresheners, perfumes, deodorants, cosmetics, photocopiers, gasoline and even cooking
- **Carbon monoxide**
- **Nitrogen dioxide**
- **Ozone**
- **Particulate Matter** such as dust, smoke, pollen (non-viable particulate matter) as well as bacteria, certain viruses, mold, algae, fungi (viable particulate matter)

Reducing pathogen spread

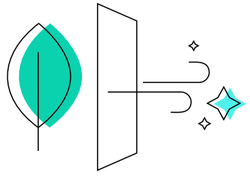
More recently, the role of indoor air quality has been focused on the spread and propagation of pathogens throughout the indoor space and the role of pollutants in the spread of airborne pathogens. The recent COVID-19 pandemic has alerted many people to the SARS-CoV-2 pathogen transmission indoors, but these same principles apply to many other common ailments such as cold and flu.

Airborne pathogens spread when bacteria or viruses travel on dust particles or small respiratory droplets that are aerosolized when an infected person sneezes or coughs or, to a much lesser extent, talks, sings or breathes.[4] For example, the size of a typical coronavirus is about 0.1 micron, these pathogens have been shown to travel on other particles to spread, such as: aerosols (up to 5 microns), droplets (>5 microns) and particulate matter. The most typical measure for particulate matter is PM2.5, which refers to particles that are 2.5 microns in diameter. The heavy presence of this fine particulate matter is what makes air appear hazy and due to their size, they can travel deep into the lungs and cause health concerns

A four-pronged approach

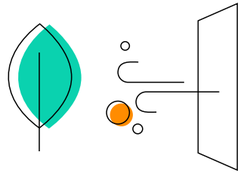
To improve indoor air quality and mitigate the causes of poor air quality a number of strategies can be used. Consistent with guidance from ASHRAE, our leading brand Trane® recommends an approach targeting four critical areas that influence the quality of indoor air.

Areas that influence the quality of indoor air:



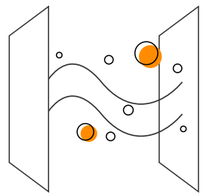
Dilute

Increase ventilation with fresh, outdoor air



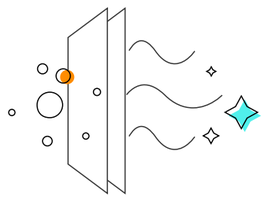
Exhaust

Ensure that the lower quality air in the space is being removed



Contain

Control humidity and pollutant sources



Clean

Safely use air cleaning technology as appropriate, including different filtration options

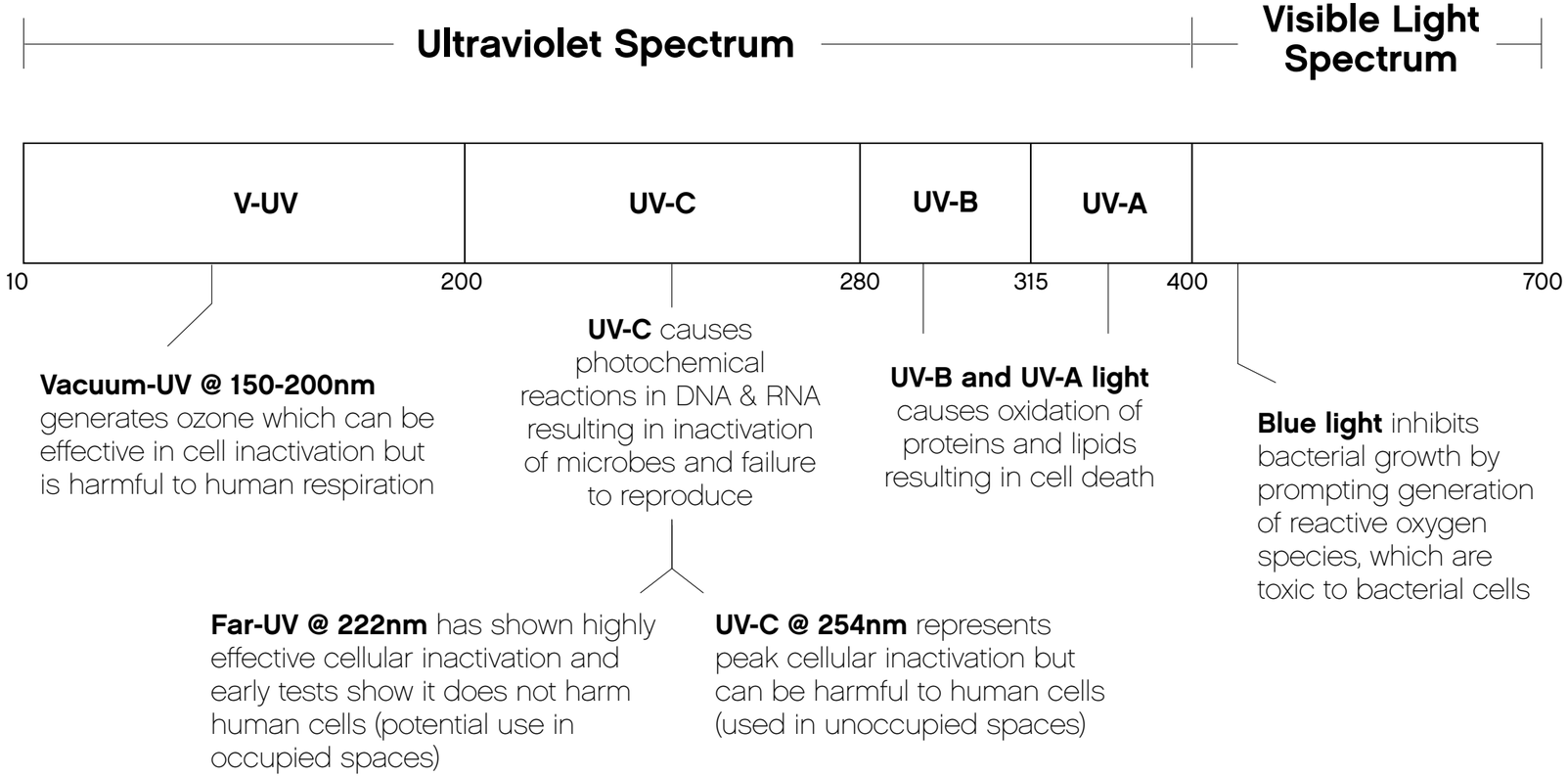
4 https://www.dhss.delaware.gov/dhss/dph/files/airbornetranspi.pdf

Lighting

Lighting is a part of a broader category of indoor environmental quality, known as visual comfort that includes both lighting conditions as well as the impact of "natural views" and social density — all of which have both a physical and psychological impact on health and well-being. In the context of indoor environmental quality, lighting refers to both the intensity and quality of lighting (light temperature and distribution), and its applicability to the activity being performed. The prevalence of LED lighting is transforming the role that lighting can play in an indoor environment. With the ability to dynamically vary intensity, lighting has the potential to better align to people's natural circadian rhythm,[5,6] thereby supporting overall health and well-being, and leading to the rise of a new area of application — human-centric lighting.

In addition to the overall role lighting plays in indoor environmental quality, multiple wavelengths in the ultraviolet light spectrum are known to incapacitate pathogens both in the air and on surfaces. The combination of strategic lighting to enhance the indoor experience and certain UV lighting strategies in efforts to reduce the total volume of pathogens in occupied and unoccupied spaces is an emerging area of importance in indoor environmental quality.

Research has shown that the amount and type of light in your environment can positively or negatively impact your circadian rhythm. According to the National Sleep Foundation, the circadian rhythm is basically a 24-hour internal clock that runs in your brain's "background," cycling between sleepiness and alertness at regular intervals.



5 Blume, Christine, Garbazza, Corrado; Spitschan, Manual, "Effects of light on human circadian rhythms, sleep and mood," Somnologie, Aug. 20, 2019, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6751071/

6 https://www.sleepfoundation.org/articles/what-circadian-rhythm

Acoustics

Acoustic comfort refers to the ability to protect the occupants of a space from potentially unwanted and harmful noise. It also refers to the ability of a space to offer an acoustic environment that is suitable for the designed purpose of the space. Depending on the space, a direct relationship has been established between acoustic comfort and occupant health and productivity. As with lighting and air quality, research has shown both potential short- and long-term implications from acoustics.

