Ensuring Occupant Health: Key Findings and Insights from Global Study of 21 Office Buildings

White Paper 505
Version 2

by Victor Avelar, Kelly Ann Bacon (AECOM), Sinan Meric, and Christopher Roberts

Executive summary

With decades of scientific research supporting the benefits of healthy buildings, the topic of occupant health is becoming increasingly important to building owners and operators, especially given the COVID-19 pandemic. Most, if not all buildings, already have some of the sensors and data needed to prompt changes, that can measurably improve the health and well-being of building occupants. Based on findings from pilot studies of 21 office buildings, this paper summarizes the key wellness factors, their underlying science, and the business benefits of healthy buildings – along with the importance of making this information accessible to building occupants. We propose three steps to improve building health and provide a view on the future of healthy buildings.

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The concept of healthy buildings is not new. The term “sick building syndrome” was coined in 1986 by the World Health Organization (WHO), based on extensive research which mostly focused on indoor air quality – one of the most critical components to a healthy building. Furthermore, healthy buildings aren’t just about the absence of sickness, as highlighted by the COVID-19 pandemic, but encompass all facets of human health including physical, emotional, intellectual, spiritual, occupational, environmental, and social well-being. Building owners or operators that embrace this holistic definition of healthy buildings, benefit not only their building occupants, but their company’s profit and goodwill. This shouldn’t surprise anyone who knows the 3-30-300 rule (utilities, rent, and payroll), coined by JLL. In short, people are the most expensive asset in a commercial office building, at roughly $300/ft² ($3,229/m²). Yet given the nature of lease structures and accounting laws, unfortunately the occupants are often viewed as a liability on a balance sheet. As a result, Real Estate and Facilities professionals are consistently challenged with keeping both capex and opex costs as low as possible. Given this, it’s no surprise that we routinely see examples of high CO₂ concentrations (illustrated in Figure 1) leaving expensive knowledge workers groggy, which dampens their performance.

Over the past few decades, the research has expanded and gone beyond just the absence of illness, to include wellness. There are hundreds of studies that quantify the impact of certain factors on occupant health, mood, absenteeism, alertness, etc. (These factors are discussed in the next section.) As of this writing, a search for the terms “sick building syndrome” on https://scholar.google.com/ returns about 139,000 results. We believe the research is clear, that actions like ventilation improvements can prevent sickness and boost performance. We believe future research will uncover further performance benefits from factors such as lighting and biophilic design. In addition to the research, there’s competitive pressure from real estate companies vying for tenants who value healthy buildings and are willing to pay a premium for them.
There is an opportunity for building owners to have their buildings certified for health and well-being. These certifications include WELL, fitwel, and RESET. The cost for a certification ranges widely, for example, depending on the building size, a WELL certification can cost a total of $2.69 to $7.53/m² ($0.25 to $0.70/ft²), including onsite performance verification. Many building owners have become increasingly interested in obtaining these certifications. To get approval, they must first determine if obtaining the certification has a positive ROI, by factoring in the tangible and intangible benefits. These include but are not limited to:

- higher employee confidence in the healthiness of the work environment
- fewer sick days
- higher worker engagement and performance
- potential for higher rents
- lower health insurance costs

While going through the budget approval process for certification, there are three steps building owners can take to improve the health and well-being of its occupants. Most, if not all buildings, already have some of the essential components needed to do this. In other words, all buildings have a “health potential”, but a few steps are needed to take advantage of it.

Based on findings from 21 pilot studies of office buildings in various parts of the globe, this paper summarizes the key wellness factors, their underlying science, the business benefits of healthy buildings, along with the importance of making this information accessible to building occupants. We propose three steps to improve building health and provide a view on the future of healthy buildings.

Few disagree with the idea that the built environment can enhance or detract from overall health, and the science is definitive. If the goal is to reap the benefits of healthy buildings (more performance with healthier occupants), there are two obstacles standing in the way of achieving this goal.

1. **The technical nature of how health and well-being factors in buildings affect humans** (occupants don’t understand this, but the architecture, engineering, and real estate community do). This knowledge gap creates a disconnect, preventing occupants from understanding the impact the built environment has on their overall health and well-being.

2. **Occupants don’t have the health and well-being data they need to make healthy choices** (either because the building isn’t instrumented, or the data isn’t accessible to occupants). For example, an occupant in a room with high CO₂ levels can choose another one. We call this “actionable insights”.

We hope to address both obstacles in this paper by 1) simplifying the complexity of this topic and 2) explaining the importance (and ease) of using sensor networks to make this information accessible.

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In order to improve human health, we need to first define the factors that affect it in the built environment. The following section outlines the basic health and well-being factors (included in our study) which impact human performance.

