Building and Environment 180 (2020) 106949

Contents lists available at ScienceDirect

Building and Environment

journal homepage: http://www.elsevier.com/locate/buildenv

Ten questions concerning well-being in the built environment

Sergio Altomonte [a,*], Joseph Allen [b], Philomena M. Bluyssen [c], Gail Brager [d], Lisa Heschong [e], Angela Loder [f], Stefano Schiavon [d], Jennifer A. Veitch [g], Lily Wang [h], Pawel Wargocki [i]

[a] Architecture et Climat, Faculty of Architecture, Architectural Engineering, Urbanism (LOCI), Université catholique de Louvain, Belgium
[b] Harvard T.H. Chan School of Public Health, USA
[c] Faculty of Architecture and the Built Environment, Delft University of Technology, The Netherlands
[d] Center for the Built Environment, University of California, Berkeley, USA
[e] Independent, Former Principal of the Heschong Mahone Group, USA
[f] International WELL Building Institute, USA
[g] National Research Council of Canada, Canada
[h] Durham School of Architectural Engineering and Construction, University of Nebraska-Lincoln, USA
[i] Department of Civil Engineering, Technical University of Denmark, Denmark

ARTICLE INFO

Keywords:
Well-being
Comfort
Health
Indoor environmental quality
Design
Building standards

ABSTRACT

Well-being in the built environment is a topic that features frequently in building standards and certification schemes, in scholarly articles and in the general press. However, despite this surge in attention, there are still many questions on how to effectively design, measure, and nurture well-being in the built environment. Bringing together experts from academia and the building industry, this paper aims to demonstrate that the promotion of well-being requires a departure from conventional agendas. The ten questions and answers have been arranged to offer a range of perspectives on the principles and strategies that can better sustain the consideration of well-being in the design and operation of the built environment. Placing a specific focus on some of the key physical factors (e.g., light, temperature, sound, and air quality) of indoor environmental quality (IEQ) that strongly influence occupant perception of built spaces, attention is also given to the value of multi-sensory variability, to how to monitor and communicate well-being outcomes in support of organizational and operational strategies, and to future research needs and their translation into building practice and standards. Seen as a whole, a new framework emerges, accentuating the integration of diverse new competencies required to support the design and operation of built environments that respond to the multifaceted physical, physiological, and psychological needs of their occupants.

1. Introduction

Well-being in the built environment is increasingly discussed in scholarly articles and design publications, in building standards and in certification schemes. However, despite being consistently among the declared goals of both, regulatory codes and voluntary rating systems, there are still many questions on how to effectively design, measure, and nurture well-being in the places we inhabit. This includes a clear interdisciplinary characterisation of what well-being implies in terms of the conception, operation, maintenance, and renovation of buildings and the spaces between and surrounding them, the interaction of different factors that may influence its achievement, and the development of suitable metrics and tools to sustain and verify the well-being of occupants.

In the general press, and in guidelines and recommendations, *well-being* (also spelled *wellbeing* or *well being*) is often simplistically intended as synonymous with *wellness*, *happiness*, and *quality of life*, or associated with *comfort* and *health*. However, various studies have proposed clear demarcations of the respective attributes of these terms, and have developed distinct scales to quantify their values [1–4], although the definitions provided have often been rooted into discipline-specific boundaries.

In the domain of the built environment, the values and beliefs about how spatial and environmental qualities may influence well-being have shifted over time, emphasising the need for greater clarity on the role, meaning, contribution, and interrelations of many factors and

* Corresponding author.
E-mail address: sergio.altomonte@uclouvain.be (S. Altomonte).

https://doi.org/10.1016/j.buildenv.2020.106949
Received 20 March 2020; Received in revised form 5 May 2020; Accepted 6 May 2020
Available online 13 May 2020

dimensions – e.g., satisfaction, aesthetics, ergonomics, performance, flourishing, affect, etc. – in research and building practice [5].

This paper does not aim to fully resolve the heterogeneity of semantic approaches to the definition of well-being in the built environment [6,7], whose conceptual connotations could be described as a wide construct of physical, physiological, social, economic, and psychological aspects, combining *hedonic* (i.e., feeling good) and *eudemonic* (i.e., functioning well) dimensions [8]. Nevertheless, in this paper, the term *well-being* is used to reflect a broader, more holistic, approach whereas these interdisciplinary attributes imply a move forward from the accepted definitions of comfort and health as, respectively: the "*condition of mind that expresses satisfaction with the* […] *environment and is assessed by subjective evaluation*" [9]; and, "*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*" [10].

The translation of these definitions into building standards and design practice, in fact, has often stifled these wide-ranging concepts into more constrained paradigms. *Comfort* – here intended as satisfaction related to individual *perception* – has been mostly confined to *acceptance* of environmental conditions, while *health* has been generally narrowed to the *prevention* of stressors and *limitation* of harmful exposures. From these bases, a trend has recently emerged whereas concerns for human *well-being* have prompted a shift from merely risk-avoidance considerations (i.e., reducing *negative* effects such as SBS, sick building syndrome) [11], or the optimisation of single narrowly-defined qualities of the indoor environment (e.g., visual, thermal, acoustic, olfactory), towards a synergistic appreciation of the *positive* relationships, quantitative and qualitative, between buildings and their occupants. In essence, research and practice into comfortable and healthy buildings have traditionally aimed at preventing discomfort and dissatisfaction, and avoiding disease and ill-health, resulting in easily-quantified metrics and generalisable models. However, because the absence of *ill*-being does not necessarily result in *well*-being, recent studies have striven to define new ways to contribute and 'add value' to the lives of individuals in the built environment, advancing positive stimuli and making their minds and affects flourish and thrive [12,13]. This shift is also starting to be seen in building standards and certification schemes.

Conventional design drivers and criteria for high-performing and green-rated buildings, in fact, have mostly focused on efficiency in terms of energy, constructability, siting, resources, costs, environmental qualities, etc. Nonetheless, although some research has supported the assumption that flagship and certified buildings improve occupants' experience in terms of measured and perceived indoor environmental quality (IEQ) [14–17], many other empirical studies have not substantiated such evidence [18,19]. This might be for several reasons. Among them, the self-assessment methods used to measure occupants' evaluations and responses, and reliance on indirect and subjective metrics [20], may effectively be the manifestation of perceptions that do not correspond to the objectives considered at the time of design and green rating [21,22].

Over the last few years, many certification schemes have started to introduce new credits to provide practical guidance to designers, stakeholders, and managers wishing to foster well-being in their projects. These criteria, generally made freely available, can offer significant insights to guide design development, and inform building standards, even if certification is then not effectively pursued.

For example, LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method) have recently extended the assessment of the direct and indirect impacts of buildings beyond IEQ and the mitigation of harmful practices. LEED has based the structure of its latest versions on a weighing framework founded on impact categories, among which the enhancement of well-being plays a significant role to "*promote the health of […] building occupants and users, the surrounding community or the supply chain*" [23]. Similarly, BREEAM has expanded its credit structure, including consideration of social and economic well-being, transport and movement, safety and security [24].

Among many other certification schemes [25], the Living Building Challenge uses seven 'petals' (i.e., place, water, energy, health and happiness, materials, equity, and beauty) and various 'imperatives' to attain certification on the grounds that 'living' buildings should give more than they take and create a positive impact on the systems they interact with. Fitwel promotes an evidence-based approach to well-being by looking at building operations and owner policies, and identifying key strategic areas such as instilling feelings of well-being, promoting occupant safety, increasing physical activity, etc. The WELL building certification scheme is organised around 10 'concepts' that affect the quality of built spaces within and beyond conventional IEQ categories (including mind, movement, nourishment, etc.) and considers design, operation, and maintenance strategies as well as a requirement for ongoing building performance testing and occupant surveys [25].

Although these new developments are promising, the voluntary nature of these schemes, the potential trade-offs between priorities, and many theoretical and practical uncertainties still hinder the consistent implementation of well-being in the design and operation of the built environment. Various questions remain, for example: How to set effective well-being goals? How should different qualities of the indoor and outdoor environment be properly weighed? How can we adequately inform the control of building systems to promote well-being? What tools should be used to measure appropriate indicators (e.g., surveys, sensors, wearables, etc.)? What design approaches and management strategies need to be adopted? How ought we to reconcile interdisciplinary research with building practice? How should building standards evolve to respond to new priorities and demands?

Cognisant of these challenges, this paper does not wish to provide a "universal", all-embracing, *recipe* invariously applicable to achieve well-being outcomes in the built environment. Rather, based on the authors' collective expertise, the ten questions and answers offer a range of perspectives on the departure from conventional agendas that the promotion of well-being requires. These perspectives are intended to be relevant to different building and occupancy types, public and private, specifically comprising commercial (e.g., offices, retail), educational (e.g., schools), and residential. Clearly, other types of buildings, such as hospitals, medical centres, etc., may require further and more specialised considerations, although the general concepts and approaches remain pertinent.

The paper is structured as follows. Initial attention is given to the principles and strategies that are necessary to promote consideration of well-being through design (Q1) and to the value of multi-sensory variability in buildings (Q2). Following these two general questions, the focus is placed on the four domains of IEQ (luminous, thermal, acoustic, and air quality) that have been proven to strongly influence user perception (Q3 to Q6) [26,27]. Then, insights are offered on how to monitor and communicate well-being (Q7) in support of buildings' organizational and operational strategies (Q8), while paving the way for future research (Q9) and its translation to, and connection with, building practice and standards (Q10). A final section brings together the ten questions and answers, emphasising the challenges to be tackled for well-being to arise as a true driver and priority in the design and operation of the built environment.

2. Ten questions (and answers) concerning well-being in the built environment

2.1. Question 1: what are the principles and strategies to promote well-being through design?

From an evolutionary perspective, humans have grown in connection to a dynamic natural ecosystem; opportunities of exposure to its rich and mutable stimuli have consistently represented key drivers to tune the pulse of their lives [28]. Moving away from the outdoors, today humans spend most of their time in the enclosed shelter of buildings

[29], whose design and operation need to continuously meet the complex requirements of comfort, satisfaction, and health of their occupants, while also responding to stringent demands and directives of energy performance [30].

This, however, presents substantial challenges. Although several design principles and strategies are included in building standards to address targets of energy efficiency and the needs of occupants, a significant gap is often detected between design predictions and measured outcomes in terms of energy use [31] and satisfaction [22]. Many design models, in fact, share similar limitations, having been developed from data gathered under tightly controlled conditions, or being restricted by constrained research hypothesis [32]. Embracing such models, most standards have assumed that energy performance and occupant satisfaction can be achieved by maintaining variations of indoor environmental settings within a narrow range of mean (or median) 'average' conditions. This implies delivering broadly stable environments that target acceptability for a 'general' population without considering the *inter*- and *intra*-individual variability of their users (i.e., respectively, the variance observed *between* people, and *within* the same person at various times or in different contexts or situations). Such a reductionist approach, almost leaning towards *environmental boredom* [33], effectively ignores the variations in perception and subjective evaluation that drive users' preferences and needs. Also, it seldom offers opportunities for personal adjustment and control [34,35], and the flexibility to choose spatial experiences (e.g., self-actualisation) that are often associated to higher gratification and enriched pleasure [36]. In addition, neutrally-acceptable environments that aim at minimising "*dissatisfaction as far as reasonably practicable*" [37] might limit exposure to dynamic stimulations that, at specific combinations, dosage, timing along the circa-*dian* or circa-*annual* cycle, etc., are emerging to have substantial influence on the sustained well-being of the individual [38].