Like lighting, acoustics and the human response to noise are both complex and personal. Several studies have examined both the intensity and quality of noise and how those elements impact people.[7] These impacts are further complicated by the body's ability to adapt to acoustic environments over time.

Three strategies are typically used for managing unwanted noise in a space:

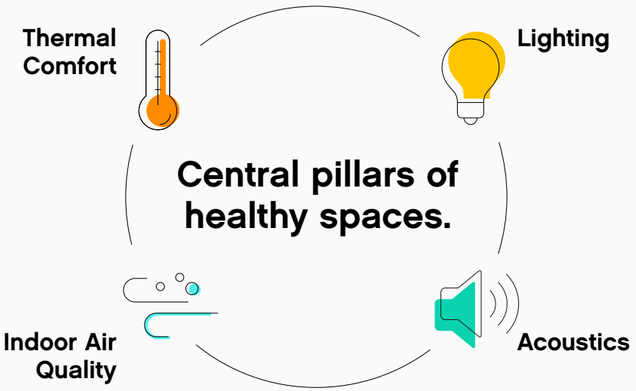
- **Absorption** of sound using noise lessening technologies at the source or between the source and the space
- **Blocking** sound by placing barriers in and around the space
- **Masking** sound using electronic masking technologies

7 Evans, Gary W., Johnson, Dana; Journal of Applied Psychology, "Stress and Open-Office Noise"

Bringing it all together: Integrated Systems

Given how much time people spend indoors, it is critical to understand and address elements of indoor environmental quality in all spaces as complex and interdependent sets of systems. The complexity is compounded by the dynamic nature of how these spaces behave with changing outdoor climate conditions, varying numbers of occupants and multiple types of activities. For this reason, a holistic, systems-based approach will help ensure people have the ability to comfortably and safely work, travel, and live in various spaces effectively.

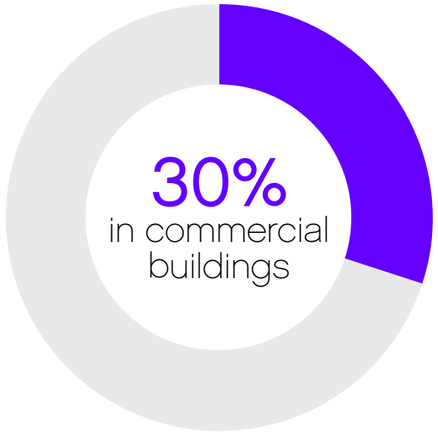
While certain circumstances may cause the caretakers of these spaces to focus on one element or another, e.g. focus on IAQ because of the COVID-19 pandemic, the long-term holistic view of a healthy and efficient space is critical to the sustainability of the built environment. In addition, since spaces and their use shift over time, it is critical to ensure ongoing and dynamic management and optimization of these spaces for both the health of the occupant and the energy efficiency of the space.



Why is Indoor Environmental Quality important?

For Commercial Buildings

The primary goal of a commercial building is to enhance the viability of the businesses and people operating within. If that is an office building, the focus may be on enhancing performance and engagement of employees. If that building is a retail location, employee performance is still important, but so is the ability of the space to attract the intended customer and create an atmosphere that encourages buying.[8] If that building is a school, the impact of the indoor environment on the academic performance and engagement of students and staff is of primary importance. Therefore, in addition to the complexity of the building systems, the application or use of the building and the specific needs of the occupants play a role in the building's ability to enhance organizational success.



Because people spend more than 30 percent of their time in commercial buildings[9] and we can now directly link commercial activity with GDP,[10] the quality of commercial spaces has received a great deal of attention in the past several decades from academic institutions and government agencies. This interest has generated a considerable body of research and a rich data set on the impact of environmental quality in many types of spaces. An example of one such study in the following table[11] shows the estimated economic impact of a few specific aspects of indoor environmental quality.

Sources of Productivity Gain	Strength of Evidence	Potential U.S. Annual Savings or Productivity Gain (1993 $U.S.)
Reduce respirator disease	Strong	$6-$19 billion
Reduce allergies and asthma	Moderate	$1-$4 billion
Reduce sick building syndrome symptoms	Moderate to Strong	$10-$20 billion
Improve worker performance: o From changes in thermal environment o From changes in lighting	Strong Moderate	$12-$125 billion

8 The effects of store atmosphere on shopping behavior-a literature review.& The Effects of Store Environment on Shopping Behaviors: a Critical Review

9 Deloitte Insights, November 2018: All in a day's work – and sleep and play: How Americans spend their 24 hours

10 Investopedia Business Essentials - Commercial

11 Fisk & Rosenfeld, 1997 "EFFECTS OF INDOOR ENVIRONMENTAL QUALITY ON PERFORMANCE AND PRODUCTIVITY"

More recently, the Center for Disease Control and prevention reported that productivity losses linked to absenteeism cost employers **$225.8 billion annually** in the United States while the Harvard Business review estimates an added **$150-$250 billion** in costs due to employees working while sick.[12]

$225.8 BILLION
Annual cost of productivity loss due to absenteeism

For simplicity, we have selected two types of commercial spaces to illustrate the importance of indoor environmental quality: office buildings and schools/educational buildings.

Office Buildings + Educational Buildings

For Office Buildings

Since the human resource costs of salaries and benefits can surpass the operating costs of an office building, strategies that improve employees' health and productivity over the long run can provide a great return on investment. For building owners, attracting and retaining tenants has increasingly required they offer environmental quality outcomes that go beyond traditional real estate services, with those demands now on the rise.

IEQ goals often focus on supplying stimulating and comfortable environments for occupants and minimizing building-related health risks. In the last year, the global pandemic has shifted that focus to include minimizing the risk of pathogen transmission. This is not a new risk in fact; it costs businesses tens of billions of dollars a year in lost productivity.[13]

To make buildings a place where people feel good and perform well, teams must strike a delicate balance between strategies that promote efficiency and conservation with those that address the needs of the occupants and promote well-being. Ideally, chosen strategies do both: conserve energy, water and materials but also contribute to a great indoor experience.

The impact of **thermal comfort** on performance in office spaces has been at the center of studies for several years. Research has shown that differences in productivity resulting from occupants being too hot or too cold have as much as a 10 percent impact on task performance in study participants. As with other elements of IEQ, actual results are affected by feelings of both thermal comfort as well as perceptions of productivity. However, field experiments all show a peak in task performance as thermal comfort improves. Results from studies that

12 Worker Illness And Injury Costs U.S. Employers $225.8 Billion Annually

13 Flu cost employers $21 billion in lost productivity last flu season: report

use both quantitative and qualitative measures and assessments produce similar results.[14]

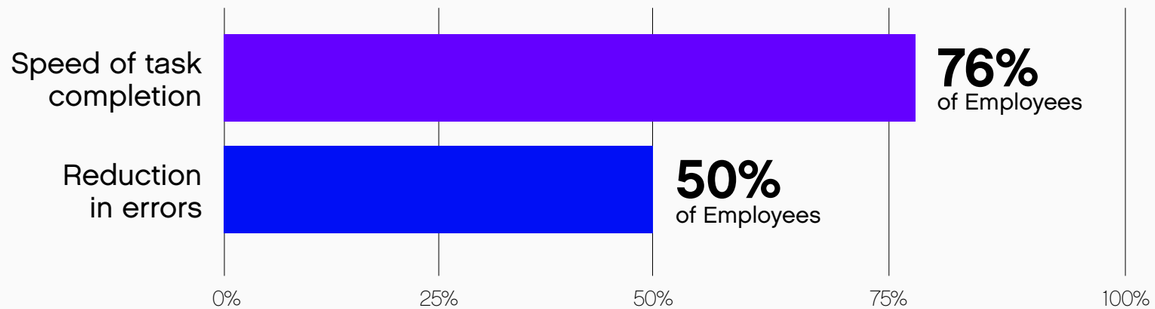
Studies on **indoor air quality** in office settings have shown opportunities for improvement in cognitive performance and **productivity enhancements of approximately 10 percent** when ventilation is increased. The three most impacted cognitive functions - information usage, strategy, and crisis response — are most critical in an office environment.[15] Finally, just an increase in airflow in a space has been shown to provide as much as a 6.5 percent improvement in intellectual productivity.[16]

Installing **human-centric lighting** featuring a "circadian-friendly" lighting sequence can also help to enhance productivity. For example, according to research conducted by the Twente University and the Free University Amsterdam,[17] a property company recorded an **employee-perceived increase of productivity by 18 percent** with installation of "circadian-friendly" lighting.[18] The study also found that after lighting was upgraded, employees improved work accuracy by 12 percent, 76 percent of employees described feeling happier and 50 percent reported that they felt healthier.