**Carbon dioxide**, or CO2 is measured by “parts per milligram” or PPM. CO2 is the element expelled by our bodies when we exhale, put simply, the lower the ppm, the healthier the air, and the higher the human performance. Table 1 lists different concentrations of CO2 and the impact on human health.

<table>
<thead>
<tr>
<th>CO2 concentration</th>
<th>Impact on human health</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 - 1,000 ppm</td>
<td>Concentrations typical of occupied indoor spaces with good air exchange. No impact on human health.</td>
</tr>
<tr>
<td>1,000 - 2,000 ppm</td>
<td>Complaints of drowsiness and poor air.</td>
</tr>
<tr>
<td>2,000 - 5,000 ppm</td>
<td>Headaches, sleepiness, and stagnant, stale air. Poor concentration, loss of attention, increased heart rate and slight nausea may also be present.</td>
</tr>
</tbody>
</table>

**Temperature** is another well-known and easily identified element. The “optimal” temperature for human beings is between 15.6°C and 23.9°C (60°F and 75°F). Outside this range has negative impacts on various elements of our physicality. Anyone who has been uncomfortably cold while attending a conference can relate to this but may not know that is likely a result of the building overcompensating in anticipation of high occupant density. The temperature issue has always resulted in a divide amongst the genders – and has historically centered around preference – though a recent study shows improved cognitive functioning at varied temperatures across genders. This information is groundbreaking and makes the case for individual controls. As it’s no longer a matter of opinion, or personal preference, it shows definitively that there is a difference in performance dependent on temperature. When discussing thermal comfort, temperature should always accompany humidity.

**Humidity** shouldn’t be discussed without temperature and visa versa. These two factors allow a building manager some flexibility in maintaining human comfort. However, there are limits, outside of which can increase the risk of disease transmission, especially in colder climates/seasons (e.g. cold dry air). Humidity levels below 40% can also cause problems for workers with respiratory issues. Other issues that arise when these two factors are mismanaged include condensation (e.g. windows) and mold growth. The Thermal Comfort Tool from the University of California at Berkeley, is an extremely useful tool to assess the thermal comfort of your occupants.

**VOC’s** or volatile organic compounds is another critical element. Webster’s dictionary defines VOCs as “any of various organic chemical compounds (as formaldehyde or gasoline) that evaporate quickly especially from solvents, adhesives, fuels, or industrial wastes and that contribute to photochemical smog in the atmosphere.” Essentially this means anything man-made in the air we breathe. The most commonly used unit of measurement for VOC’s is parts per billion (ppb) or parts per million (ppm). Table 2 provides the level of concern over various VOC concentrations.

6 https://iaqscience.lbl.gov/vent-office
7 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4892924/
8 https://www.ohsrep.org.au/offices_temperature_and_humidity_-_what_are_the_rules#:~:text=Opti-mum%20humidity%20levels%20are%20between,with%20conditions%20such%20as%20sinusitis
9 https://comfort.cbe.berkeley.edu/
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### Table 2

<table>
<thead>
<tr>
<th>Total VOC (TVOC)</th>
<th>Level of concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 0.3 mg/m³</td>
<td>Low</td>
</tr>
<tr>
<td>0.3 to 0.5 mg/m³</td>
<td>Acceptable</td>
</tr>
<tr>
<td>0.5 to 1.0 mg/m³</td>
<td>Marginal</td>
</tr>
<tr>
<td>1.0 to 3.0 mg/m³</td>
<td>High</td>
</tr>
</tbody>
</table>

**Noise** (i.e. sound level) and how it relates to acoustic comfort is a complex topic. How the human brain absorbs and differentiates positive from negative noise varies across individuals and is largely related to psychological profiles. Any noise beyond a certain frequency triggers our instinctual “flight or fight” reflex and has a chemical reaction in a release of cortisol. Anyone who has tried to focus on a task can attest the fact that sound is a key enabler (or detractor) to performance.¹¹

**Lighting** research tells us that it has a profound effect on humans through our circadian rhythms. Though there’s much to prove, it is certain that since the invention of the light bulb, humans have significantly altered their natural circadian rhythms. Evidence suggests that this has links to negative health effects such as melatonin suppression and altered quality of sleep.¹² Other studies have suggested that lighting has physical, physiological, and mental effects¹³, but some of these studies rely on self-reported survey data which has its own issues. Ultimately, most people are aware of “glare” and “eye strain” and other obvious factors, but most are not aware of just how important natural and artificial lighting, much less have access to measured light data.