As research suggests [39,40], there may be large discrepancies between requirements for buildings' *energy efficiency*, the 'transient' conditions that users demand for their *comfort* and *satisfaction*, and what they need to *be healthy* and *feel well* over time. Physical and physiological well-being depends on current states as well as on previous history of exposures, while anticipation of future events can drive neural mechanisms and psychological balance [41]. For example, solar ingress in built spaces might be favoured, particularly in a cold climate or season, to bring passive heating and decrease lighting energy use. However, bright sunlight could cause glare and reduce visual task performance. Yet, direct exposure to natural light particularly in the morning, due to its spectrum and its temporal occurrence along the circadian cycle, can enhance mental delight and pleasure, and contribute to entrain the metabolic system with benefits for the well-being of the individual for the rest of the day. Besides – as also addressed in the following questions – increased experience of well-being may improve the perception of comfort (e.g., the presence of plants, pleasant scents, etc., can lead to higher satisfaction with the quality of the environment [42,43]) or increase tolerance to subjective discomfort (e.g., an interesting view out of a window can mitigate the occurrence of glare [44,45]). Design and operation criteria should negotiate such multifaceted phenomena, offering opportunities to dynamically adjust priorities based on the variable needs of buildings and their users.

In essence, to promote well-being in the built environment, no longer can design principles and strategies be informed by inconsistent and limited model predictions and energy efficiency targets based on neutral acceptability of a static range of ambient physical factors, without considering boundaries of preferences and adaptation, and their changes over time. Rather, spaces offering dynamic stimuli – celebrating and taking as an opportunity the *value of variance* within the complexity of buildings' experiences and populations – should support, at once, demands of transient comfort and satisfaction and the sustained needs of health and well-being over longer timeframes. Other than improving the quality of life through increased well-being, this design approach could ultimately also address the requirements of energy performance, since building management systems could maintain environmental settings under wider and more relaxed ranges, avoiding over-regulation while leaving opportunities for personal control and adjustments.

These aspects are further discussed in the questions below, emphasising the value of multi-sensory variability (Q2) and how the experience of individual factors of indoor environmental quality – light (Q3), heat (Q4), sound (Q5), air (Q6) – can support well-being in buildings.

2.2. Question 2: what is the value of multi-sensory variability in buildings?

Too often, today's buildings are not only designed without the planet in mind, but they also neglect the occupant. We intentionally design for static, uniform, neutral conditions in our buildings, often dissociating people from nature and the inherent cycles of the natural environment. This is experiential monotony, and there is nothing pleasurable about it. And the variability we hear about is usually just the negative side – sick building syndrome, sealed buildings with inoperable windows, poor lighting, etc. But we have an opportunity to create indoor environments that are not only comfortable and healthy, but are connected to the natural environment, provide a sense of place, and are a delight to be in. Designing for experience requires us to embrace a broader view of building aesthetics, moving beyond simplistic and static metrics, and encompassing an experiential, multi-sensory perspective. Here, 'multi-sensory' refers to the ways in which we experience the lighting, thermal, acoustic, and olfactory environments, each of which will represent the focus of subsequent questions individually, while recognizing that the body experiences them simultaneously and the interactions between them remain an area that needs further study.

We need to begin with a paradigm shift in how we think about the built environment. Building performance standards and conventional building practice are all about 'reducing the negative'. The western goal of indoor environmental quality seems to be 'if no one notices, and no one complains, we're successful'. But what if the design goal *was* for occupants to *notice* the environment they live in, and in *positive* ways? To create a framework for thinking about this, we can borrow from Maslow's hierarchy of needs (Fig. 1) [46], which suggests that we need to first satisfy our basic requirements for life at the bottom of the pyramid – breathing, food, water, etc. – before we move upward to aspire towards our higher desires for pleasure, love, self-worth, and creativity.

We can reinterpret this hierarchy as one of environmental experience, as shown in Fig. 2 (focusing on the area of thermal comfort, but applicable to other senses as well). At the lowest level, the goal is simply to avoid heat and cold stress. This is often the basis for occupational safety and health standards, or guidelines for resilient buildings to be habitable in the event of power outages during natural disasters. Moving upwards, our buildings are generally operated to meet the next level,

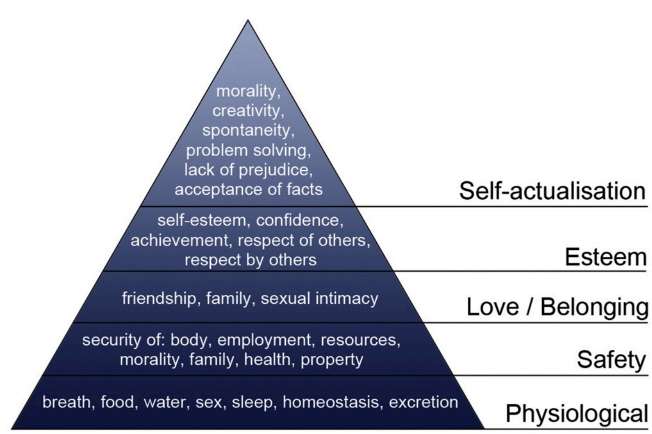

Fig. 1. Maslow's hierarchy of needs (adapted from [46]).

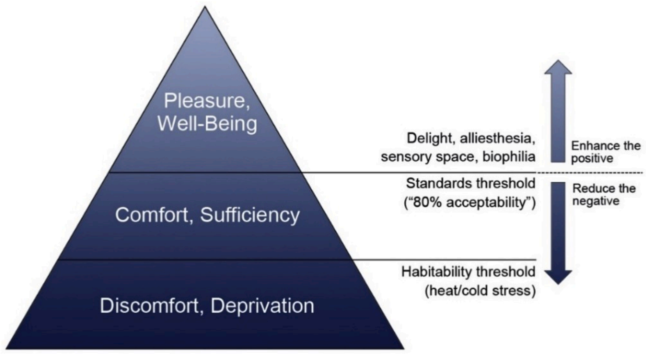

Fig. 2. A re-interpretation for indoor spaces: spectrum of occupant experience (adapted from [49]).

where the goal is simply thermal neutrality. A familiar example is ASHRAE Standard 55, which prescribes conditions in which 80% of the occupants will find the conditions 'acceptable' [9]. In many other fields (e.g., manufacturing, recreational), a 20% rate of unhappiness or dissatisfaction would never be accepted! But that is all our industry aspires to in our buildings. We need to aim for a higher level of experiential delight, expressed in the third level, described eloquently by Heschong [47] and Erwine [48], among others. And at the very top is the idea of well-being, and how we can create environments that support our physical, social, and emotional health, our cognitive function, and productivity.

But how do we get beyond mere 'comfort' and design for these higher-level experiences? As introduced in Q1, the premise is that one of the keys to moving upward on this pyramid is *sensory variability*, where the environmental conditions we encounter vary in subtle ways, either dynamically throughout the day, or spatially across the different places we inhabit. This can have benefits for our health, cognitive performance, and overall experiential delight.

As one example of health benefits, exposure to mildly cold or warm environments outside of the standard comfort temperature range was found to increase metabolism and energy expenditure, which can help to tackle obesity [50]. The study also found that for those with type-2 diabetes, exposure to mild and intermittent coldness influences glucose metabolism and increased insulin sensitivity by more than 40%. This is comparable with the best pharmaceutical solutions available. The authors of the study advocated, therefore, that buildings such as homes and offices should adopt drifting temperatures to create a healthier environment [50].

There have been limited but interesting studies on the effects of variability on our cognitive performance. For example, in the thermal environment, a study exposed subjects to both constant and sawtooth temperatures with similar mean values, and found that the variable temperatures reduced symptoms of drowsiness and difficulty in concentration [51]. Although more work is needed in this area, since the costs of people in offices is two orders of magnitude higher than energy operating costs, if variable conditions improved productivity, then the building and business communities would find such results quite compelling.

And finally, the evidence for variability on our sensory delight is even more persuasive, although a detailed summary is beyond the scope of this paper. A great deal of that evidence is found in the literature on biophilic design [52–55]. For thermal variability, in particular, there is increasing evidence for the concept of *alliesthesia* – the physiological basis for thermal delight, which also has analogies to other senses as well [40,56,57]. The premise is that hedonic sensations of 'pleasure' come from the dynamic component of thermoreceptors in our skin [58–60]. As such, the best potential for alliesthesia will come from having some degree of variability, or contrast, either over time, or across different parts of our body.

Further details on the well-being benefits of variability in individual domains of indoor environmental quality are provided in the answers to the questions below (Q3 to Q5), including topics such as the importance of variable luminous environments on our circadian health, the benefits of personal comfort systems, and the relevance of design to creating dynamic soundscapes (and, while Q6 focuses on pollutants and reducing their negative effects, we are all well aware of the more positive olfactory delight we experience from the variety of smells in a garden, for example).

2.3. *Question 3: how can the luminous environment support well-being in buildings?*

The luminous environment was traditionally engineered to support optimal visual task performance, such as reading numbers written with a thin pencil. Today, with the rapid evolution of digital technologies that have made self-illuminating screens ubiquitous in our lives, visual task performance is often more a function of screen resolution than ambient lighting quantity and quality. Thus, the challenges of lighting design are becoming more diverse. Furthermore, just as our ears have two functions – hearing, plus balance – it is now understood that our eyes also perform two key functions, vision, plus input to our body's circadian system, which coordinates the daily and seasonal rhythms of nearly every process in our bodies [61,62].

Daily patterns of exposure to light and dark are key determinants of our circadian rhythms, influencing sleep cycles, memory formation, immune response, growth, development, and metabolic health. Initially, it was thought that exposure patterns to white light, including timing, intensity, and duration, were the key factors in determining circadian responses, but further research has suggested that more subtle patterns of spectral content, the history, and geometry of exposure may also be important [63,64]. The eye's circadian photoreceptors are most sensitive to the sky's dominant blue wavelengths [65], and it is now established that exposure to this blue portion of the visible spectrum at night, whether indoors or outdoors, can cause sleep disruption via suppression of the hormone melatonin [66]. Thus, at a minimum, evening and night-time electric lighting should have reduced content in the blue short wavelengths, and thus be more similar to fire light or candlelight. Logically, it follows that those lighting patterns closest to the Earth's natural cycle of bright days and dark nights, under which humans evolved, are likely to prove the healthiest lighting scenarios. Some researchers posit that the dynamic colour shifts experienced at sunrise and sunset may also be biologically significant [67]. Given this, the easiest way to achieve locally appropriate circadian stimulus inside of buildings is via naturally daylit spaces.

In addition to providing appropriate patterns of ambient illumination, buildings can also support occupants' circadian well-being via attractive window views of the outdoors, which can offer about an order of magnitude more circadian stimulus to 'the eye of the beholder' than even ambient daylight inside of a space [39]. With window views, occupants can choose to take a sip of brighter daylight whenever they feel a thirst for more circadian stimulus. Access to window views is also important for general eye health. Vision is one of the most complex and energy intensive functions of our bodies and deserves thoughtful hygiene. For many office workers, dry eye or eye strain is a common complaint. Many optometrists recommend that workers should frequently refocus their eyes, at least 6 m (20 feet) away, at least every 20 min, in order to maintain muscle tone and lubrication. An interesting window view provides the motivation to do exactly that. Access to views of the outdoors may also enhance cognitive function in many ways, simultaneously providing information, stimulation, and relaxation [68]. Glare-free window views have been positively associated with many objectively measurable outcomes, including greater educational progress in schools [69,70], faster processing speed by call centre workers [71], and, in office settings, improved sleep [72], greater working memory capacity, and fewer reports of fatigue and other health complaints [71].