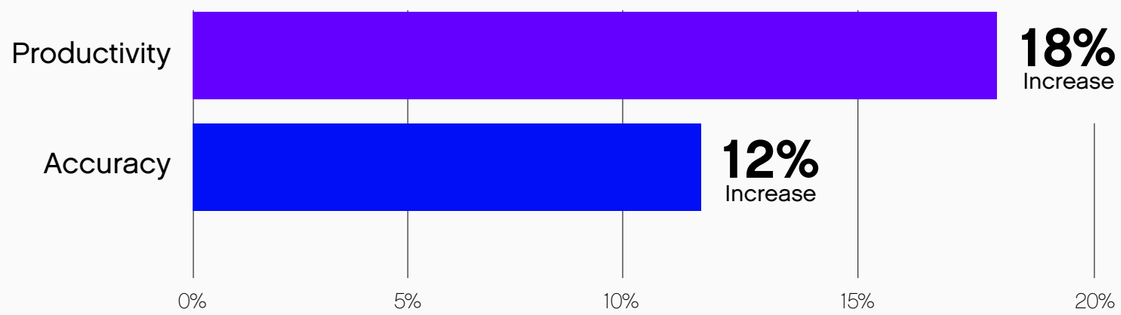
While it may be tempting to dismiss workplace lighting as insignificant, research shows otherwise. A study conducted by the American Society of Interior Design showed that 68 percent of people complain about the lighting situation in their offices.[7]

Employee Mood Improvements

Evans, Gary W., Johnson, Dana; Journal of Applied Psychology, "Stress and Open-Office Noise"



Employee Work Improvements



14 Quantitative measurement of productivity loss due to thermal discomfort, THERMAL COMFORT AND PRODUCTIVITY, Effect of temperature on task performance in office environment , How Indoor Environment Affects Performance

15 A Controlled Exposure Study of Green and Conventional Office Environments

16 Objective and quantitative evaluation of intellectual productivity under control of room airflow

17 Human Centric office lighting 'boosts productivity

18 The Growing Case for Human-Centric Workplace Lighting.

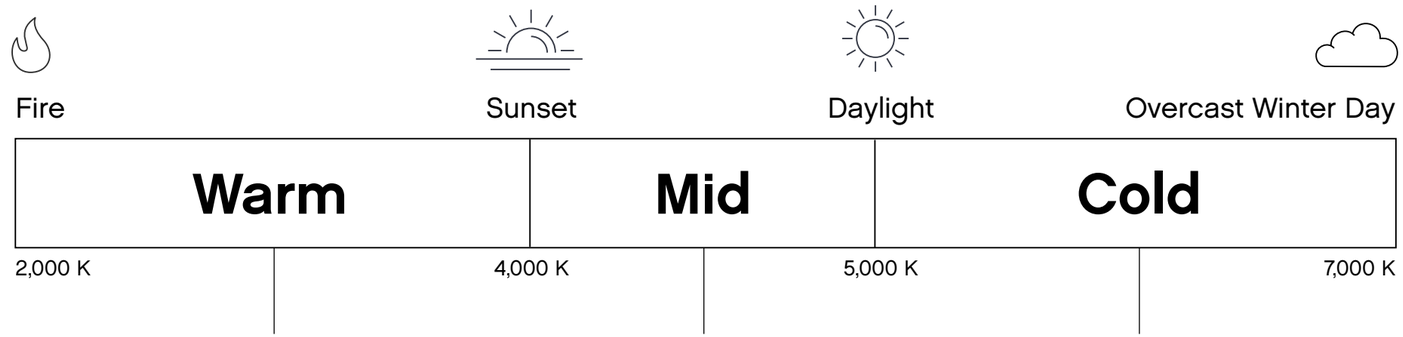
In addition, studies looking at the impact of lighting on various productivity measures such as visual sharpness, attention, typing etc. have shown significant differences in performance based on color temperatures.

Finally, a time-controlled lighting system implemented at the same property company featured a circadian rhythm-friendly lighting sequence that varies color temperature and intensity throughout the day. During the morning and early afternoon, high illumination levels and cool indirect white light stimulates employees. Light levels fall and become warmer at mid-day and during late afternoon[7] to aid in the continuation of the circadian rhythm and help the body prepare for melatonin secretion and subsequent sleep.

Studies on **ambient noise** also show that noise can be an important environmental variable affecting performance. Like thermal comfort, less noise is not always better, and more noise is not always bad.

How light affects productivity:

One of the most striking factors influencing how we work is the color temperature — measured in Kelvin (K) — of the light sources we're exposed to on a regular basis.



USE IN
Intimate settings, break rooms
Creates a sense of comfort and relaxation.

USE IN
Conference rooms
Welcoming but still cool enough to promote alertness.

USE IN
Brainstorming rooms
Improves alertness, mood and productivity. Lowers melatonin which reduces fatigue.

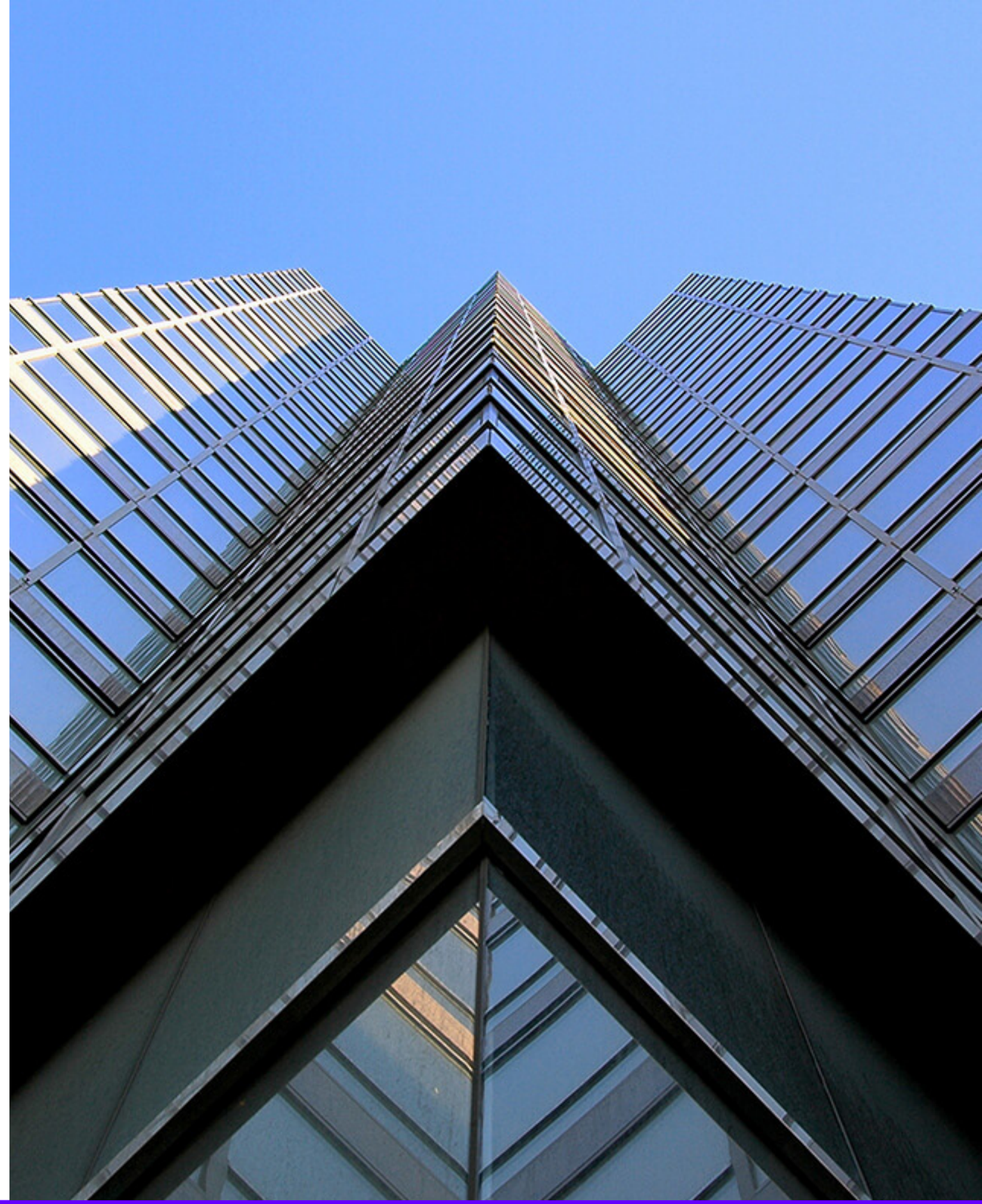
Sources:
http://www.westinghouselighting.com/color-temperature.aspx
https://www.jcircadianrhythms.com/articles/10.1186/1740-3391-5-2/