Though not covered in our study, two other important factors are water and particulate matter. **Water** is present in different spaces within a building and can be a health risk if not monitored. Drinking water should be tested periodically to ensure that it is within safe drinking limits. Water used in HVAC systems is a major concern for buildings, especially those that use cooling towers, a known source of Legionella¹⁴ outbreaks. Cooling system water should be monitored and tested periodically. **Particulate matter** is sometimes included as part of VOC and other times not¹⁵ but it’s important to note that it is usually defined as PM₂.₅, or particles that are less than 2.5 µm in diameter which are small enough to enter the lungs. Similarly, a larger type of particle is known as PM₁₀.

We know the six environmental factors above have impacts on human performance both individually and collectively. While the science is definitive, proving it on a case by case basis is costly. This is the primary reason Schneider partnered with AECOM to conduct these studies – we saw the opportunity to identify, integrate, and measure these elements individually and collectively. As Joe Allen states in his book¹⁶, many of the critical components relating to human health in the built environment

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¹⁰ [https://www.tecamgroup.com/acceptable-voc-levels/](https://www.tecamgroup.com/acceptable-voc-levels/)
¹² [https://www.nature.com/articles/s41514-017-0010-2.pdf](https://www.nature.com/articles/s41514-017-0010-2.pdf)
¹⁴ [https://en.wikipedia.org/wiki/Legionnaires%27_disease](https://en.wikipedia.org/wiki/Legionnaires%27_disease)
are invisible to the naked eye – so the ability to monitor and understand real time performance seemed obvious to the Schneider Electric and AECOM teams. Since December 2018, Schneider Electric implemented pilot studies across 21 different buildings throughout the globe, starting with an AECOM office building at 125 Broad Street. These studies helped to inform much of the guidance discussed in this paper. The team outfitted the buildings, with a family of sensors which measured CO2, VOC, Humidity, temperature, noise, and light. The installation was surprisingly quick. For example, over 240 sensors were deployed in the AECOM building, taking only an afternoon. Each pilot ran over the course of 4 weeks. Though the standard approach is to use sensors which assess a single element, those data streams are often desperate and connected to various building systems.

The goal of the study was to connect the data streams and look at the performance of each element in aggregate. In some cases, it validated what we already knew, about how spaces were used – occupancy and utilization which we have observed, though now have data over a statistically significant period. One of the most interesting findings was anecdotal. The AECOM team was working on an assignment – and had all the makings of a productive day – a team that got along, an energizing topic that engaged the team, and each person (self-reported) had properly slept, ate, etc. Though in the second hour of a lively work session, one member had a headache, another couldn’t stop yawning, but more interestingly, the team collectively had difficulties articulating their thoughts. Difficulty finding the words to articulate a concept and build upon one another’s ideas. After a particularly humorous, though frustratingly ineffective conversation, someone suggested to “check the comfort score” and sure enough, it was in the “red” in terms of temperature, CO2, and humidity (see Figure 1). The team was experiencing cognitive failure. In that moment, they simply changed rooms and within minutes, were back to normal.

Why is this important? Why is it even interesting? Because human beings are creatures of habit. They chose that room because it was closest to their desks, but mostly because it was “their room”. Without that wellness data available to them, they would likely have taken a break, loaded up on caffeine, and gone right back into the room and fumbled their way through the rest of the brainstorming session. Thinking it was just fatigue, they would have worked twice as hard to conjure the same thoughts as was possible with a room with better air circulation. This is why a monitoring system is so important. Knowledge is power, but data is not knowledge until it is accessible and understandable to the users.

At a high level, the study revealed these four key findings:

1. Currently most building managers do not know how to get information on air quality, especially not in a way that allows for decisions.
2. Technology exists today to provide insight into temperature, CO2, VOC, humidity, sound, and light, and can be tightly correlated to a specific space.
3. Building managers empowered with this data adjust air quality management and as a result, complaints decrease and employee satisfaction increases.
4. It is possible to use the IoT sensor information on health to automatically control the building, helping the building manager even more.

With a better understanding of the key health and well-being factors, stakeholders are better prepared to uncover the health potential of their building. This section is about identifying what already exists (and what is needed) in a building, then assessing data through a wellness lens, and acting to improve occupant experience and performance. Creating a healthy building environment is a process that requires a thorough assessment of the existing infrastructure such as HVAC sensors, set
point devices, IoT sensors, etc. The data collected allows for analysis and given the proper platform, yields actionable insights to drive continuous occupant health and well-being. The actions from the analysis can help to resolve technical and equipment issues and ensure optimal occupant health and comfort. In this section, we describe three steps stakeholders can take to improve occupant experience and performance:

Step 1 **Assess** existing and required sensors and other data sources  
Step 2 **Analyze** the information to form insights  
Step 3 **Act** on insights to improve the health and well-being of building occupants

**Step 1: Assess**

The assessment step is critical because, as most data scientists will agree, the quality of the data into a model determines the usefulness of the analysis. Poor data yields poor results. The key questions to ask during this step are:

- Are the existing sensors accurate and calibrated?
- Does the sensor density and distribution accurately measure the impact on building occupants?
- Is there a need for additional sensors to cover all relevant building zones?