Individual differences also need to be considered, of course. For example, the health and age of a person can both directly impact the sensitivity of photoreception and circadian stimulus, resulting in differences in visual perception and circadian rhythms throughout life [73]. In particular, improved health outcomes have been shown with increased access to windows and daylight.

Adding the dynamics of daylight and windows views into the mix of designing the luminous environment creates new challenges for designers. It is important to remember that the visual environment includes not just the *sources* of light, whether they be daylight or electric, but rather *everything* that we look at. Reflections off of surfaces also determine the colour and distribution of light within a space. Shadows and sparkle can influence mood. For the visual comfort of occupants, relative brightness is more important than absolute levels of illumination, and interest in a visual scene is often much more important than glare [74]. The visual scene needs to be considered holistically, accounting for the dynamic contribution of all sources of direct and reflected light, and where occupants are most likely to be looking.

A beautiful luminous environment importantly provides aesthetic pleasure and motivation for people. It should also be designed to support eye health, visual comfort, cognitive performance, and overall circadian well-being.

2.4. Question 4: how can the thermal environment support well-being in buildings?

A large part of energy in buildings is used for keeping the indoor environment thermally comfortable. Yet, in various climatic contexts worldwide, we still measure a very large percentage of dissatisfied occupants [75–77]. A study in US commercial buildings, for example, showed that only roughly 40% of occupants are satisfied with the thermal environment, while 20% are neutral and 40% are dissatisfied [75]. A very small number of buildings is able to achieve the goal present in thermal comfort standards of having at least 80% of the occupants satisfied [9]. Typical thermal conditions in buildings, even when uncomfortable, do not pose an immediate health risk (e.g., hypo- and hyper-thermia) [78]. Nevertheless, thermal discomfort may cause building-related symptoms and reduce performance [79,80]. The relationship between thermal comfort and productivity has been for long a focus of research [81]. In this essay, we assume that well-being is supported when people are thermally satisfied and comfortable. As discussed in Q2, to have the thermal environment supporting well-being, we do not need to assume that we must keep the thermal conditions in a constant and narrow range. Thermal comfort is a personal experience and it should primarily be assessed by subjective evaluation [9]. Physical measurements are only moderately related to thermal comfort [82].

Existing green certifications, like LEED, or general HVAC systems, like radiant systems, do not substantially increase thermal satisfaction levels [22,83]. So, how can we enhance thermal comfort? To date, the main technology that showed in labs and field studies the potential to provide a high level of thermal comfort is the use of a *personal comfort system* (PCS). A PCS is a personally-controlled apparatus used to heat and/or cool an occupant or their immediate surroundings. A personally adjustable thermostat, a desktop fan, and a personal heater are examples of PCSs. ASHRAE Standard 55 committee is in the final phases of publishing an addendum to its standard that will introduce a comfort control classification scheme. The higher the level of personal control, the higher the classification, the higher the thermal comfort. This change to the standard introduces important improvements to existing approaches used to promote personal control. The addendum specifies the minimum thermal and temporal requirements for personal comfort systems, five distinct levels of thermal control (the highest occurring when each occupant is provided with two or more control measures for their personal environment), and a list of personal comfort systems.

Another issue that needs to be addressed is related to the thermal comfort models that we are using. As already mentioned in Q1, thermal comfort standards, green certification programs, and building control practice are based on thermal comfort models able to predict the answer from an 'average'/'standard' person, but these general population models – like the PMV (Predicted Mean Vote) [84] and the adaptive comfort [85] – have low prediction accuracy. For example, by using the ASHRAE Global Thermal Comfort Database II, it was shown that the PMV predicts thermal sensation correctly only one-third of the times [82]. The applicability of current thermal comfort models to occupants of different age (e.g., young and older adults) has also been questioned [86]. A modelling strategy that showed higher accuracy is named *personal comfort models* (PCM). PCM is a new approach to thermal comfort modelling that predicts individuals' thermal comfort responses, instead of the average response of a large population [87]. Personal comfort models can be based on environmental measurements (e.g., air temperature, location, relative humidity), occupant feedback (e.g., online voting), occupant behaviour (e.g., thermostat set points) and physiological parameters (e.g., skin temperature, heart rate) to train a model that is valid for a specific person or group [88]. PCMs have the ability to adapt as new data are introduced in the model [87]. Personal comfort models can be used to control personal comfort systems, but they can also be applied to general mechanical systems, both in buildings and other environments (e.g., cars and airplanes). Personal comfort systems and models have the potential to increase thermal satisfaction and, therefore, well-being.

2.5. Question 5: how can the acoustic environment support well-being in buildings?

One of the most frequent complaints by building users is often related to acoustic conditions, as seen for example in occupant surveys from open plan offices [75,89] and restaurants [90]. Too often, the acoustic environment does not satisfy the lower levels of the occupant experience pyramid shown in Fig. 2; the aural environment should be one in which occupants can maintain healthy hearing, perform as expected, and participate comfortably in the primary purpose of the facility. Past research in architectural acoustics has focused primarily on addressing the lower parts of the pyramid, gathering data that confirm how appropriate acoustic design can reduce negative effects on occupants. Moving forward, though, there is great potential in studying how the aural environment can be designed to address the upper parts of the pyramid, by enhancing pleasure and overall well-being.

To achieve acoustic environments that support well-being, one must first consider the purpose of the built space. Are people working? Learning? Socializing? Enjoying a performance? Recovering? The acoustic requirements will vary depending on the facility's usage, and can be addressed by – among other measures – varying the room's volume, shape, materials, construction, etc. Such characteristics have an impact on how sound energy is internally distributed and transmitted to and from the room. Acoustic conditions also depend on other sound sources impacting the space, such as other occupants, activity from adjacent spaces, building mechanical systems, alarms, machinery, background music, and more. Control strategies can be implemented to prevent noise or unwanted sound from impacting a space, by adding absorptive materials, constructing barriers with higher sound transmission loss, mitigating flanking noise paths, closing sound leaks, and/or reducing structure-borne sound transmission.

Different acoustic considerations are required for spaces with diverse purposes. Classrooms are used primarily for teaching and learning, so optimising speech comprehension is key. This typically requires lower background noise levels, lower reverberation times, and wall/door/window constructions with high sound transmission loss [91]. Recent studies have logged sound levels in occupied classrooms over multiple days and found that the variation of occupied sound levels in time can provide deeper insight than traditional noise metrics like equivalent sound pressure level [92]. For restaurants where patrons socialise in small groups, the acoustic design calls for a less reverberant space with an appropriate density and layout of seats and consideration of other expected noise sources, such as an open kitchen or continuous background music. Investigations focused on how restaurant sound levels change in time with occupancy [93] are helping to validate proposed restaurant noise prediction models [94]. In facilities where occupants are recovering from health issues, the acoustic environment must support as much uninterrupted sleep as possible. This requires consideration of architectural factors (e.g., materials, construction, layout) but also of minimising other noise sources such as alarms, and implementation of behavioural interventions such as 'Quiet Time' protocols [95].

Reducing noise in the built environment is, of course, key towards supporting well-being, as noise can not only cause discomfort in the moment but also auditory and non-auditory health effects. Auditory effects are often experienced as hearing loss and measured in terms of reduced sensitivity to sound at various frequencies. Disabling hearing loss impacts more than one-third of persons who are 65 years or older [96], due to age-related factors but also to noise-induced hearing loss, prevalently experienced in occupational and recreational settings. Tinnitus – that is, the perception of ringing or other noise in the ears that does not stem from an external source – often follows acute and chronic noise exposure, and may have severe impacts on the quality of life of affected individuals (e.g., depression, impaired attention, etc.) [97]. Conversely, evidence of the severe non-auditory health effects of environmental noise (e.g., from roads, railways, air traffic, etc.) is growing [98]; chronic exposure can lead to stress, sleep disturbance, hypertension, cardiovascular diseases (e.g., ischaemic heart diseases, stroke), cognitive impairment (especially in children), etc. In the workplace, distractions caused by noise sources in the environment, such as background speech from other persons, can have negative effects on the ability to sustain cognitive flows, influencing absenteeism, job satisfaction, and work performance [99]. While standards exists to protect building users from harmful occupational noise exposures, and to regulate sound transmission into and within buildings, current efforts focus primarily on hearing protection rather than control of lower noise levels in the built environment (i.e., less than 80 dB). Inter-personal differences with respect to aural preference and habituation are also often not properly taken into account.

Better appreciation and understanding of how the soundscape changes dynamically in time and is subjectively perceived by people due to the built environment's conception, layout, usage, and noise sources, can help to better predict, design, and manage occupant experiences of aural settings. In this context, the recent shift of attention from stimulus-oriented to human-centred evaluation of acoustic environments is placing a relevant responsibility to acousticians in the interdisciplinary soundscape field [100,101]. Acoustic design can be much more than just limiting noise, and its negative impacts, to include producing better aural environments that are pleasurable and enhance auditory delight. In support of this, greater consideration of the multifactorial nature of sound perception, and the restorative impact of positively evaluated soundscapes on stress recovery and physio-psychological well-being – e.g., the sound of trickling water or birds chirping – is also undergoing wide scientific investigation [102]. Understanding acoustic diversity in existing spaces, and its impact on occupants, can help move the field towards more thoughtful and deliberate designs that may incorporate acoustic sensory variability for positive outcomes.

2.6. *Question 6: how can the quality of air support well-being in buildings?*

Indoor air quality (IAQ) refers to pollutants inside occupied built spaces originating from indoors and from outdoors, and comprising physical, chemical, and biological species. Typically, air in non-industrial buildings contains hundreds of pollutants at low levels, some of which are not primary emissions but products of transformation of indoor pollutants.

Despite many attempts, no simple unified and universal index has been successfully established to prescribe the levels and components of indoor air quality [103]. The most widespread and generally accepted proxies for indoor air quality are ventilation rate and concentration of carbon dioxide. However, the level of ventilation is strongly dependent on the strength of pollution, and consequently, it is the level of exposure that is determining the effects on humans [104,105]. With respect to carbon dioxide, this is a proxy for ventilation efficiency but only in the presence of humans, i.e. when there are sources of carbon dioxide indoors; no systematic data provide evidence that it should be considered as a pollutant at the typical concentrations of non-industrial buildings [106].

Due to the complexity of air pollution indoors, the levels and pollutants of concern are seldom defined. An exception is the WHO (World Health Organization) air quality guidelines [107–109], which provide a list of 16 pollutants with their levels. Also, a European Commission committee defined about 200 potentially harmful indoor pollutants, providing the lowest concentration of interest to be observed particularly when considering emissions from building products [110]. Indoor air quality is addressed in many building certification schemes [111], but seemingly to an extent that is not adequate, considering its importance.

The uptake of air pollution occurs mainly through breathing but, as shown recently, it can also occur through the skin [112]. Despite many attempts to improve IAQ in buildings, still a relatively large proportion of building occupants complains of problems and symptoms related to poor air quality [76]. This proportion reduced since the studies in the 1990s [113], but is still considerable.