Both noise level and quality have been proven to have a direct impact on cognitive functions,[19] which lends itself to the concept of noise tuning for the task. Therefore, like temperature, acoustic optimization for the task is key. Studies have shown that moderate ambient noise levels enhance performance on creative tasks, while both low- and high-levels of ambient noise diminish performance.[20] They go further to show that office noise with and without speech can cause disruption in more critical thinking like arithmetic, while a quiet environment produces the best results.[21]

Better indoor environmental quality can:

- **Enhance** the lives of building occupants
- **Increase** the potential resale value of the building
- **Reduce** liability for building owners[22]

As we see in these examples, each element of IEQ is complex and tuning the microenvironment to the occupant needs requires a holistic and dynamic approach. This is complicated by the fact that various elements interact with each other to create a total occupant experience and often happen without the occupant noticing any issues in the indoor environment.



19 Evans, Gary W., Johnson, Dana; Journal of Applied Psychology, "Stress and Open-Office Noise"

20 Is Noise Always Bad? Exploring the Effects of Ambient Noise on Creative Cognition

21 Disruption of office-related tasks by speech and office noise

22 Green Building 101: What is indoor environmental quality?

For Educational Facilities

While many of the studies looking at cognitive deficiencies in office spaces can apply to learning environments, there are several lines of research that specifically delve into the impact of various elements of IEQ on academic performance in school environments.

> **Studies have shown that varying classroom temperatures to enhance thermal comfort can improve student performance on psychological tests and school tasks by 20 percent on average,**

and the effect of temperature on schoolwork seems to be greater in magnitude than for office work.[23]

Similarly, improved indoor air quality with reduced CO2 levels have been linked to **improved speed of task completion by 12 percent**, reduction of errors by 2 percent and improvement of daily attendance by 2.5 percent.[24]

In addition, studies conducted on various forms of ventilation, including natural and mechanical ventilation, indicate that building energy efficiency is increased by 30 percent with mechanical ventilation thanks to heat recovery.[25] Compared to its natural counterpart, mechanical ventilation improves both energy efficiency and indoor air quality — this is especially common in densely populated urban areas with poor ambient air quality. Further research has confirmed this correlation of balanced mechanical ventilation and student performance. Students in classrooms with balanced automated ventilation performed better on standardized testing and other indicators of performance than those in unventilated rooms and those in naturally ventilated rooms.[26]

While research on **indoor air quality** in classrooms has historically focused on common air quality factors such as CO2 and PM2.5 and their impact on student performance, current events have increased the focus on pathogen transmission. Although the COVID-19 pandemic has placed greater emphasis on this issue, it is certainly not a new issue for educational facilities.

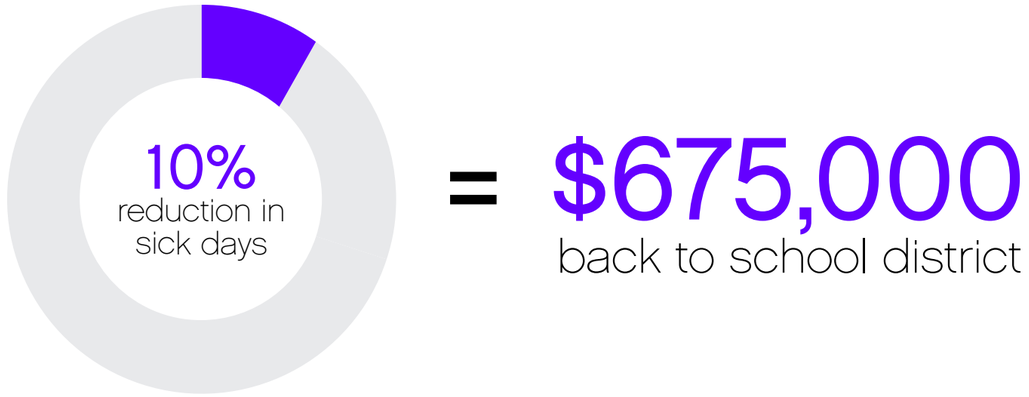
23 The relationship between classroom temperature and children's performance in school

24 The relationships between classroom air quality and children's performance in school

25 The effect of the ventilation retrofit in a school on CO2, airborne particles, and energy consumptions

26 Association between classroom ventilation mode and learning outcome in Danish schools

It is estimated that, prior to the current pandemic, in the U.S. alone, 164 million school days are lost each year in grades K-12 due to cold and flu.[27] While reimbursement numbers from absenteeism can vary by district, it averages between $30-$50/per student, resulting in a minimum $4.9 billion in lost revenue to schools annually. For a school district of 50,000 students @ $30 per student per day that could mean $6.75 million in lost revenue per year. If improving indoor air quality could reduce the number of sick days by reducing the degree to which illnesses spread within schools by even 10% that is worth over $675,000 a year to a district.



Therefore, by developing solutions to mitigate the risks associated with the current pandemic, there is an opportunity to build long-term value into schools by reducing overall absence due to illness. Studies have shown that student illness also contributes to missed workdays across businesses. Parents caring for their sick children contributes to the more than $20 billion of costs employers lose from employee absenteeism due to illnesses.[28]

Several studies also looked at whether advances in LED **lighting** can help improve the learning environment in classrooms. A 2018 study published in the journal, Optics Express,[29] suggests that dynamic lighting can support student classroom learning. In the study, researchers found that lighting can be optimized for various activities from test-taking to reading, based on correlated color temperatures.[19]

Another study found that students felt more alert and scored higher on their tests when they were in a classroom with 6,600 K lighting, a cool, blueish white that mimics natural daylight, when compared with two other kinds of enriched lighting — and against a control group in a classroom using stagnant florescent lighting.[30]

A crucial point is that just as lighting can have a profoundly positive impact on the way people perceive their mood, well-being, and productivity — using the wrong technology, or using it in the wrong way can have a detrimental impact. For example, leaving the lighting at 6,600K throughout the day could have adverse effects on the students' circadian rhythms.[19] The modulation of intensity and color temperature throughout the day or selecting particular intensities

27 SCHOOL ABSENTEEISM DUE TO ILLNESS - FACT OR FICTION?

28 The Economic Burden of Non–Influenza-Related Viral Respiratory Tract Infection in the United States

29 How Just The Right Lighting May Improve Learning In Classrooms

30 Dynamic lighting system for the learning environment: Performance of elementary students

and color temperatures for specific tasks are proven to be the most effective way to influence positive productivity.

Finally, studies have correlated **ambient noise** to learning, showing that high ambient noise can influence all areas of learning including intentional and incidental recall,[31] speech, listening comprehension, reading, and writing. In addition, studies have shown that children are much more impacted by noise than their adult counterparts and chronic exposure to high ambient noise may affect a child's cognitive development.[32] One study indicated that ambient noise has as strong a correlation to a student's test performance as student GPA.[33]

For Homes

As people have traditionally spent most of their time at home, the role IEQ can play in residential environments is critical to the long-term health and well-being of individuals.