These are important questions, as sometimes it may be a simple calibration or a firmware update that may unlock or enable large sets of data with a small effort. In other cases, it could be the deployment of IoT sensors to enrich the overall input. A significant number of buildings contain sensors and equipment that are either aging, or not fully functional, or improperly commissioned. Determining these challenges early and addressing them, provides a reliable baseline for the next steps.

Walking through a building with a building manager can reveal sources of existing data in the form of installed sensors, set point devices, or data-tracking processes (e.g. maintenance records, attendance records, occupant complaints, etc.). In addition, there’s bound to be a monitoring system, or at the very least, a building management system (BMS). While we list key data sources in this paper, it is not an exhaustive list. You may have other sources of existing data specific to your company or even specific to a building.

The following are a list of data sources to look for and are prioritized in order of most critical (top) to least critical (bottom), in terms of improving the health of your building. If you don’t have the top **six sources** of data (CO2, temperature & humidity, VOCs, light, and sound), we strongly encourage building owners to implement these, given their importance to occupant health, as described in the previous section.

**CO2** – It is possible that there are CO2 sensors within the HVAC system as a means of regulating air flow rates/changes (i.e. providing additional outdoor air to dilute pollution concentration). Conference rooms should also have CO2 sensors. Some sensors provide multiple measurements in a single package, making it easy to report on – CO2, VOC, temperature, humidity, sound level, light level, pressure, etc. **Figure 2** shows an example of sensor that measures five factors. These types of sensors can typically monitor conference rooms that accommodate 6-8 people.

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17Set point device allows a user to set the value of a variable such as temperature, humidity, etc. A thermostat is an example of a set point device.
Temperature sensors – These sensors are typically found in buildings and capable of integrating with a BMS. Some sensors may be located in the return duct or in other locations outside of the “life space” of occupants and therefore fail to measure actual thermal comfort at the occupant level.

Relative humidity sensors – These existing sensors are likely installed in central return ducts and in the ventilation system return duct. For this reason, new sensors are likely required in the life space to monitor thermal comfort at the occupant level.

VOC sensors – these systems can detect CO2 and other gases, fumes, etc.

Light level sensors – “Light Level or Illuminance, is the amount of light measured in a plane surface.”¹⁸ This is a common sensor found in commercial office buildings and is a key input into improving occupant environment.

Sound level sensors – These sensors are not typically found in commercial buildings. However, installing these sensors is more effective when there are parts of the office that are (or will be) designated as quite spaces. Further investment may be required to soundproof the walls of the quiet spaces.

Temperature scanners – With the advent COVID-19, building owners will likely want to invest in temperature scanners at the entrances to their buildings. This type of data is proactive in that it tries to prevent sickness by preventing people with fevers from making it past the lobby. See White Paper 506, Using a Building Management System (BMS) to Detect and Respond to Infectious Disease Threats, for more information on this topic.

Filter replacement frequency data – tracking the number filter replacements helps identify an air quality issue. A BMS likely won’t track when a filter is replaced, but it should track the number of dirty filter alarms, which can be used a proxy for filter changes for each alarm cleared. An increase in replacement frequency could indicate a health threat such as pollutants from a neighboring business (e.g. construction) in the ventilation air. In some cases, outdoor air quality sensors are used to shut fresh air dampers during a temporary increase in particulate count.

Occupancy sensors – These sensors are a popular method of reducing energy and are likely part of your building. For example, they’re used in conference rooms to automatically turn on the lights. Desk sensors are also available that install under desks (Figure 3) and provide a means of monitoring social distancing, for example, if every other cubicle should be empty. We discuss this in the “Step 2: Analyze” section next. Whereas in the past, these sensors were used to accommodate as many occupants as possible, today they provide a means of practicing social distancing during pandemics.

¹⁸https://www.noao.edu/education/QLTkit/ACTIVITY_Documents/Safety/LightLevels_outdoor+indoor.pdf
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**PM$_{2.5}$ sensors** – these sensors detect particle diameters of 2.5μm or smaller and are sometimes found outdoors near fresh air dampers.

**Area-counting sensors** – While occupancy sensors provide binary data ("occupied" or "not occupied"), area counting sensors provide a headcount in a particular room or space. This provides the data needed to address air quality issues like high CO2 BEFORE people complain or the CO2 levels exceed the maximum threshold. These types of sensors do not capture peoples’ identity, ensuring privacy.

**People-flow sensors** – As the name suggests, these sensors count how many people enter or leave a building. In office buildings, they are usually placed at every accessible building entrance. They essentially provide the total number occupants in a building at any given time. This is critical data for things like fire-loading and social distancing limits.