Research on indoor air quality does not leave any doubt on its importance to support well-being in buildings. Reducing levels of pollutants, or avoiding them indoors, leads to decreased discomfort, lower health risks, better work performance and learning [114–117]. Poor indoor air quality has also been associated with increased sick absence, both in offices and in schools [118,119]. Here, the transmission of infectious diseases can play a role that needs to be better understood and characterised. Some studies have shown that ensuring high air quality in bedrooms results in improved quality of sleep and better next-day cognitive performance [120,121]. Positive effects on perceived air quality can be enhanced when air temperature and humidity are reduced [80] and air speed is increased [122,123]. Improving air quality can reduce the intensity and prevalence of acute health symptoms reported by occupants, these including irritation of mucous membranes, problems with airways, headaches, difficulty to concentrate, fatigue, allergies, asthma, etc. [124–128]. Most of these effects relate to acute responses. However, nearly no data is available on chronic health effects of indoor air pollution, although some studies have estimated the impact in terms of Healthy Life Years (HLY) lost due to exposure to poor indoor air quality [129,130].

So far, the research on IAQ in buildings has focused on reducing negative impacts, while very little has been done on promoting positive aspects such as satisfaction and pleasure. This requires understanding the composition of indoor air and how different species interplay to create an environment that is conducive to well-being. Studies have addressed how this could be achieved by the addition of fragrances, but this may also have negative consequences [131]. Better understanding of the human microbiome, and its role in health, could provide more answers on this matter.

2.7. *Question 7: how should well-being in the built environment be monitored and communicated?*

Buildings have the capacity to protect us or harm us, connect us to nature or wall us off, be places of community or places of isolation, and act as places of refuge or as places that are constant assaults on our health. Old definitions of health as "*absence of disease and infirmity*" are being replaced with ones that capture well-being and health promotion; a move from *pathogenesis* to *salutogenesis* [132,133]. This change in definition demands a corresponding change in what we monitor and measure in our buildings. Further, the language we use matters. Here, we can learn from the business community and adopt, or rather co-opt, their language to advance the health of people in buildings.

The demands of the business and investing world require businesses to monitor *Key Performance Indicators* (KPI). Every minute of every day, every week, every month, and annually, businesses are tracking metrics to evaluate performance because, in the words of management expert and author Peter Drucker, "*if you can't measure it, you can't improve it*" [134]. The building is often not included in these KPIs. More importantly, the reason the building is ignored may have to do with the limiting language of KPIs, which does not put people at the centre of decision-making.

To effectively monitor health and well-being in the built environment requires us to do a better job of defining what needs to get tracked and measured. We have previously promulgated a framework for doing just this, promoting the case for a fundamental shift from using the language of KPIs to using HPIs, for *Health Performance Indicators* [21]. The HPI approach puts health and human performance at the centre of business decision-making [135].

With this shift in language comes a shift in what gets tracked, and therefore improved. The HPI framework brings concepts from the world of health science to a language and way of thinking that is familiar and recognisable to business executives – we encourage businesses to consider leading, lagging, direct and indirect indicators of health performance. In doing so, the performance of the building naturally becomes a central HPI because it influences the health and performance of people (and, ultimately, the performance of their business). Factors like building design, operation, and maintenance become critical HPIs, as does air quality, water quality, and the other factors that comprise the foundational elements of a healthy building [136], as also shown in previous questions.

Why the focus on the business community? They ultimately control a large share of the spaces where we live and work globally. If we make a compelling health and business argument, our community of scientists can influence the lives of millions of people globally, and fast. With the two forces of population growth and urbanization creating unprecedented demands on our natural world – and the human race having become an indoor species [29] – the decisions we make today regarding our buildings determine our collective health today and for generations. From this derive the dual exigencies of needing to place health at the centre of our decision-making and needing to bridge the academic and business communities. Moving to the language of HPIs begins to create that bridge.

2.8. Question 8: how can the organization and operation of buildings support well-being?

Buildings exist to serve human needs. Schools exist to provide a place for learning; stores exist to provide a place for vendors to sell products; offices (the most-studied location) exist to support a wide variety of white-collar work; etc. The entities that own the buildings often seek organizational efficiency to maximise the value of their outputs while minimising the cost of inputs [137]. However, because the building and its operation are far less expensive than the salaries and benefits of those who work in it, building-related decisions must always ensure that the individuals' needs are provided for [138]. Choices made only to save energy, or to be the lowest cost to purchase, will cost more than they will save if they do not support users' requirements for spaces that are comfortable, functional, healthful, and attractive.

Supporting individual well-being in existing buildings demands coordination between corporate functions for human resources and facilities management. Human resources departments should be the keepers of detailed functional analysis of job types and knowledge of how work is structured. From the earliest schematic design for a workplace, they should be engaged in a realistic discussion about how, for example, to provide adequate space for those who handle materials, suitable quiet space for those whose roles require concentration and freedom from distraction, and proper adjacencies to support the workflow. Facility management, supported by design functions, needs this information to determine how best to provide for the specific needs of each work unit [139,140].

This collaboration needs to be ongoing through the life of the building. Human resources units are often responsible for ongoing employee evaluations (e.g., job satisfaction, environmental satisfaction, etc.) that can be sources of information about which environmental features work well, and which do not. These may be combined with other key performance indicators (e.g., energy use, facility maintenance records, etc.) in an ongoing scorecard approach to track environmental and built environment performance together, for all buildings [141–143]. Again, facility management units will be the source of expertise about how best to maintain the desired conditions, always balancing against other corporate goals including environmental targets and budgets.

As already noted (Q7), corporate officers need to be engaged in this collaboration, and to track these KPIs as part of their routine monitoring of organizational performance. Corporate leaders would be wise also to make structural changes to financial planning and reporting, to provide feedback between facility management and human resources. When each unit is responsible for its own budgets, facility management remains unaware of the consequences of their decisions but may also lack budget room to make slightly larger investments that could benefit employees. Both capital and operating budgets may be fixed at the start of a reporting period, and the managers of these budgets may be rewarded if they under-spend; alternatively, they may be able to use unspent funds from one area to compensate for overages elsewhere or to complete other projects earlier. There is generally no reward for making a greater investment than originally planned, even if the behavioural science evidence supports it. As far as we are aware, it is the rare facility management department that receives a reward for decisions made that enable employees to work more effectively, or a penalty for decisions that harm the work of the organization. This may account for the enthusiastic adoption of open-plan offices and reductions in space allocation despite the evidence that this design choice does not support organizational productivity metrics [140].

As previously emphasised (e.g., Q1, Q2), individuals differ one from another, and no fixed condition is likely to be suitable for all [144]. Thus, another element of successful building operation will be local control. This may be in the form of hands-on adjustments to conditions that are available to the user, or adjustments made by an automated system based on user settings – the technology is immaterial. The important consideration is to make it possible for individuals to experience conditions that they prefer, which are associated with better outcomes for both individuals and the organization (e.g. [145,146]) and organizational supports that respond promptly to conditions requiring building operator intervention. This was expressed succinctly nearly 20 years ago; "*[Occupants'] greatest friends are simplicity, intelligibility, managed feedback, respect for people's comments and rapid response*" [147]. Building technologies and many work tasks have changed over the years, but this fundamental truth has not.

There is at least a 35-year history of research on, and advocacy for, work environments that support individual and organizational goals [138], and yet the existence of this paper demonstrates that significant gaps remain in both evidence and practice. Both could be addressed with systematic thinking about the integration of facilities and human resources functions in organizations.

2.9. Question 9: what research agenda is needed to support well-being in buildings?

The previous questions have stressed the importance of understanding the combined (Q1-Q2) and individual (Q3-Q6) effects of positive and negative IEQ stress factors on people in buildings (*patterns of stressors*) and the occupants' dynamic personal needs and preferences (*profiles*) (Q7-Q8). Research has shown that staying indoors is not necessarily good for our health and well-being, even if the conditions seem to comply with current guidelines for IEQ. These, in fact, are mostly based on preventing diseases and disorders rather than focusing on positive outcomes [148]. The built environment is a complex system characterised by feedbacks, interrelations among agents, and discontinuous non-linear relations. Nevertheless, IEQ is still most of the time assessed mainly by dose-related indicators, based on linear single dose-response relationships for negative stressors, developed for the average occupant (whoever that is); ignoring that we are dealing with individuals in different scenarios (e.g., homes, offices, schools, etc.) and situations (sitting behind a desk, in a meeting room listening, on the phone, washing, cooking, sleeping, etc.); neglecting other stressors (physical, physiological, personal, psychological, and social) and their integrated effects over time; and ignoring interactions between stressors in complex real-life exposure situations at environment level, and interactions between various body responses to exposure(s) at human level.

There is clearly a need for a more complex research model to explain symptoms and complaints in specified (exposure) situations, acknowledging other stressors and their integrated effects, interactions, and different needs and preferences of the occupant: a model that includes interactions for both the environment (the situation) and the occupants (Fig. 3).

This model features the stress factors caused by the (indoor) environment that a person is exposed to (patterns of stressors, the Environment model in Fig. 4) as well as the individual differences in needs and preferences (profiles of people, the Human model in Fig. 5), depending on their behaviour (activities). Such a model, moving well beyond conventional dose-response, would make it possible to match profiles of people with patterns of positive and negative stressors for a given situation.

The following needs can be suggested as drivers of the research agenda to complete this integrated analysis approach:

- To be able to determine patterns of stressors of importance to people in different situations, other factors and stressors than the environmental parameters used in guidelines – whether of psychological, physiological, personal, social, or environmental nature – will need to be identified. Recent studies have given preliminary proof for the determination of patterns of stressors for offices and workers [76], homes and students [150], and schools and children [151].

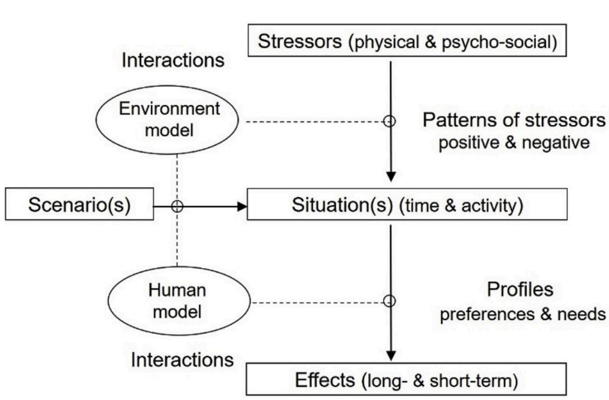

Fig. 3. Model for the integrated analysis approach (from [149]).

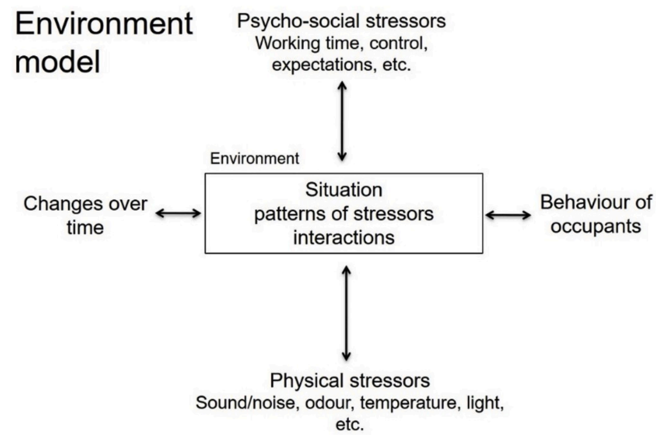

Fig. 4. The Environment model (from [149]).