> **This issue is amplified due to the recent pandemic and the expected shift in proportionality of "work from home" and "learn from home" arrangements vs. the pre-COVID-19 state.**

According to the U.S. Census Bureau, one-third of all American workers and half of all so-called "information workers" are able to work from home, and 98 percent of people surveyed would like the option of working from home for the rest of their career.[34]

This movement toward increased time at home also means they are spending time doing activities from home that they would normally do in commercial spaces…working, shopping, learning, etc. Therefore, the conditions that promote effective work and learning performance need to be considered in the home environment. A great deal of the research and findings previously associated with office environments now needs to translate to home environments as people try to create healthy micro-environments within their homes to ease dual working and learning demands.

Because these shifts in the expanded use of home spaces for more activities are relatively new, previous research in this area has focused on the impact of residential environments on overall health and well-being; especially as they relate to the most vulnerable members of a household with chronic health conditions as well as the elderly.

31 AMBIENT NOISE AND COGNITIVE PROCESSES AMONG PRIMARY SCHOOL CHILDREN

32 Does noise affect learning? A short review on noise effects on cognitive performance in children

33 Effects of Ambient Noise on the Measurement of Mathematics Achievement for Urban High School Students

34 Working from home. It's now a thing.

A recent market study by Green Builder's COGNITION Smart Data[35] shows significant shifts in buying behavior consistent with this change in the usage of home spaces. Consumer preferences appear to have changed due to the current pandemic with health and wellness becoming the most important factor in home environments. It is possible that the current pandemic has permanently created a heightened awareness of indoor environmental quality in homes that will continue beyond the current COVID-19 outbreak.

In this same way, the focus on indoor environments in homes has been on avoiding poor conditions — improving air quality, ending thermal discomfort, and correcting poor lighting — rather than deliberately creating environments fine-tuned to the activity of the occupant. Until recently, little focus was placed on "creating" the right environment for various activities at home.

In addition to the direct impacts on productivity and performance, **thermal comfort** is linked to lower sleep quality which leads to health issues and indirect impacts on productivity and performance, a result of disruption in circadian rhythm.[36] In fact, studies indicate that sleep efficiency and stability were influenced not only by thermal comfort during sleep but also by the pre-sleep thermal environment. A sleep environment that is either too cold or too warm had similar negative effects — implying that more precise thermal control is required to support a healthy sleep cycle.[37]

While there are several studies associated with the indirect impacts of thermal health, there is also an emerging body of research associated with the direct impact of increased and persistent heat levels on human health and mortality. While this may not be a major issue in more temperate climates, it is critical in more tropical and sub-tropical climates. As climate change progresses, the impact of thermal health will be felt by more people due to more extreme seasonal temperatures globally.

> Poor **indoor air quality** has an impact on both short- and long-term health.

The most notable of these connections is between air quality and asthma, but affects also include respiratory tract infections, allergic reactions, headaches, congestion, eye and skin irritations, coughing, sneezing, fatigue, dizziness, and nausea.[38]

35 Cognition Hot Take: Home Buying Surges

36 The Relationship between Thermal Comfort and Light Intensity with Sleep Quality and Eye Tiredness in Shift Work Nurses

37 Effects of phased sleeping thermal environment regulation on human thermal comfort and sleep quality

38 Household air pollution: Disease impacts

Overall, studies have shown that better indoor air quality (lower carbon dioxide and particulate matter) results in better quality sleep. Early studies indicate a strong correlation between air quality and the severity of symptoms associated with COVID-19.[39] Like thermal comfort, indoor air quality — as measured by levels of CO2[40] and particulate matter (PM2.5)[41] — has an impact on sleep quality as well as next day alertness and performance.

In addition, there are several studies linking **lighting** quality to sleep disorders and the loss of productivity associated with disruptions in circadian rhythm. The Centers for Disease Control and Prevention (CDC) and the National Institute for Occupational Safety and Health (NIOSH) acknowledge the impact of lighting just before and after normal sleep times to help regulate sleep schedules.[42] Specifically, exposure to artificial light designed for highly productive tasks too close to the time for natural sleep is known to cause sleep disorders while the suppression of daylight early in the morning can have an impact on sleep the following night and therefore alertness and productivity the following day.

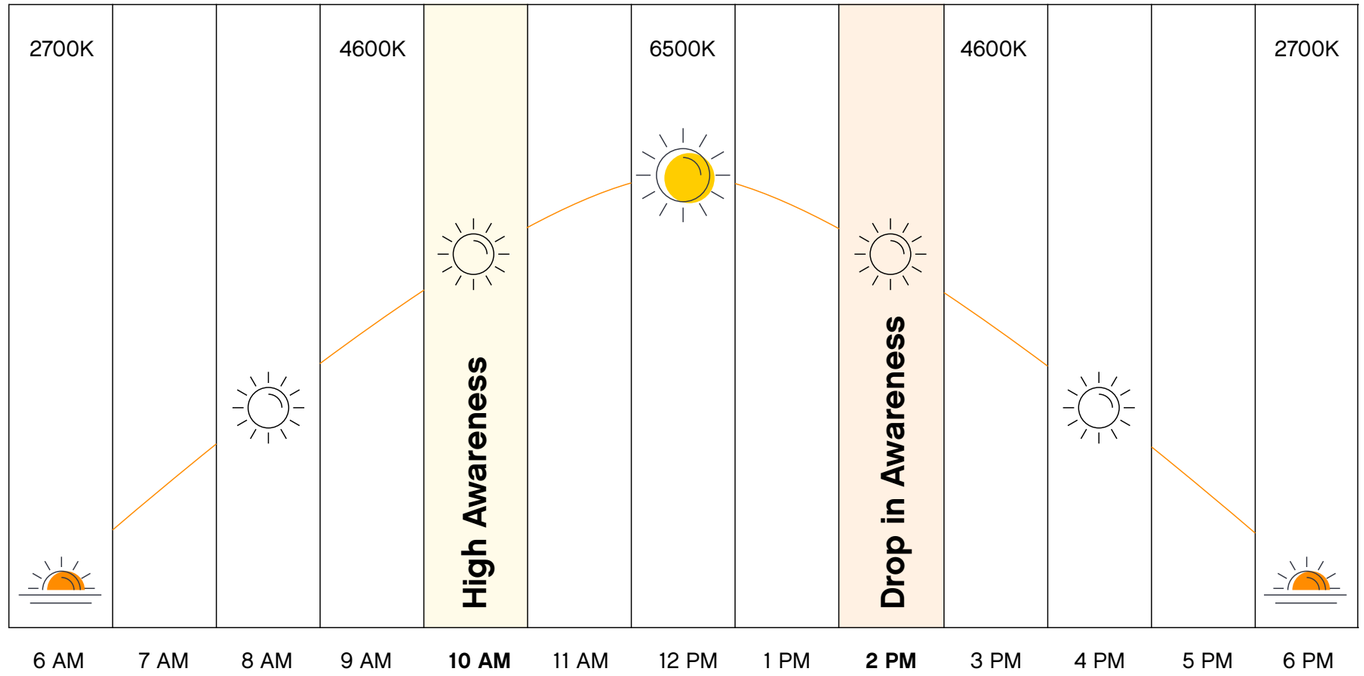
39 Analysis Links Poor Air Quality to Increased COVID-19 Deaths

40 The effects of bedroom air quality on sleep and next- day performance

41 Association between Indoor Air Quality and Sleep Quality

42 Interim NIOSH Training for Emergency Responders: Reducing Risks Associated with Long Work Hours

Sunlight temperatures and awareness levels



Source: What is Circadian Lighting?

Prolonged disruption of the human circadian rhythm can have chronic effects on both mental and physical health.[43] Conversely, studies have proven that tuned circadian lighting (light therapy) when targeted correctly can mitigate chronic conditions such as dementia and Alzheimer's, and aid in the recovery of stroke patients.[44].