**Reported data by occupants** – This type of data is generally collected by human resources such as complaints about unpleasant smells, headaches, temperature (too cold/hot), broken equipment, empty sanitizer, etc.

**Employee surveys** – Some companies survey employees using tools like smart phone apps or kiosks. Data collected may include employee mood, opinion on air quality, temperature comfort level, suggestions, opinions, broken systems, or other concerns.

**Sick day frequency data** – Tracking the number of days employees are sick can be used with other data to indicate a health problem within the building. For example, an increase in sick days after new office furniture is delivered could indicate a VOC issue.

**Use of healthcare benefits** – An increase in the use of diagnostic healthcare by occupants could be an indication that there’s a health issue in the building. Obviously, this type of data must be used carefully so as not to violate health information privacy laws.

**Informal knowledge** – as an occupant and co-worker in a building, building managers are in a good position to find out about an illness “going around”, or a sudden onset of allergies outside of allergy season, or other anomalies that, when overlaid with other data, can indicate a healthy building issue. A walk around the building may also reveal water stains on ceiling tiles or on a wall, leading to a potential mold problem.

**Inspection reports** – Facility management should have reports on record from previous testing on things like water, air quality, equipment maintenance, etc. These reports serve as another piece of data that, when combined with other data (of the

Figure 3
Example of a desk sensor that detects the presence people at their desk.
same time period) and reviewed through a health lens, can reveal potential issues with a building.

**Laptop and smart phone location data** – Laptops and smart phones can act as location data inside a building to determine occupancy. The location of these devices is typically tracked using Bluetooth low energy (BLE) beacons. Building occupants will likely have to install an application (on the phone or laptop) associated with the tracking solution. This type of technology is very useful in contact tracing, to stop the spread of infectious diseases and for finding your way around a building (i.e. way-finding).

**Aspirating smoke detection (ASD) system** – These systems are sometimes used in data centers within an office building. In some cases, these systems are able to detect CO2 and other gases. If the existing pipe network can extend into office areas, this may be a potential data source for air quality.

**Monitoring system** – While it’s likely that a building has a BMS, it’s generally less expensive to install a dedicated cloud-based monitoring system (with analytics that improve over time) for monitoring utilization, wellness, and comfort indexes. These systems allow building managers to see data that provide them more insight into the health of the space and help them plan strategies to improve the health of occupants, whether this is HVAC-related or related to the layout of the physical space. Furthermore, BMSs are generally designed for a building manager, making it more difficult, and expensive, to create an occupant-friendly portal. You may also discover HVAC system limitations that prevent the system from addressing some health-related actions like bringing in extra ventilation air into a specific conference room or controlling the humidity in a particular area. The point is, you must assess these systems, understanding the level of control you have with them and determine if it’s enough. Regardless of the system chosen, we recommend polling sensors at 5-minute intervals during office hours and 15 minutes during non-office hours throughout the year.

Devices like sensors that were originally installed in the building are rarely upgraded. After assessing your building, it is likely that at least some of the sensors you identified are incompatible with the system that will monitor the data streams. In these cases, new sensors may be required. If investing in new sensors, make sure they are compatible with the monitoring system. We recommend wireless sensors as opposed to wired sensors given their lower installation cost. Today, these types of installations are based on a subscription model and the cost varies depending on the type of sensor. For example, the total cost of a wireless air quality sensor is about $3/m² per year ($0.30/ft² per year). Note that wired sensors are preferred when used for system control.

**Step 2: Analyze**

With the sensors and set point devices installed and reporting into a monitoring system, the next step is to analyze the sensor data and other data, to get insights into occupants’ environment. There are two audiences that benefit from this insight, building managers and building occupants.

**Building managers**

Building managers are ultimately responsible for addressing the health and well-being of building occupants. Typically, they use a BMS to monitor these sensors, but sometimes they use a purpose-built stand-alone monitoring application that analyzes data either on-premise or in the cloud. Analysis from these systems generate insights, helping building managers to determine actions that will improve occupant health and well-being. Typical outputs vary from a detailed status report to a
highlighted problem in a specific zone or room within a building. For larger sites, with multiple buildings, comparative analysis can highlight room for improvement on similar zones or rooms (i.e. benchmarking). For example, there may be discoveries such as CO2 levels that are high in spaces where fresh airflow is insufficient, leading to fatigue and lower levels of employee engagement. Figure 1 illustrates the CO2 concentration over time from one of the buildings in our study, which may prompt a building manager to increase the amount of outdoor air into the space. Setting smart alarms and monitoring critical parameters such as CO2 levels, temperature, humidity, etc., can ensure occupant well-being and efficiency.