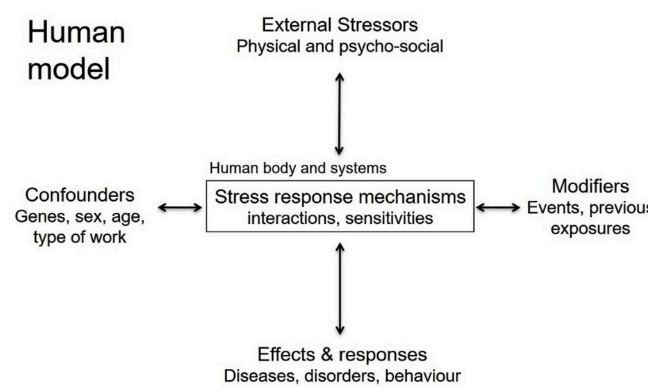

Fig. 5. The Human model (from [149]).

- To be able to determine profiles of people for different scenarios and situations, preferences and needs of individuals, as well as positive and negative effects, will need to be identified. Several studies showed that people can differ in their preferences and needs, and that it seems possible to distribute them into clusters [152,153].
- Possible interactions at and between different levels (human and environment) over time need to be explored for different scenarios and situations. Previous studies have shown that, at occupant level, interactions occur via the mechanisms the human body has to cope with the different environmental stressors [26]. More recently, it was seen in a lab study with 250 primary school children – who assessed, in a four-way factorial design, temperature, noise, light, and smell of 36 different environmental configurations in the experience room of the SenseLab [154] – that interactions between different acoustic, olfactory, and visual stressors probably occur at the level of the central nervous system [155].
- To determine patterns of stressors, profiles of people, and interactions at both environment and human level, and their ranges of variation, combined field and laboratory studies, using a mixed (quantitative and qualitative) design and non-linear analysis methods, are required. These might form the basis for the development of a new generation of rigorous, comprehensive, and consistent – yet, flexibly adaptable – pre- and post-occupancy evaluation (POE) tools and performance measurement protocols, beyond the unique objective assessment of physical indoor environmental qualities. Initial mixed method studies with primary school children seem successful [151,152,155].

2.10. Question 10: how to connect well-being research with building practice and standards?

While there is increasing agreement on the potential positive and negative impact of buildings on human health and well-being [156–158], translating that evidence into real-world practice can be challenging and requires regular revision, real-world testing, and evaluation. The example of those certification schemes that require a holistic assessment of *objective* environmental performance and *subjective* occupant responses on an annual basis can be used to highlight some of the challenges and opportunities involved in connecting research and practice around how buildings impact well-being [159,160].

As outlined in the introduction to this paper, the very foundation of healthy building research is made complex by its interdisciplinary nature and different discipline-specific understandings of the same terms, or research paradigms, that result in different methods of evaluation [161]. The real-world implications of an interdisciplinary approach can be seen in the evolution of post-occupancy evaluation (POE) requirements for projects. To date, most POE surveys address indoor environmental quality (IEQ) satisfaction [162], employee engagement and performance [163,164], or, sometimes, workplace wellness programs [165,166], but rarely do they comprise all of these components, nor do they often directly address the impact on occupant health and well-being. This requires a shift in thinking for both researchers, who need to embrace interdisciplinary metrics, and design teams, who are more familiar with simpler IEQ satisfaction surveys and who may not understand the value of third-party involvement.

Translating scientific data to building-level interventions can, however, be challenging. For example, while strong evidence exists on the relationship between poor indoor air quality, human performance, and health outcomes [15,167,168] (see Q6), this is not yet captured at a population level [169]. This means that, to connect building-level interventions with public health data recognisable by design teams (such as risks from poor air quality), non-building level data must often be used as proxy for some of the long-term public health impacts. For example, in describing the health risks from poor air quality, a combination of environmental (non-building specific from WHO) and case-study data (building or case-study specific) can be used to give a more holistic picture of the evidence [15].

Similarly, there has been some progress in associating certain features of building standards – and, more specifically, of certification schemes [170] – to the risk factors included in the Global Burden of Disease database [169]. While promising in their linkage of building-level interventions with population-level health data, these connections need to be framed as an important, but incomplete, picture of the evidence around health and well-being in buildings, since no population level data is yet available to represent a holistic, interdisciplinary approach. For example, while ample evidence exists on the link between access to nature and benefits to humans [171,172], these data points are not currently being collected at a population level. This means that communicating the possible benefits of specific building features and interventions to design teams requires education, adaptability, and constant evaluation of the best available evidence and recognition of which scale is being used.

While these considerations provide ongoing challenges, they are also squarely where research on health and well-being in buildings should be, offering numerous opportunities for interdisciplinary studies that are adaptive and checked against real-world implementation constraints. Ensuring ongoing dialogue between researchers and standard-setting bodies who influence building design and operations, feedback loops through both building and occupant evaluations, a commitment to interdisciplinary collaboration, and the creation of key priorities for well-being and building research that can be communicated to funding bodies, policy makers, and researchers, are some ways to achieve these goals.

3. Conclusion

The built environment has an indisputable role in driving the well-being of its occupants. The 2014 and 2017 Nobel Prizes in Medicine – awarded, respectively, for the discovery of an inner positioning system in the brain, and of the molecular mechanisms controlling the internal biological clock that regulates circadian rhythms – are a testament of the intimate connection between the character of the spaces we inhabit and their impacts on human responses and behaviours. Underpinned by a growing body of interdisciplinary research, scientific evidence and design practice are providing substantial support to the statement made by Winston Churchill while debating the rebuilding of the House of Commons: "*we shape our buildings, and afterwards our buildings shape us*" [173].

In this context, this paper has articulated a theoretical position with respect to a theme that, for different reasons – either linked to social, environmental, or financial concerns, or simply due to increased attention for personal preservation – is becoming mainstream, but that is also frequently misinterpreted. The recent heightened awareness of the threats of infectious disease epidemics is placing a further, profound, emphasis on the shared responsibility that preserving human well-being today represents. The design and the operation of the built habitats that enclose a large portion of our lives – mediating our experiences, dictating our environmental stimulations, accompanying the rhythms of our bodies, facilitating or hindering our social interactions, offering opportunities for pleasure and delight, but also exposing to potential dangers and harms – are part of a wider set of challenges that we, as a species, are collectively summoned to respond to [174]. Rather than focusing on the negative impacts of disease, this paper has explored how built environments can enhance positive outcomes, and how, from the range of perspectives offered, a new framework can emerge.

We may or not agree that well-being is becoming the *new green* for the building industry. Certainly, moving forward from the conventional agenda of sustainability in the built environment, for long centred on energy efficiency, attention is now focusing on the integration of new and diverse competences, catalysing interdisciplinary knowledge and discoveries for their transfer to building practice. Promoting the well-being of people is essential to achieve a more sustainable future, as explicitly featured in the UN Sustainable Development Goals [175]. In the design and operation of buildings, this requires a *paradigm shift* from the established methods and metrics typically used to evaluate indoor and outdoor environmental qualities. Design agendas should depart from the creation of neutral and 'static' conditions targeting avoidance of risks and minimisation of discomfort and dissatisfaction, towards the promotion of positive outcomes and the simultaneous consideration of environmental performance, human preference, and experience. This is relevant across building and occupancy types, particularly as demographic (e.g., an ageing population), cultural (e.g., home working) and public health (e.g., social distancing) phenomena are actively shifting the use-patterns of our buildings, and often increasing the diversity of task types therein performed.

A new design agenda needs also to embrace other aspects, although not directly addressed in this paper, that have often been considered ancillary to the design of built spaces, but that can play a crucial role in promoting the well-being of those that occupy them: biophilia, sensory environments, traveling policies, physical activity, safety and security, ecology, inclusive design, food, sleeping, social connectedness, etc. Pleasantly experienced indoor and outdoor environments require more than just the absence of negative stimuli. The aim should be, therefore, that of conceiving flexible and adaptable settings where, through form, space, and materiality, the opportunities for well-being can emerge. This includes envisaging how such settings might change over time, responding to diverse purposes, accommodating varied requirements, being transformed based on user profiles and needs, and how the role of occupants might evolve from passive recipients of deterministically pre-set conditions to active, aware, and engaged inhabitants securing their preferences and aspirations.

As all scientific advances, this is "*far from a cumulative process",* but rather it might demand "*a reconstruction of the field from its fundamentals*" [176]. There are still many challenges to be tackled for well-being to fully arise as a driver and a priority in the design principles and operational strategies that inform the conception and use of our built habitats, addressing disconnections between different demands (e.g., financial returns, environmental preservation, personal welfare) to craft indoor and outdoor environments that can afford resilience and restoration, offer variation, provide controllability, and advance positive stimuli towards better living qualities.

Although there is certainly no obvious and universal 'one-size-fits-all' solution, this paper has intended to provide a contribution in this direction. Yet, if a process of reconstruction is needed to nurture the required paradigm shift from the solid foundations of knowledge so far acquired and practiced, this represents a stimulating and exciting avenue of development for research and practice whose pursue might ultimately be in the very best interest of us all: the planet and the people that inhabit it.

3.1. Expertise of the authors

- **Sergio Altomonte** is Professor of Architectural Physics at the Université catholique de Louvain (Belgium). His research expertise focuses on indoor environmental quality, daylighting, green certification, and building psychophysics. Prof. Altomonte responded to Q1
- **Joseph Allen** is Assistant Professor of Exposure Assessment Science and Director of the Healthy Buildings program at the Harvard T.H. Chan School of Public Health (USA). His research work focuses on health-promoting opportunities in buildings around the '9 Foundations of a Healthy Building'. Dr Allen responded to Q7.
- **Philomena Bluyssen** is Professor of Indoor Environment at the Delft University of Technology (Netherlands). Her research is centred on the quality of the indoor environment of buildings, looking at the possibilities to create healthy and comfortable spaces based on the needs and preferences of their users. Prof. Bluyssen responded to Q9.
- **Gail Brager** is Professor of Architecture at the University of California, Berkeley (USA). She conducts research and teaching across multiple dimensions of sustainability, with a focus on thermal comfort, adaptation, and passive design. Prof. Brager responded to Q2.
- **Lisa Heschong**, former principal of the Heschong Mahone Group and architect, is recognised in the building industry as an expert on daylighting, lighting energy use, and human factors in design. Ms Heschong responded to Q3.
- **Angela Loder** is Vice President of Research at the International WELL Building Institute, being responsible for managing evidence-based research that supports the WELL standard. Her expertise includes the health impacts of access to urban nature and interdisciplinary approaches to health in buildings. Dr Loder responded to Q10.
- **Stefano Schiavon** is Associate Professor at the University of California, Berkeley (USA). His work focuses on finding ways to reduce energy consumption in buildings and improve indoor environmental quality. Dr Schiavon responded to Q4.
- **Jennifer Veitch** is Principal Research Officer at the National Research Council of Canada. An environmental psychologist, she is best known for her research on lighting quality and workplace organization and their effects on health, well-being, work performance, and behaviour. Dr Veitch responded to Q8.
- **Lily Wang** is a Professor at the University of Nebraska – Lincoln (USA). Her research interests are in room acoustics and noise control, human perception, and performance. Prof. Wang responded to Q5.
- **Pawel Wargocki** is Associate Professor at the Technical University of Denmark. His expertise is on human requirements in buildings, air quality, pollutants, and ventilation strategies. Dr Wargocki responded to Q6.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

Funding contribution has been provided by: FAI (Fond d'Appui à l'Internationalisation - International Initiative Fund), Université catholique de Louvain, and Fondation Universitaire de Belgique (Sergio Altomonte); TU Delft Fellowship (Philomena M. Bluyssen); International WELL Building Institute (Angela Loder); National Research Council of Canada – High Performance Buildings Program (Jennifer A. Veitch); University of Nebraska – Lincoln (Lily Wang). Joseph Allen contribution was made possible by grant n. T42 OH008416, from the National Institute for Occupational Safety and Health (NIOSH). The contents of this paper are solely the responsibility of the authors and do not necessarily represent the official views of the NIOSH or any other funding body.