Similarly, room **acoustics** are connected to sleep quality. Studies show that the reduction of noise level and reverberation leads to an increase in deep sleep and a reduction of nocturnal arousal events, especially important for poor sleepers.[45] Exposure to prolonged or excessive noise is capable of causing a range of chronic health issues ranging from stress to poor concentration to communication difficulties to more serious effects such as cardiovascular disease and cognitive impairment — in addition to traditional hearing conditions such as tinnitus or hearing loss.[46]

> **The more time people spend at home, the more significant the role of the home environment on these outcomes.**

43 Effects of light on human circadian rhythms, sleep and mood

44 Shine a Healing Light: Circadian-Based Lighting in Hospitals

45 The Effect of Room Acoustics on the Sleep Quality of Healthy Sleepers

46 Health effects of environmental noise pollution

This is especially true of the more vulnerable members of society, such as the elderly or those with chronic physiological and psychological conditions. In the long-term, this has considerable implications for health services and health insurance. The more we can enhance the health of home environments — where people spend most of their lives — the more we can reduce many related health impacts. With today's technologies around air cleaning, LED lighting and home automation, these home-based strategies can be implemented in a way that not only supports life indoors, but also reduces the carbon footprint and overall electrical costs of the residential built environment.

For Transport

The role of indoor environmental quality for the transportation of people is slightly different from that for commercial or residential spaces. On average, people spend 7 percent of their time in transit to and from their various daily activities. In large urban environments that involves the use of public transit for anywhere from 30 percent to 50 percent of the population of those cities.[47] Those numbers increase for cities in Europe and Asia where public transit is more readily available.[48]

The role of mass transit in the sustainable built environment has been established by several researchers — and to enable a significant reduction in the energy intensity of urban environments the availability and safety of mass transit solutions must be addressed.[49]

The unique challenges of mass transit are both the density and diversity of the occupants within a bus or rail car. In addition, mass transit systems also serve to enhance the economic mobility of the most vulnerable members of society. Conversely, issues that affect mass transit systems, disproportionately affect those who are the most vulnerable since they tend to have no alternate forms of transportation.[50]

While the amount of time spent in transit is less than that for other spaces, the same principles around indoor environmental quality apply. In fact, compared to other spaces, the indoor environmental quality of transport spaces is perhaps the most difficult to manage and maintain. Spaces tied to transit tend to have more exposure to the ambient environment than other spaces, and less control over the intrusion of ambient influences including temperature fluctuations, air pollutants and noise.

47 American Community Survey (ACS)

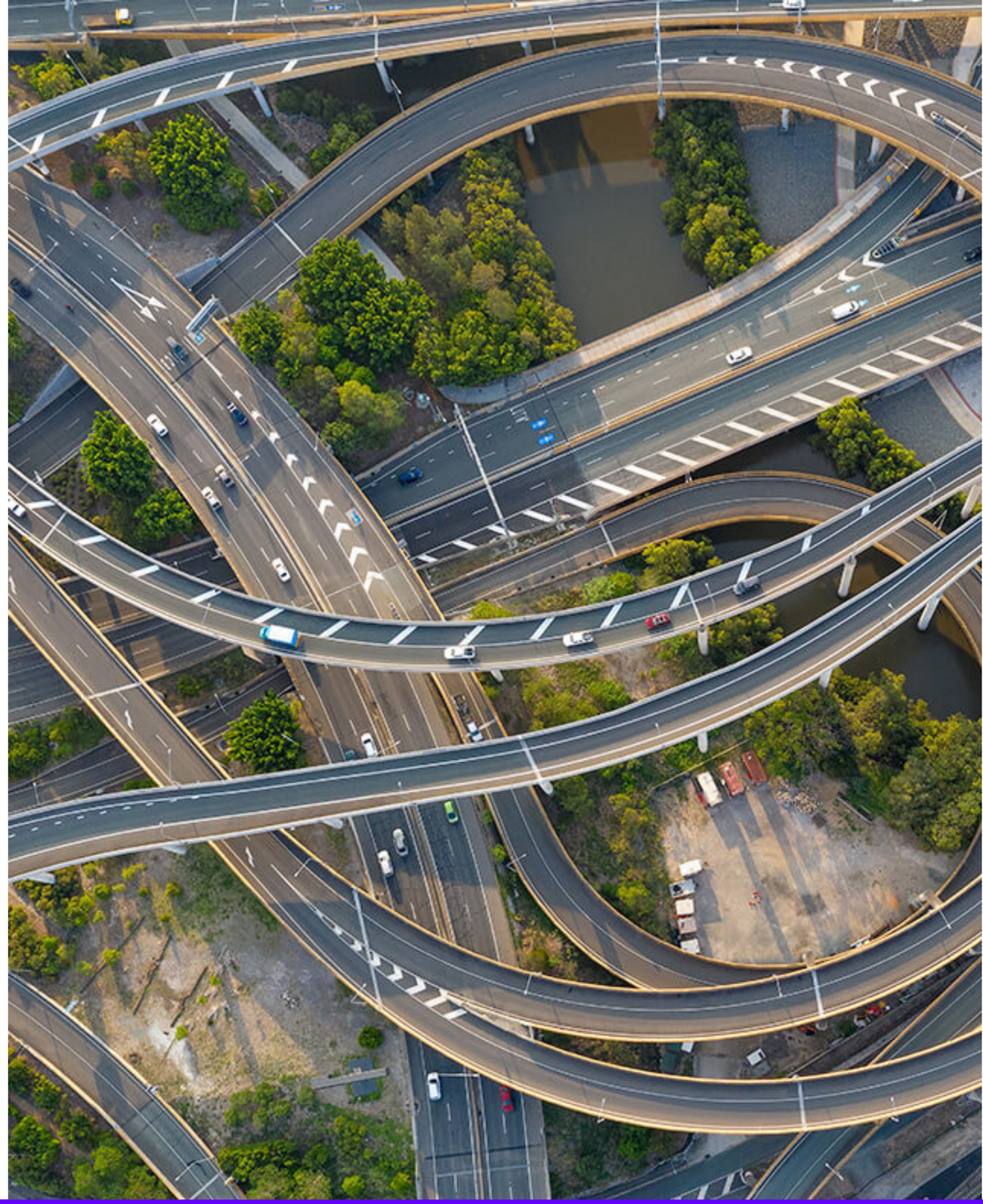
48 Breaking Down the Many Ways Europe's City-Dwellers Get to Work

49 Transit's Role in Environmental Sustainability

50 Impact of COVID-19 on Public Transit Accessibility and Ridership

In addition, the density of occupants in a bus or rail car poses a unique challenge to mitigating the impact of occupants on the environmental quality of the space. Take for instance longer duration transport modes like tour buses, where traffic accidents are the primary cause of injury among tourists. In the past few years, researchers have examined the concentration of carbon dioxide (CO2) in different types of vehicle cabins to evaluate safety issues based on suspicion that elevated CO2 levels were leading to drowsiness and fatigue among occupants, including drivers, and limiting the ability to concentrate.[51]

Take for instance, solutions that ensure thermal comfort while effectively mitigating air and noise pollutants are critical to the success of public or mass transit. This issue is highlighted by the recent pandemic as fear of pathogen spread and the demands of social distancing keep people from using mass transit, thus calling into question the long-term viability of this critical part of sustainable cities.[52]



51 Carbon Dioxide Concentrations and Temperatures within Tour Buses under Real-Time Traffic Conditions

52 Impact of COVID-19 on public transport

Indoor Environmental Quality & Energy Efficiency

Why is the holistic approach important?

Every space is unique — in terms of design, surrounding environment and use.

Indoor spaces also consist of interconnected systems – and the interactions between these systems result in an occupant experience around indoor environmental quality.

To ensure that these systems work together to deliver the desired outcome at the expected time, a holistic approach is needed — otherwise addressing an issue with a single solution can create unintended issues with other systems.