Analyzing this data across the building allows managers to prioritize areas with the lowest Comfort Score and make adjustments if necessary (Figure 4 illustrates and example). More importantly, tracking the variability of such parameters over time can indicate asset/equipment issues and can help with predictive maintenance. Ideally, non-sensor data (e.g. surveys, sick days, complaints, etc.) would also be pulled into the monitoring system to provide a holistic view of building health, but unfortunately, this is still a manual process for most, if not all, applications today.

Until machine learning technology is available that comprehends non-structured data like complaints, maintenance records, sick days, employee surveys, etc., the building manager’s job is a bit harder. They need to monitor sensor data for a particular building space over time. If there are anomalies, perhaps elevated VOCs on a particular floor, they should look for any complaints over that same time period, new furniture installed, new construction, anything that can be a possible cause for the anomaly. Or perhaps the VOCs were always there but airflow in that space has decreased, leading to a higher VOC concentration. Then perhaps the root cause is a failed ventilation system component, or perhaps the decreased airflow coincided with a routine maintenance visit where an operator adjusted a setpoint. This is where analytics can be used to model the performance of HVAC equipment and detect when there are issues with system performance. This provides a continuous check on the equipment to ensure it is working as designed and can be used to help facilities plan maintenance activities based on identified faults. When in doubt about whether a particular sensor data point is truly an issue, building managers can look to other buildings in their company, or buildings managed by their colleagues and compare notes. There are also solutions that monitor the health of building systems against a baseline model to help building managers identify issues like this.
Though not part of our study, another best practice is to schedule regular testing of air quality, water (drinking water, cooling tower water, condensate, etc.), mold, asbestos, etc. These tests are generally more comprehensive than what sensors can provide and add an additional layer of assurance that health threats are found.

As a side benefit to health and well-being insights, some of the same sensors in Step 1 also allow building managers to analyze building utilization. For example, a “heat map”, as shown in Figure 5, visually illustrates which rooms and spaces are underutilized or overutilized over a given period, providing quantitative justification to convert spaces like workstations into open collaboration areas, or to combine smaller conference rooms into larger ones.

Building occupants
Whereas building managers need detailed data to do their jobs, building occupants need only the basics. When informing occupants of building health, we recommend a methodology that incorporates several wellness factors into a single score19, giving occupants a quick and easy way of assessing their environment. For example, Schneider Electric used a “Comfort Score” in the 21 buildings studied. The score calculated based on four factors; temperature, humidity, CO2, and VOC and averaged into a single score. How do you know if a single score is good or bad? This is determined by a range of values that are assigned a green, yellow, or red color coding (green being good) as illustrated in Figure 6. These scores can be posted in a variety of ways (kiosk, TV monitor, mobile app, etc.) at the room level, floor level, and building level. For example, at the room level, occupants expect to see a Comfort Score for a conference room they’re meeting in. Note that the acceptable comfort parameters vary widely depending on location. For example, occupants in coastal areas have higher acceptance of relative humidity versus those in dry areas. Similarly, seasonal changes impact thermal comfort expectations; hence comfort score measurement should be flexible to adapt various conditions.

19Note that building managers, site leads, and workplace managers may have reservations about posting well-being information for occupants. Depending on the building, this may generate more complaints (at least initially).
Step 3: Act

This step is about corrective action. By the time a building manager gets to this step, they should know the root cause of the issue, and have a plan to address it. Some building systems can create automated tickets for the maintenance team (especially for large buildings) when measurements fall outside of pre-set thresholds. With smart alarms and pre-set thresholds, the events triggered can be logged as tickets creating a healthy backlog of actionable items for the building management team. In some cases, the monitoring system can pass data directly to the BMS, automating certain actions like rescheduling of supply temperature and humidity setpoints and modulation of dampers to allow for additional fresh air.

The following are some accepted practices that improve the health of occupants:

**Increase fresh air ventilation**

The ASHRAE Standard 62.1 minimum ventilation for commercial office space is composed of a fixed “People Outdoor Air Rate” of 2.36 lps/person (5 cfm/person) and a variable “Area Outdoor Air Rate” of 0.3048 lps/m² (0.06 cfm/ft²). With a default people density of 18.6 m²/person (200 ft²/person) for an office space, this yields 8 lps/person (17 cfm/person) for a positive impact on wellness and worker performance. Normally CO2 sensors are used (at least in part) when demand-based ventilation is required, however, with occupancy sensors, the BMS can become more proactive. Demand-based ventilation uses CO2 sensors to adjust the ventilation rate based on CO2 levels. When the levels increase, the ventilation adjusts and provides more fresh air, and when CO2 levels drop, the ventilation reduces (saving energy). With the addition of occupancy sensors and knowing the amount of people in the room, the BMS can proactively adjust the ventilation rate before the CO2 levels rise. This allows the BMS to have multiple ventilation targets based on people count. Note that this dynamic control is only practical if the existing HVAC system can control the airflow to specific spaces. Similarly, one needs to understand how much airflow an HVAC system can provide, since it may lack the capacity to provide increased airflow to all spaces. Occupancy sensors can also alert building managers to rooms where occupants are violating social distancing rules, prompting security personnel to address workers.