References

[1] E. Diener, R. Emmons, R. Larsen, S. Griffin, The satisfaction with life scale, J. Pers. Assess. 49 (1985) 71–75.
[2] WHO, The World Health Organization Quality of Life Instrument (WHOQOL), World Health Organization, Geneva, 1997.
[3] P. Hills, M. Argyle, The Oxford Happiness Questionnaire: a compact scale for the measurement of psychological well-being, Pers. Indiv. Differ. 33 (7) (2002) 1073–1082.
[4] M. Harari, C. Waehler, J. Rogers, An empirical investigation of a theoretically based measure of perceived wellness, J. Counsel. Psychol. 52 (1) (2005) 93–103.
[5] M. Hanc, C. McAndrew, M. Ucci, Conceptual approaches to wellbeing in buildings: a scoping review, Build. Res. Inf. 47 (6) (2019) 767–783.
[6] R. Dodge, A. Daly, I. Huyton, L. Sanders, The challenge of defining wellbeing, International Journal of Wellbeing 2 (3) (2012) 222–235.
[7] L. Rohde, T. Steen Larsen, R. Lund Jensen, O. Kalyanova Larsen, Framing holistic indoor environment: definitions of comfort, health and well-being, Indoor Built Environ. (2019) 1–19, https://doi.org/10.1177/1420326X19875795.
[8] E. Diener, D. Wirtz, W. Tov, New measures of well-being: flourishing and positive and negative feelings, Soc. Indicat. Res. 39 (2010) 247–266.
[9] ASHRAE, Standard 55 - Thermal Environmental Conditions for Human Occupancy, ASHRAE, Atlanta, 2013.
[10] WHO, Preamble to the Constitution of the World Health Organization as Adopted by the International Health Conference, World Health Organization, New York, 1946, 19-22 June.
[11] A. Ghaffarianhoseini, H. AlWaer, H. Omrany, A. Ghaffarianhoseini, C. Alalouch, D. Clements-Croome, J. Tookey, Sick building syndrome: are we doing enough? Architect. Sci. Rev. 61 (3) (2018) 99–121.
[12] F. Huppert, T. So, Flourishing across Europe: application of a new conceptual framework for defining well-being, Soc. Indicat. Res. 110 (3) (2013) 837–861.
[13] A. Wierzbicka, E. Pedersen, R. Persson, B. Nordquist, K. Stålne, C. Gao, L. Harderup, J. Borell, H. Caltenco, B. Ness, E. Stroh, Y. Li, M. Dahlblom, K. Lundgren-Kownacki, C. Isaxon, A. Gudmundsson, P. Wargocki, Healthy indoor environments: the need for a holistic approach, Int. J. Environ. Res. Publ. Health 15 (9) (2018) 1–13.
[14] G. Newsham, B. Birt, C. Arsenault, A. Thompson, J.A. Veitch, S. Mancini, G. J. Burns, Do Green Buildings Outperform Conventional Buildings? Indoor Environment and Energy Performance in North American Offices, Research Report RR-329, National Research Council, Ottawa, Canada, 2012.
[15] J. Allen, P. MacNaughton, U. Satish, S. Santanam, J. Vallarino, J. Spengler, Associations of cognitive function scores with carbon dioxide, ventilation, and volatile organic compound exposures in office workers: a controlled exposure study of green and conventional office environments, Environ. Health Perspect. 124 (6) (2016) 805–812.
[16] P. MacNaughton, J. Spengler, J. Vallarino, S. Santanam, U. Satish, J. Allen, Environmental perceptions and health before and after relocation to a green building, Build. Environ. 104 (2016) 138–144.
[17] J. Lee, P. Wargocki, Y. Chan, L. Chen, K. Tham, Indoor environmental quality, occupant satisfaction, and acute building-related health symptoms in Green Mark-certified compared with non-certified office buildings, Indoor Air 29 (1) (2019) 112–129.
[18] S. Altomonte, S. Schiavon, Occupant satisfaction in LEED and non-LEED certified buildings, Build. Environ. 68 (2013) 66–76.