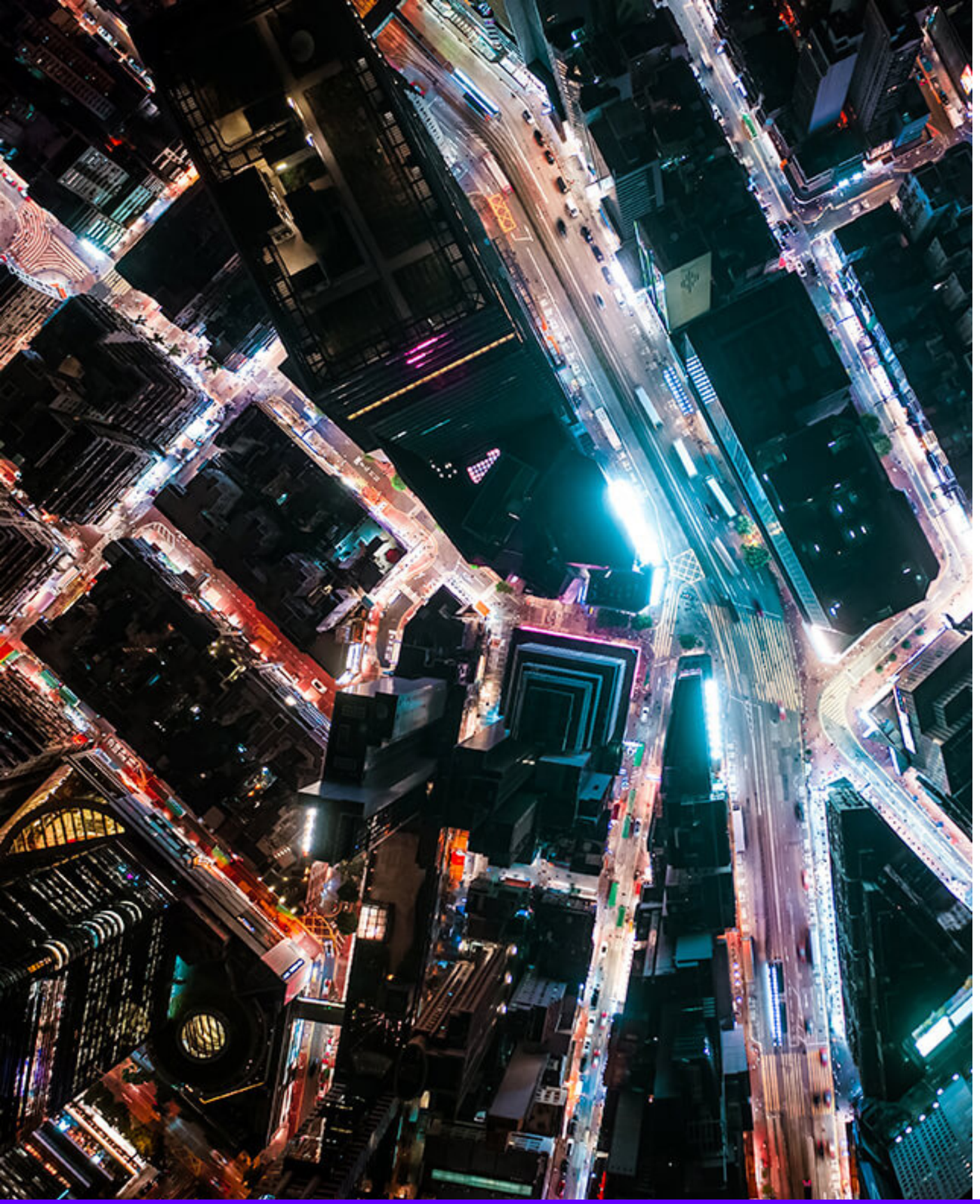
For example, increasing the volume of outdoor air into indoor spaces without controlling the quality of the air, and without addressing humidity or other external factors, can create either an immediate negative effect on indoor air quality, or contribute to long-term harmful effects such as mold. In addition, the imbalance can negatively impact the energy efficiency of the space.

Dynamic Integration, Optimization and Control

Because the conditions of a space are constantly changing based on the number, types and activities of occupants, these systems controlling indoor environmental quality need to be managed not just holistically — but also dynamically. The dynamic management of these systems allows for demand-based systems which use energy only when needed.

Digital technologies and connected solutions enable both near-real time optimization of energy, IEQ and hyper-personalization. By extending our analysis of IEQ from just systems into a specific space and even further to an individual occupant, hyper-personalized and optimized systems can lead to unprecedented improvements in energy efficiency. This can be accomplished by adding personal cooling, IAQ and lighting devices and integrating those devices into the broader system controls to optimize for personal comfort.[53]

53 Artificial Intelligence for Efficient Thermal Comfort Systems: Requirements, Current Applications and Future Directions



Linking IEQ to Energy Efficiency and Sustainability

Strategies for healthy spaces that also reduce energy intensity, come with an added health benefit thanks to a reduction in emissions from greenhouse gases. As with human performance and business performance, the social performance benefit can also be quantified. Initial analyses have shown that for every $1 saved in energy in the United States another $0.59 is gained in health and climate co-benefits because of the reduction of pollutants generated by the energy sources.[54] In the developing world, these co-benefits approach a $10 benefit in health and climate for every $1 saved on energy. Therefore, solutions that aim to optimize indoor environmental quality along with energy efficiency can have a compounded societal impact leading to a virtuous cycle of improvements in both indoor and outdoor environments. It is this approach and outcome that is at the core of the Center for Healthy and Efficient Spaces.

54 Healthy Buildings: How Indoor Spaces Drive Performance and Productivity

What is Trane Technologies approach to IEQ and Energy Efficiency?

Assess

Because every space is unique in its design, environment, and use, it is critical to assess the needs of that space first to determine the best approach to optimize IEQ for its occupants. In addition, as the use of the space evolves over time, ensuring that the proper indoor environment is supported may require recurring or continuous assessment techniques.

Assessments come in many forms and can address specific pieces of equipment, entire systems or even the application of those systems to the space and its need. Standards like LEED and other traditional approaches address how a system or space is designed but not how a space performs over time. Emerging methodologies and those recommended by the WELL Building Institute aim to address the issues associated with the performance of a space holistically.

In addition, there are several approaches and tools that can be applied to assess the indoor environmental quality of a space — ranging from simple measurement practices to assure minimum compliance with industry standards, to sophisticated modeling and simulation of airflow, lighting and acoustics in the space, and real-time surveys of occupants on various elements of IEQ. Solutions should therefore be tailored to the needs of the space, the occupants in that space and the needs of the customers who are charged with ensuring the right type of indoor environment is created to support its occupants.

Mitigate

Based on the outcomes of an assessment, mitigation strategies can be developed to eliminate issues with indoor environmental quality. In addition, micro-climates can be specifically designed to meet the needs of specific spaces by using occupant centric approaches. Since there are a great deal of options when it comes to mitigation and design strategies, it is critical to the select the right approach for the right situation.