**Upgrade air filters**

Upgrading air filters to minimum efficiency reporting value (MERV) 13 will improve the air quality for occupants and will likely show a decrease in the VOC monitoring data. MERV 13 or higher can even control against Legionella and other bacteria.

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**Post room capacity according to CO2 data**
If a conference room is consistently above the maximum CO2 level, and the HVAC system is unable to increase ventilation to that room, post a sign limiting that room to less people than originally planned. Also, remove the chairs in the room to discourage larger groups.

**Create quiet zones**
To improve the productivity of those workers who need to focus on a task, designate a quiet space that is buffered from louder areas. Use sound-attenuating material on the walls to dampen the sounds from outside the quiet zone.

**Empower occupants with mobile applications**
Improving occupant well-being isn’t limited to the changes building managers make to the building and its systems. Part of well-being is having relaxed (less anxious), confident, and productive occupants. Building managers can improve occupant wellness by also providing them with the ability to “Act” with mobile applications. Several examples are listed below:

- **Touchless controls** – Using a mobile app to control things like elevators, pin pads, lighting switches, audio/visual equipment, thermostats, etc. reduces worker anxiety about getting sick.

- **Building entry pre-assessment** – Completing a health form on your mobile device prior to arriving reduces stress and saves time. This is discussed in depth in WP506, *Using a Building Management System (BMS) to Detect and Respond to Infectious Disease Threats.*

- **Hot desking** – It is becoming increasingly common for organizations to implement flexible workspace scheduling. Employees can use their mobile app to book an available clean desk; saving time and not stressing about finding a space to work.

- **Smart parking** – Similar to finding a desk, parking in an urban location can be stressful. Using an app to find an available parking space reduces stress.

- **Room booking** – Scrambling to find an available conference room in time for a meeting can be stressful. Using a mobile app to quickly find an available conference room can save a lot of time walking around a building, and lower stress.

- **Wait times** – Before leaving their desk, employees can check their app to see how long the wait time is for the lunch line. Setting expectations lowers stress. Area-counting sensors make this possible.

- **Wayfinding** – For employees who are not familiar with a new building, using an app to help them find a conference room or office goes a long way in reducing stress and saving time.

- **Maintenance tickets** – Whether it’s a foul smell, empty towel dispenser, or water leak, having a mobile app makes it easier to submit a maintenance request and more likely for the maintenance staff to learn about issues.

The following stories illustrate some of the outcomes we found in our study across 21 buildings. These show how the Assess, Analyze, and Act steps come together to improve occupant health and well-being.

- At a site in London, the temperature throughout the day would drop and occupants were complaining about being cold. The building management team tracked temperature complaints along with the data from the monitoring system. After understanding the trends, the building manager made changes to the airflow and temperature set point schedule, and the Comfort Score improved from 71 to 96, over a 60-day period.
Occupants were complaining about an odor in the building. Building managers noted a trend of high VOC in the mornings, before employees arrived at work. After looking at the data, they were able to determine that odor occurred during startup of the system in the morning. They decided to adjust the airflow schedule to ensure the odor disappeared a few hours prior to employees arriving.

CO2 data revealed poor ventilation, and heat gain from a set of large windows made the room uncomfortably hot. Building managers increased the airflow and added shades on the windows to lower the heat gain. The Comfort Score in a Schneider office increased from 77 to 94 from March to May.

While the analyze step discussed previously is still, for the most part, a manual process, technology is progressing to the point where building management systems are automating an increasing number of monotonous tasks. Although we’d like to say that artificial intelligence can process all data (sensor and “analog” data), determine health threats, and automatically address them, unfortunately, we’ll need to leave this to the next section, “The future of healthy buildings”.

Not only have advances in technology made IoT sensors smarter, but the cost of these sensors has decreased significantly. There are advances going on right now that will capitalize on what will eventually be ubiquitous, personalized, and wearable health monitoring. For example, there is research happening to develop a personalized light monitor, giving building occupants access to personal light data to help improve their circadian system. In another example, a wearable sensor was developed for NASA astronauts.23 There are even signs of it today like watches that measure your heart rate and glucose meters. With wearables and low-cost sensors as the foundation, it’s only a matter of time before occupants will know how their environment is impacting them, giving them the actionable insights to improve their situation, wherever they are. As the algorithms become more intelligent, you can expect to see this ecosystem of technology advising the user on their ideal environment (CO2, light, sound, temperature, etc.) for brainstorming, for concentrating, for writing, for running, etc.