[19] S. Schiavon, S. Altomonte, Influence of factors unrelated to environmental quality on occupant satisfaction in LEED and non-LEED certified buildings, Build. Environ. vol. 77 (2014) 148–159.
[20] M. Ucci, J. Godefroy, "Are metrics and data the answer to delivering 'healthy buildings'? Build. Serv. Eng. Technol. 41 (2) (2020) 133–136.
[21] J. Allen, P. MacNaughton, J. Laurent, S. Flanigan, E. Eitland, J. Spengler, Green buildings and health, Current Environmental Health Reports 2 (2015) 250–258.
[22] S. Altomonte, M. Kent, S. Schiavon, G. Brager, Indoor environmental quality and occupant satisfaction in green-certified buildings, Build. Res. Inf. 47 (2019) 255–274.
[23] B. Owens, C. Macken, A. Rohloff, H. Rosenberg, LEED V4 - Impact Category and Point Allocation Development Process, USGBC, 2013.
[24] T. Taylor, H. Pineo, Health and Wellbeing in BREEAM, BRE Global, Watford, 2015.
[25] J. McArthur, C. Powell, Health and wellness in commercial buildings: systematic review of sustainable building rating systems and alignment with contemporary research, Build. Environ. 171 (2020), https://doi.org/10.1016/j.buildenv.2019.106635.
[26] M. Frontczak, P. Wargocki, Literature survey on how different factors influence human comfort, Build. Environ. 46 (2011) 922–937.
[27] M. Frontczak, R. Andersen, P. Wargocki, Questionnaire survey on factors influencing comfort with indoor environmental quality, Build. Environ. 50 (2012) 56–64.
[28] R. Potts, Hominin evolution in settings of strong environmental variability, Quat. Sci. Rev. 73 (2013) 1–13.
[29] N. Klepeis, W. Nelson, W. Ott, J. Robinson, A. Tsang, P. Switzer, J. Behar, S. Hern, W. Engelmann, The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants, J. Expo. Anal. Environ. Epidemiol. 11 (3) (2001) 231–252.
[30] M. Donn, S. Selkowitz, B. Bordass, The building performance sketch, Build. Res. Inf. 40 (2) (2012) 186–208.
[31] P. de Wilde, The gap between predicted and measured energy performance of buildings: a framework for investigation, Autom. ConStruct. 41 (2014) 40–49.
[32] J. Kim, Y. Zhou, S. Schiavon, G. Brager, Personal comfort models: predicting individuals' thermal preference using occupant heating and cooling behavior and machine learning, Build. Environ. 129 (2018) 96–106.
[33] K. Gerlach, Environmental design to counter occupational boredom, Journal of Architectural Research 3 (3) (1974) 15–19.
[34] G. Yun, Influences of perceived control on thermal comfort and energy use in buildings, Energy Build. 158 (2018) 822–830.
[35] M. Kwon, H. Remøy, A. van den Dobbelsteen, U. Knaack, Personal control and environmental user satisfaction in office buildings: results of case studies in The Netherlands, Build. Environ. 149 (2019) 428–435.
[36] G. Brager, H. Zhang, E. Arens, Evolving opportunities for providing thermal comfort, Build. Res. Inf. 43 (2015) 274–287.
[37] CIBSE, Environmental Design - CIBSE Guide A, 8th ed., CIBSE, London, 2015.
[38] A. Birchler-Pedross, C. Schröder, M. Münch, V. Knoblauch, K. Blatter, C. Schnitzler-Sack, A. Wirz-Justice, C. Cajochen, Subjective well-being is modulated by circadian phase, sleep pressure, age and gender, J. Biol. Rhythm. 24 (3) (2009) 232–242.
[39] M. Aries, M. Aarts, J. van Hoof, Daylight and health: a review of the evidence and consequences for the built environment, Light. Res. Technol. 6 (2015) 6–27.
[40] R. de Dear, Revisiting an old hypothesis of human thermal perception: alliesthesia, Build. Res. Inf. 39 (2) (2011) 108–117.
[41] Y. Luo, X. Chen, S. Qi, X. You, X. Huang, Well-being and anticipation for future positive events: evidences from an fMRI study, Front. Psychol. 8 (2018) 1–8.
[42] G. Mangone, S. Kurvers, P. Luscuere, Constructing thermal comfort: investigating the effect of vegetation on indoor thermal comfort through a four season thermal comfort quasi-experiment, Build. Environ. 81 (2014) 410–426.
[43] R. Baron, Environmentally induced positive affect: its impact on self-efficacy, task performance, negotiation, and conflict, J. Appl. Soc. Psychol. 20 (5) (1990) 368–384.
[44] N. Tuaycharoen, P.R. Tregenza, View and discomfort glare from windows, Light. Res. Technol. 39 (2) (2007) 185–200.
[45] S. Kaplan, The restorative benefits of nature: towards an integrative framework, J. Environ. Psychol. 15 (1995) 169–182.
[46] A. Maslow, A theory of human motivation, Psychol. Rev. 50 (4) (1943) 370–396.
[47] L. Heschong, Thermal Delight in Architecture, MIT Press, Cambridge, MA, 1979.
[48] B. Erwine, Creating Sensory Spaces - the Architecture of the Invisible, Routledge, New York, 2017.
[49] J. Vischer, The concept of workplace performance and its value to managers, Calif. Manag. Rev. 49 (2) (2006) 1–18.
[50] W. van Marken Lichtenbelt, M. Hanssen, H. Pallubinsky, B. Kingma, L. Schellen, Healthy excursions outside the thermal comfort zone, Build. Res. Inf. 45 (7) (2017) 819–827.
[51] M. Miura, T. Ikaga, Human response to the indoor environment under fluctuating temperature, Science and Technology for the Built Environment 22 (6) (2016) 820–830.
[52] J.H. Heerwagen, G.H. Orians, Humans, Habitats and Aesthetics, in: S.R. Kellert, E. O. Wilson (Eds.), The Biophilia Hypothesis, Island Press, Washington, 1993, pp. 138–172.
[53] S. Kellert, J. Heerwagen, M. Mador, Biophilic Design - the Theory, Science and Practice of Bringing Buildings to Life, Wiley, Hoboken, NJ, 2008.
[54] W. Browning, C. Ryan, J. Clancy, 14 Patterns of Biophilic Design - Improving Health & Well-Being in the Built Environment, Terrapin Bright Green LLC, Washington, DC, 2014.
[55] S. Kellert, Nature by Design, Yale University Press, New Haven, 2018.
[56] T. Parkinson, R. de Dear, Thermal pleasure in built environments: physiology of alliesthesia, Build. Res. Inf. 43 (3) (2015) 288–301.
[57] L. Brondel, M. Cabanac, Alliesthesia in visual and auditory sensations from environmental signals, Physiology & Bahaviour 91 (2007) 196–201.
[58] T. Parkinson, R. de Dear, C. Candido, Thermal pleasure in built environments: alliesthesia in different thermoregulatory zones, Build. Res. Inf. 44 (1) (2016) 20–33.
[59] T. Parkinson, R. de Dear, Thermal pleasure in built environments: spatial alliesthesia from contact heating, Build. Res. Inf. 44 (3) (2016) 248–262.
[60] T. Parkinson, R. de Dear, Thermal pleasure in built environments: spatial alliesthesia from air movement, Build. Res. Inf. 45 (3) (2017) 320–335.
[61] D. Berson, F. Dunn, M. Takao, Photo-transduction by retinal ganglion cell that set the circadian clock, Science 295 (2002) 1070–1073.
[62] G. Brainard, J. Hanifin, J.M. Greeson, B. Byrne, G. Glickman, E. Gerner, M. Rollag, Action spectrum for melatonin regulation in humans: evidence for a novel circadian photoreceptor, J. Neurosci. 21 (2001) 6405–6412.
[63] S. Hughes, T. Watson, R. Foster, S. Peirson, M. Hankins, Nonuniform distribution and spectral tuning of photosensitive retinal ganglion cells of the mouse retina, Curr. Biol. 23 (17) (2013) 1696–1701.
[64] M. Lucas, S. Peirson, D. Berson, T. Brown, H. Cooper, C. Czeisler, M. Figueiro, P. Gamlin, S. Lockley, J. O'Hagan, L. Price, I. Provencio, D. Skene, G. Brainard, Measuring and using light in the melanopsin age, Trends Neurosci. 37 (1) (2014) 1–9.
[65] S. Lockley, E. Evans, F. Scheer, G. Brainard, C. Czeisler, D. Aeschbach, Short-wavelength sensitivity for the direct effects of light on alertness, vigilance, and the waking electroencephalogram in humans, Sleep 29 (2006) 161–168.
[66] C. Cajochen, S. Chellappa, C. Schmidt, What keeps us awake? The role of clocks and hourglasses, light, and melatonin, in: A. Clow, L. Thorn (Eds.), International Review of Neurobiology, 93, Academic Press, Oxford, 2010, pp. 57–90.
[67] L. Walmsley, L. Hanna, J. Mouland, F. Martial, A. West, A. Smedley, D. Bechtold, A. Webb, R. Lucas, T. Brown, Colour as a signal for entraining the mammalian circadian clock, PLoS Biol. 13 (4) (2015), e1002127.
[68] R. Ulrich, View through a window may influence recovery from surgery, Science 27 (224) (1984) 420–421.
[69] Heschong Mahone Group, Daylighting in Schools, Re-analysis Report, California Energy Commission, 2002. PIER Technical Report 500-03-082-A-3.
[70] Heschong Mahone Group, Windows and Classrooms: A Study of Student Performance and the Indoor Environment, California Energy Commission, 2003. PIER Technical Report P500-03-082-A-7.
[71] Heschong Mahone Group, Windows and Offices: A Study of Office Worker Performance and the Indoor Environment, California Energy Commission, 2003. PIER Technical Report P500-03-082-A-9.
[72] M. Boubekri, N. Cheung, K. Reid, C.-H. Wang, P. Zee, Impact of windows and daylight exposure on overall health and sleep quality of office workers: a case-control pilot study, Journal of Clinical Sleep Medicine 10 (6) (2014) 603–611.
[73] S. Hood, S. Amir, The aging clock: circadian rhythms and later life, J. Clin. Invest. 127 (2) (2017) 437–446.
[74] N. Tuaycharoen, P.R. Tregenza, Discomfort glare from interesting images, Light. Res. Technol. 37 (4) (2005) 329–341.
[75] M. Frontczak, S. Schiavon, J. Goins, E. Arens, H. Zhang, P. Wargocki, Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design, Indoor Air 22 (2) (2012) 119–131.
[76] P.M. Bluyssen, C. Roda, C. Mandin, S. Fossati, P. Carrer, Y. de Kluizenaar, V. Mihucz, E. de Oliveira Fernandes, J. Bartzis, Self-reported health and comfort in 'modern' office buildings: first results from the European OFFICAIR study, Indoor Air 26 (2) (2016) 298–317.
[77] B. Bordass, A. Leaman, et al., Assessing building performance in use 5: conclusions and implications, Build. Res. Inf. 29 (2) (2001) 144–157.
[78] K. Parsons, Human Thermal Environments: the Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort, and Performance, CRC Press, Boca Raton, 2014.
[79] P. Wargorcki, O. Seppänen, Indoor Climate and Productivity in Offices, Brussels: REHVA - Federation of European Heating, Ventilation and Air Conditioning Associations, 2006.
[80] L. Fang, D. Wyon, G. Clausen, P. Fanger, Impact of indoor air temperature and humidity in an office on perceived air quality, SBS symptoms and performance, Indoor Air 14 (2004) 74–81.
[81] F. Zhang, R. de Dear, P. Hancock, Effects of moderate thermal environments on cognitive performance: a multidisciplinary review, Appl. Energy 236 (2019) 760–777.
[82] T. Cheung, S. Schiavon, T. Parkinson, L. Peixian, G. Brager, Analysis of the accuracy on PMV – PPD model using the ASHRAE Global Thermal Comfort Database II, Build. Environ. 153 (2019) 205–217.
[83] C. Karmann, S. Schiavon, L. Graham, P. Raftery, F. Bauman, Comparing temperature and acoustic satisfaction in 60 radiant and all-air buildings, Build. Environ. 126 (2017) 431–441.
[84] P. Fanger, Thermal Comfort, Danish Technical Press, Copenhagen, 1970.
[85] R. de Dear, G. Brager, Developing an adaptive model of thermal comfort and preference, ASHRAE Transactions 104 (1) (1998) 1–19.
[86] J. van Hoof, L. Schellen, V. Soebarto, J. Wong, J. Kazak, Ten questions concerning thermal comfort and ageing, Build. Environ. vol. 120 (2017) 123–133.
[87] J. Kim, S. Schiavon, G. Brager, Personal comfort models – A new paradigm in thermal comfort for occupant-centric environmental control, Build. Environ. 132 (2018) 114–124.