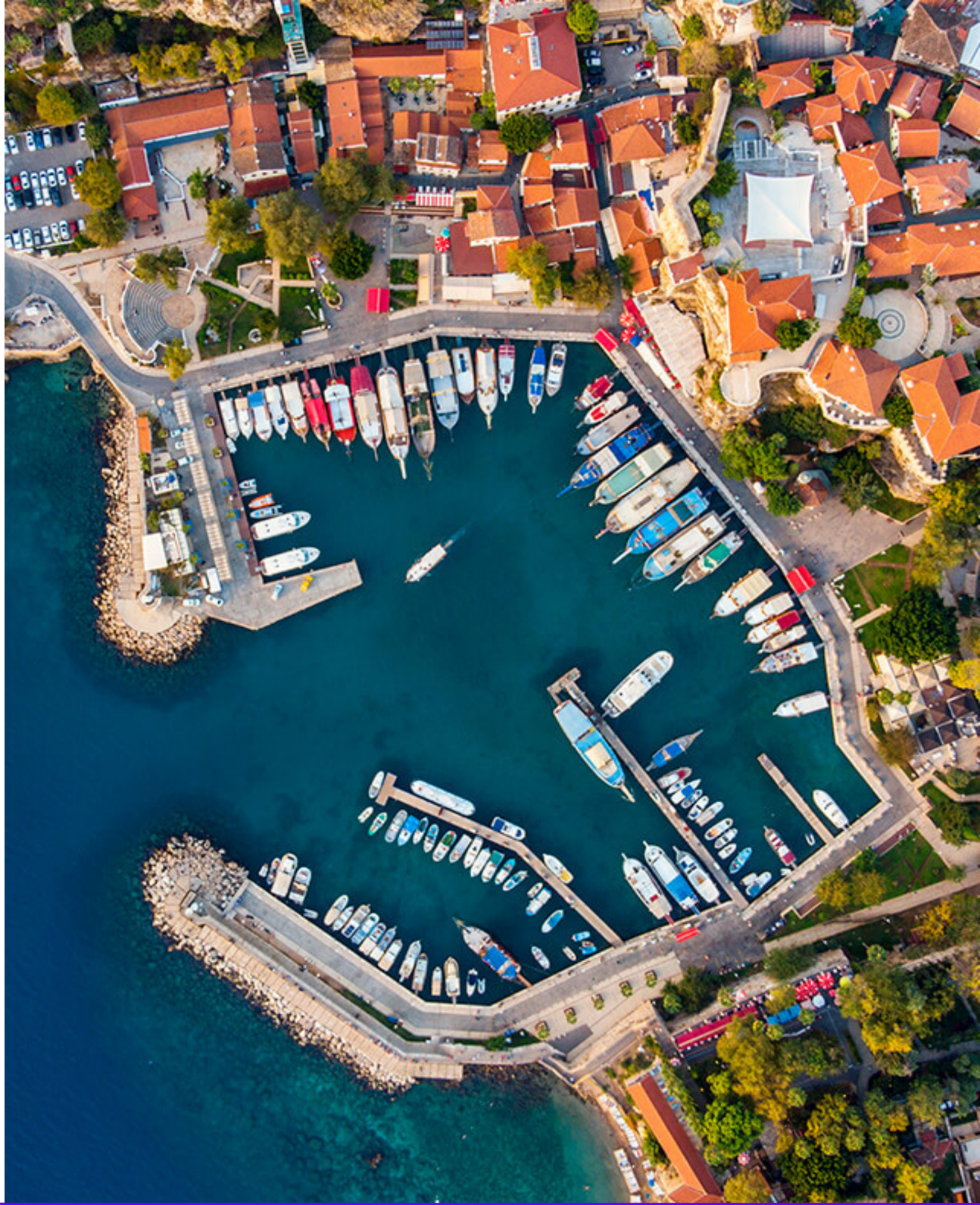
> **At Trane Technologies, our focus is on mitigation strategies that optimize indoor environmental quality while jointly maintaining focus on energy efficiency and sustainability, thereby resulting in a resounding positive impact.**

It is that critical balance that differentiates us as a partner in the sustainable built environment. In fact, we have demonstrated that by focusing on use-centric strategies and optimizing systems around occupants, much greater energy savings can be achieved. We also focus on uncovering and maturing innovations that support the goal of reducing risk and improving energy efficiency simultaneously.

Manage

Since the purpose and use of any space can change over time, it is not sufficient to address indoor environmental issues just once. It is important to continue monitoring critical spaces and managing indoor environmental quality, ensuring that spaces always meet the needs of their occupants. Sensors and real time occupant surveys which provide feedback to automated control mechanisms enable real-time adjustments of indoor environments. Connected systems can enable remote experts to monitor and diagnose issues and recommend improvements based on sensors and system diagnostics, enabling a space to "react" to activities and incidents over time.

By continuously managing and monitoring spaces, we continue to ensure the best environments for occupants while optimizing energy usage, minimizing costs and carbon footprint. As digital and IoT (Internet of Things) technologies advance, our ability to control micro-climates, predict potential issues and improve the performance and environmental footprint of various spaces will also increase; enabling healthy and efficient spaces that endure over time.



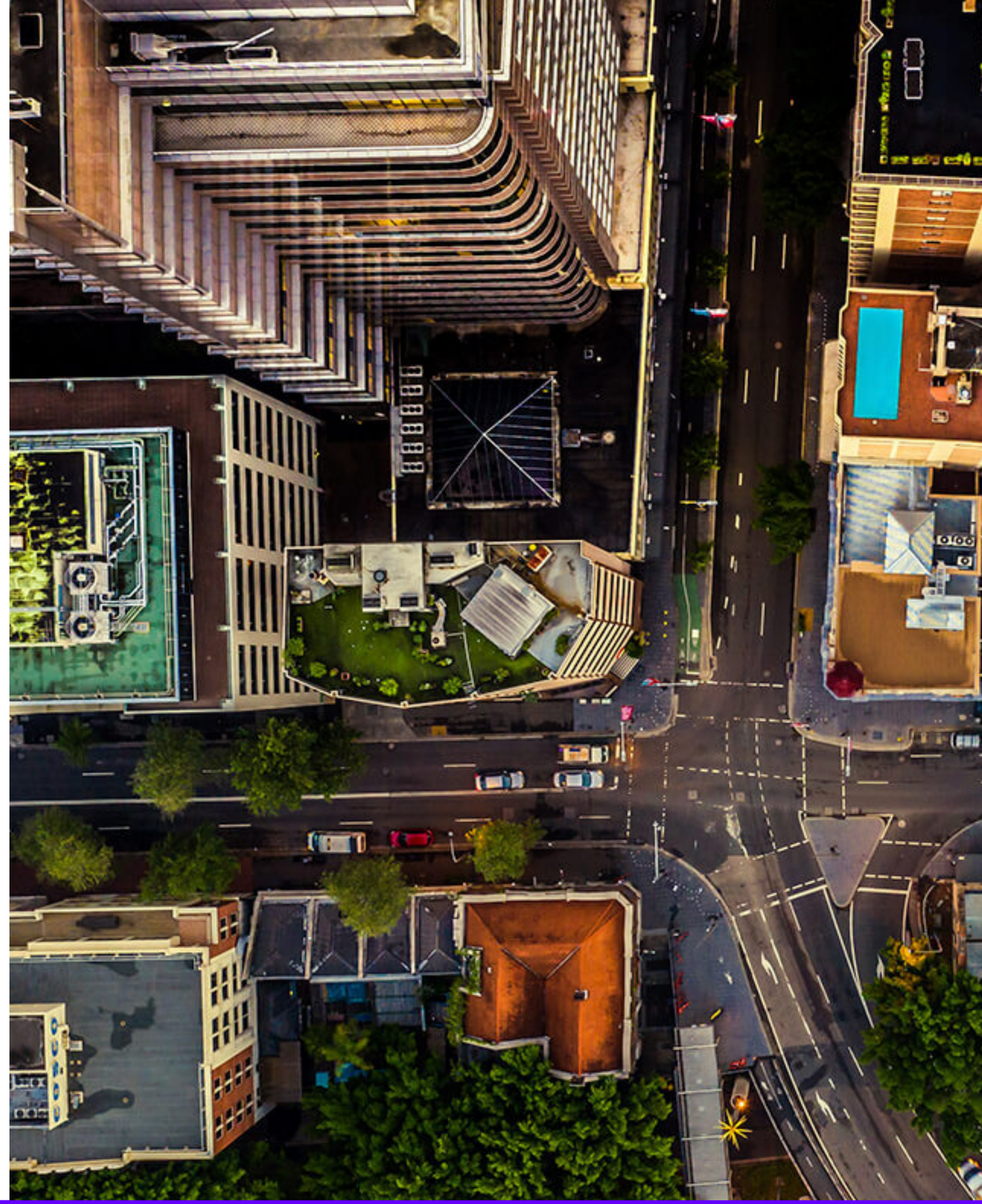
Conclusion

The takeaway is clear: people are spending most of their time inside. Even if that mix of how time indoors changes based on new post-pandemic norms and lifestyles, the need to improve indoor environmental quality and the resulting quality of life in all types of spaces should remain a health and economic priority.

> **There is unmistakable evidence that healthier spaces are good for the performance of people — and efficient spaces are better for the health of the planet.**

Improvement for one environmental condition does not need to come at the expense of others. While the elements of indoor environmental quality may be complex and intertwined, the payback through both short- and long-term benefits for the occupants and operators of these spaces should not be under-estimated.

When systems and conditions are viewed together as an ecosystem and actively managed for better human and environmental outcomes, the co-benefits for occupants, building owners and the environment can be reached harmoniously.

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