Now imagine that an occupant’s technology ecosystem communicates with the building, when they arrive at the office. They come in through a wellness checkpoint, where a thermal camera scans their temperature to validate that they are fever-free. The gates open and they enter the office, at which point they are escorted via their wayfinding app (virtual assistant) to an open and clean desk, in the quiet zone. Then the HVAC will provide the occupant with the ideal temperature and humidity (their own micro-climate) and notify them when the lunch line is short enough to head down.

This is also the future when machine learning makes self-autonomous buildings a reality. That is, the building management system predicts the chiller, or furnace, or damper is about to fail, schedules a maintenance visit, and adapts its control strategy so as not to impact building operations. It’s the future, when the BMS knows how to balance the productivity gains that come from keeping the occupants comfortable, with the energy efficiency goals of an environmentally conscious company, all while ensuring the building is performing to peak performance and not impacting the functional usage of the space.

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23 https://www.co2meter.com/blogs/news/co2-sensor-nasa-wearable-co2-monitor
Conclusion

Many, if not all, building owners and operators have heard the term “healthy buildings” and are generally familiar with the intent, but evidence suggests that few realize that they can improve the health score of their buildings, using data they already have but may not be leveraging. Of the thousands of studies available, we referenced just a few that explain why a healthy building is good for occupants. The paper summarizes the findings from the joint Schneider Electric and AECOM study. We discussed the three basic steps (Assess, Analyze, Act) to improve building health, leading to happier, healthier, and more productive building occupants.

If your goal is to reap the benefits of healthy buildings (more performance with healthier occupants), we hope that this paper simplified the technical complexity of this topic, removing one of the obstacles to this goal. We also hope that we explained the importance of instrumenting a building and providing occupants access to wellness data, allowing them to improve their health and well-being with actionable insights. As a building owner or manager, you can start reaping the rewards of a healthier building today by leveraging the data you may already have. This will put you ahead of the game, since many of your occupants will soon be wearing health sensors that report on your buildings’ data.

About AECOM

AECOM is the world’s premier infrastructure consulting firm, delivering professional services throughout the project lifecycle – from planning, design and engineering to program and construction management. We partner with our clients in the public and private sectors to solve their most complex challenges and build legacies for generations to come. On projects spanning transportation, buildings, water, governments, energy and the environment, our teams are driven by a common purpose to deliver a better world.

About Schneider Electric

At Schneider, we believe access to energy and digital is a basic human right. We empower all to make the most of their energy and resources, ensuring Life Is On everywhere, for everyone, at every moment. We provide energy and automation digital solutions for efficiency and sustainability. We combine world-leading energy technologies, real-time automation, software and services into integrated solutions for Homes, Buildings, Data Centers, Infrastructure and Industries. We are committed to unleash the infinite possibilities of an open, global, innovative community that is passionate about our Meaningful Purpose, Inclusive and Empowered values.
About the authors

**Victor Avelar** is the Director and Senior Research Analyst at Schneider Electric’s Science Center. He is responsible for design and operations research, and he consults with clients on risk assessment and design practices to optimize the availability and efficiency of their environments. Victor holds a Bachelor’s degree in mechanical engineering from Rensselaer Polytechnic Institute and an MBA from Babson College. He is a member of AFCOM.

**Kelly Ann Bacon** leads a workplace practice in the United States. Her degrees in business, sociology, and predictive analytics enable her to provide a societal context for organizational change. Kelly has deep expertise in applying behavioral research methods and diverse design strategies in corporate environments to drive impactful and sustainable transformation. Kelly is dedicated to multiple areas of research – human-computer interaction, occupier wellbeing, and cognitive ergonomics. She recognizes that a corporate environment is an ecosystem, and takes a holistic view in her approach to evidence-based workplace strategies.

**Sinan Meric** is a CTO of the Digital Buildings line of business at Schneider Electric and Director of Engineering for Field Devices Division. Sinan brings a unique background of technology & international experience to his role with over 14 years of transformational/strategic leadership in Digital Power, Power Products and Energy Business at Schneider Electric. Sinan holds multiple advanced degrees from USC and UT.

**Christopher Roberts** is the Global Solution Architect for the Schneider Electric’s Healthcare segment, and is responsible for design, development, and support of intelligent healthcare infrastructure solutions. He leads a team of technical experts, and works with external partners to develop integrated architectures that have improved the environment of care and the operating efficiency for healthcare facilities around the world. In addition, he designed and built the Schneider Electric Healthcare StruxureLab where all Healthcare solutions are tested, validated, and documented.
Reducing Infectious Disease Risks with Smart Building Technologies and Management Systems

White Paper 506

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For feedback and comments about the content of this white paper:

Schneider Electric Science Center
desc@schneider-electric.com