[88] S. Liu, S. Schiavon, H. Prasanna Das, M. Jin, C. Spanos, Personal thermal comfort models with wearable sensors, Build. Environ. 162 (2019), https://doi.org/10.1016/j.buildenv.2019.106281.
[89] J. Kim, R. de Dear, Workspace satisfaction: the privacy-communication trade-off in open-plan offices, J. Environ. Psychol. 36 (2013) 18–26.
[90] G. Farber, L. Wang, Analyses of crowd-sourced sound levels, logged from more than 2250 restaurants and bars in New York City, in: 174th Meeting of the Acoustical Society of America, Louisiana, New Orleans, 2017.
[91] D. Valente, H. Plevinsky, J. Franco, E. Heinrichs-Graham, D. Lewis, Experimental investigation of the effects of the acoustical conditions in a simulated classroom on speech recognition and learning in children, J. Acoust. Soc. Am. 131 (2012) 232–246.
[92] L. Brill, K. Smith, L. Wang, Building a sound future for students – considering the acoustics in occupied active classrooms, Acoust. Today 14 (3) (2018) 14–22.
[93] K. Smith, V. Anderson, L. Wang, Characterization of restaurant soundscapes based on logged sound levels and occupancy measurements, J. Acoust. Soc. Am. 145 (3) (2019), https://doi.org/10.1121/1.5101967.
[94] J. Rindel, Restaurant acoustics - verbal communication in eating establishments, Acoustics in Practice 7 (2019) 1–14.
[95] G. Gardner, C. Collins, S. Osborne, A. Henderson, M. Eastwood, Creating a therapeutic environment, Int. J. Nurs. Stud. 46 (2009) 778–786.
[96] WHO, Multi-Country Assessment of National Capacity to Provide Hearing Care, World Health Organization, Geneva, 2013.
[97] H. Jensen, B. Rasmussen, O. Ekholm, Neighbour and traffic noise annoyance: a nationwide study of associated mental health and perceived stress, Eur. J. Publ. Health 28 (6) (2018) 1050–1055.
[98] M. Basner, W. Babisch, A. Davis, M. Brink, C. Clark, S. Janssen, S. Stansfeld, Auditory and non-auditory effects of noise on health, Lancet 383 (2014) 1325–1332.
[99] C. Beaman, Auditory distraction from low-intensity noise: a review of the consequences for learning and workplace environments, Appl. Cognit. Psychol. 19 (2005) 1041–1064.
[100] A. Brown, Soundscapes and environmental noise management, Noise Contr. Eng. 58 (5) (2010) 1–8.
[101] W. Davies, M. Adams, N. Bruce, R. Cain, A. Carlyle, P. Cusack, D. Hall, K. Hume, A. Irwin, P. Jennings, M. Marselle, C. Plack, J. Poxon, Perception of soundscapes: an interdisciplinary approach, Appl. Acoust. 74 (2013) 224–231.
[102] O. Medvedev, D. Shepherd, M.J. Hautus, The restorative potential of soundscapes: a physiological investigation, Appl. Acoust. 96 (2015) 20–26.
[103] L. Salis, M. Abadie, P. Wargocki, C. Rode, Towards the definition of indicators for assessment of indoor air quality and energy performance in low-energy residential buildings, Energy Build. 152 (2017) 492–502.
[104] P. Carrer, P. Wargocki, A. Fanetti, W. Bischof, E. de Oliveira Fernandes, T. Hartmann, S. Kephalopolous, S. Palkonen, O. Seppänen, What does the scientific literature tell us about the ventilation–health relationship in public and residential buildings? Build. Environ. 94 (2015) 273–286.
[105] P. Carrer, E. de Oliveira Fernandes, H. Santos, O. Hänninen, S. Kephalopoulos, P. Wargocki, On the development of health-based ventilation guidelines: principles and framework, Int. J. Environ. Res. Publ. Health 15 (7) (2018) E1360.
[106] W. Fisk, P. Wargocki, X. Zhang, Do Indoor CO2 levels directly affect perceived air quality, health, or work performance? ASHRAE J. (2019) 70–78.
[107] WHO, Guidelines for Indoor Air Quality: Global Update 2005. Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide, World Health Organization, Regional Office for Europe, Copenhagen, 2006.
[108] WHO, Guidelines for Indoor Air Quality: Dampness and Mould, World Health Organization, Regional Office for Europe, Copenhagen, 2009.
[109] WHO, Guidelines for Indoor Air Quality: Selected Pollutants, World Health Organization, Regional Office for Europe, Copenhagen, 2010.
[110] ECA, Report No 29. Harmonisation Framework for Health Based Evaluation of Indoor Emissions from Construction Products in the European Union Using the EU-LCI.European Concerted Action, JRC Publications, Ispra, Italy, 2013.
[111] W. Wei, O. Ramalho, C. Mandin, Indoor air quality requirements in green building certifications, Build. Environ. 92 (2015) 10–19.
[112] G. Bekö, G. Morrison, C. Weschler, H. Koch, C. Pälmke, T. Salthammer, T. Schripp, A. Eftekhari, J. Toftum, G. Clausen, Dermal uptake of nicotine from air and clothing: experimental verification, Indoor Air 28 (2) (2018) 247–257.
[113] P.M. Bluyssen, E. de Oliveira Fernandes, L. Groes, G. Clausen, P. Fanger, O. Valbjørn, C. Bernhard, C. Roulet, European indoor air quality audit project in 56 office buildings, Indoor Air 6 (4) (1996) 221–238.
[114] P. Wargocki, J. Sundell, W. Bischof, G. Brundrett, P. Fanger, F. Gyntelberg, S. Hanssen, P. Harrison, A. Pickering, O. Seppänen, P. Wouters, Ventilation and health in non-industrial indoor environments: report from a European Multidisciplinary Scientific Consensus Meeting (EUROVEN), Indoor Air 12 (2002) 113–128.
[115] J. Sundell, H. Levin, W. Nazaroff, W. Cain, W. Fisk, D. Grimsrud, F. Gyntelberg, Y. Li, A. Persily, A. Pickering, J. Samet, Ventilation rates and health: multidisciplinary review of the scientific literature, Indoor Air 21 (3) (2011) 191–204.
[116] P. Wargocki, D. Wyon, Ten questions concerning thermal and indoor air quality effects on the performance of office work and schoolwork, Build. Environ. 112 (2017) 359–366.
[117] P. Wargocki, D. Wyon, Providing better thermal and air quality conditions in school classrooms would be cost-effective, Build. Environ. 59 (2013) 581–589.
[118] D. Milton, P. Glencross, M. Walters, Risk of sick leave associated with outdoor air supply rate, humidification, and occupant complaints, Indoor Air 10 (4) (2000) 212–221.
[119] M. Mendell, E. Eliseeva, M. Davies, M. Spears, A. Lobscheid, W. Fisk, M. Apte, Association of classroom ventilation with reduced illness absence: a prospective study in California elementary schools, Indoor Air 23 (6) (2013) 515–528.
[120] X. Zhou, L. Lian, Experimental study on a bedside personalized ventilation system for improving sleep comfort and quality, Indoor Built Environ. 23 (2) (2014) 313–323.
[121] P. Strøm-Tejsen, D. Zukowska, P. Wargocki, D. Wyon, The effects of bedroom air quality on sleep and next-day performance, Indoor Air 26 (2016) 679–686.
[122] A. Melikov, J. Kaczmarczyk, Air movement and perceived air quality, Build. Environ. 47 (2012) 400–409.
[123] S. Schiavon, B. Yang, Y. Donner, V. Chang, W. Nazaroff, Thermal comfort, perceived air quality and cognitive performance when personally controlled air movement is used by tropically acclimatized persons, Indoor Air 27 (3) (2017) 690–702.
[124] O. Seppänen, W. Fisk, M. Mendell, Association of ventilation rates and CO2 concentrations with health and other responses in commercial and institutional buildings, Indoor Air 9 (4) (1999) 226–252.
[125] W. Fisk, A. Mirer, M. Mendell, Quantitative relationship of sick building syndrome symptoms with ventilation rates, Indoor Air 19 (2009) 159–165.
[126] J. Sundell, M. Wickman, G. Pershagen, S. Nordvall, Ventilation in homes infested by house-dust mites, Allergy 50 (2) (1995) 106–112.
[127] L. Øie, P. Nafstad, G. Botten, P. Magnus, J. Jaakkola, Ventilation in homes and bronchial obstruction in young children, Epidemiology 10 (3) (1999) 294–299.
[128] C. Bornehag, J. Sundell, C. Weschler, T. Sigsgaard, B. Lundgren, M. Hasselgren, L. Hägerhed-Engman, The association between asthma and allergic symptoms in children and phthalates in house dust: a nested case–control study, Environ. Health Perspect. 112 (14) (2004) 1393–1397.
[129] M. Jantunen, E. de Oliveira Fernandes, P. Carrer, S. Kephalopoulos, Promoting Actions for Healthy Indoor Air (IAIAQ), European Commission, Brussels, 2011.
[130] J. Logue, P. Price, M. Sherman, B. Singer, A method to estimate the chronic health impact of air pollutants in US residences, Environ. Health Perspect. 120 (2) (2011) 216–222.
[131] A. Steinemann, Ten questions concerning air fresheners and indoor built environments, Build. Environ. vol. 111 (2017) 279–284.
[132] WHO, Constitution of the World Health Organization - Basic Documents, World Health Organization, New York, 2006. Supplement.
[133] A. Antonovsky, Health, Stress and Coping, Jossey-Bass Publishers, San Francisco, 1979.
[134] P. Drucker, The Practice of Management, Routledge, Oxon, 2012.
[135] J. Allen, J. Macomber, Healthy Buildings: How Indoor Spaces Drive Performance and Productivity, Harvard University Press, Boston, 2020.
[136] J. Allen, A. Bernstein, X. Cao, E.S. Eitland, S. Flanigan, M. Gokhale, J. Goodman, S. Klager, L. Klingensmith, J.G. Cedeno Laurent, S. Lockley, P. Macnaughton, S. Pakpour, J. Spengler, J. Vallarino, A. Williams, A. Young, J. Yin, The 9 Foundations of a Healthy Building, Harvard T.H. Chan School of Public Health, 2017 [Online]. Available: https://forhealth.org/9_Foundations_of_a_Healthy_Building.February_2017.pdf [Accessed 07 May 2020].
[137] R. Pritchard, Organizational productivity, in: 2nd. ed., in: M. Dunnette, L. Hough (Eds.), Handbook of Industrial and Organizational Psychology, 3, Consulting Psychologists Press, Palo Alto, CA, 1992, pp. 443–471.
[138] M. Brill, S. Margulis, E. Konar, A. Bosti (Eds.), Using Office Design to Increase Productivity, Workplace Design and Productivity, Buffalo, NY, 1984.
[139] J.A. Veitch, How and why to assess workplace design: facilities management supports human resources, Organ. Dynam. 47 (2018) 78–87.
[140] G. Newsham, J.A. Veitch, M. Zhang, A. Galasiu, Comparing better building design and operation to other corporate strategies for improving organizational productivity: a review and synthesis, Intell. Build. Int. (2019), https://doi.org/10.1080/17508975.2019.1588700.
[141] J. Heerwagen, Green buildings, organizational success and occupant productivity, Build. Res. Inf. 28 (5–6) (2000) 353–367.
[142] A. Thompson, J.A. Veitch, G. Newsham, Improving Organizational Productivity with Building Automation Systems, Continental Automated Buildings Association, Ottawa, ON, 2014.
[143] WGBC, The Business Case for Green Buildings, World Green Building Council, Toronto, Canada, 2013.
[144] G. Newsham, J.A. Veitch, Lighting quality recommendations for VDT offices: a new method of derivation, Light. Res. Technol. 33 (2001) 97–116.
[145] P. Boyce, J.A. Veitch, G. Newsham, C. Jones, J. Heerwagen, M. Myer, C. Hunter, Lighting quality and office work: two field simulation experiments, Light. Res. Technol. 38 (3) (2006) 191–223.
[146] J.A. Veitch, G. Newsham, S. Mancini, C. Arsenault, Lighting and Office Renovation Effects on Employee and Organizational Well-Being (NRC-IRC RR-306), NRC Institute for Research in Construction, Ottawa, ON, 2010.
[147] A. Leaman, B. Bordass, Assessing building performance in use. 4: the Probe occupant surveys and their implications, Build. Res. Inf. 29 (2) (2001) 129–143.
[148] P.M. Bluyssen, The Healthy Indoor Environment: How to Assess Occupants' Wellbeing in Buildings, Routledge, Oxon, 2014.
[149] P.M. Bluyssen, Towards an integrated analysis of the indoor environmental factors and its effects on occupants, Intell. Build. Int. (2019), https://doi.org/10.1080/17508975.2019.1599318.
[150] P.M. Bluyssen, M. Ortiz, C. Roda, Self-reported rhinitis of students from different universities in The Netherlands and its association with their home environment, Build. Environ. 110 (2016) 36–45.
[151] P.M. Bluyssen, D. Zhang, S. Kurvers, M. Overtoom, M. Ortiz, Self-reported health and comfort of school children in 54 classrooms of 21 Dutch school buildings, Build. Environ. 138 (2018) 106–123.

[152] D. Zhang, M. Ortiz, P.M. Bluyssen, Clustering of Dutch school children based on their preferences and needs of the IEQ in classrooms, Build. Environ. 147 (2019) 258–266.
[153] M. Ortiz, P.M. Bluyssen, Proof-of-concept of a questionnaire to understand occupants' comfort and energy behaviours: first results on home occupant archetypes, Build. Environ. 134 (2018) 47–58.
[154] P.M. Bluyssen, F. van Zeist, S. Kurvers, M. Tenpierik, S. Pont, B. Wolters, L. van Hulst, D. Meertins, The creation of SenseLab: a laboratory for testing and experiencing single and combinations of indoor environmental conditions, Intell. Build. Int. 10 (1) (2018) 5–18.
[155] P.M. Bluyssen, D. Zhang, D. Kim, A. Eijkelenboom, M. Ortiz, First SenseLab studies with primary school children: exposure to different environmental configurations in the Experience room, Intell. Build. Int. (2019), https://doi.org/10.1080/17508975.2019.1661220.
[156] M. An, S. Colarelli, K. O'Brien, M. Boyajian, Why we need more nature at work: effects of natural elements and sunlight on employee mental health and work attitudes, PloS One e0155614 (2016) 1–17, https://doi.org/10.1371/journal.pone.0155614.
[157] L. Engelen, H. Dhillon, J. Chau, D. Hespe, A. Bauman, Do active design buildings change health behaviour and workplace perceptions? Occup. Med. 66 (5) (2016) 408–411.
[158] P. MacNaughton, U. Satish, J. Cedeno Laurent, S. Flanigan, J. Vallarino, B. Coull, S. JD, J. Allen, The impact of working in a green certified building on cognitive function and health, Build. Environ. 114 (2017) 178–186.
[159] W. Wei, P. Wargocki, J. Zirngibl, J. Bendžalová, C. Mandin, Review of parameters used to assess the quality of the indoor environment in Green Building certification schemes for offices and hotels, Energy Build. 209 (2020), https://doi.org/10.1016/j.enbuild.2019.109683.
[160] International WELL Building Institute, The WELL Performance Verification Guidebook, IWBI, New York, 2020.
[161] A. Loder, S. Altomonte, Promoting human health and well-being in buildings, in: E. Naboni, L. Havinga (Eds.), Regenerative Design in the Digital Practice, Bolzano, Eurac Research, 2019, pp. 285–288.
[162] J. Park, V. Loftness, A. Aziz, Post-Occupancy Evaluation and IEQ measurements from 64 office buildings: critical factors and thresholds for user satisfaction on thermal quality, Buildings 8 (11) (2018) 156–170.
[163] Afriforte, Metrics that Matter - the Organisational Human Factor Benchmark, 2019 [Online]. Available: http://www.afriforte.com/ohfb.php [Accessed 29 May 2019].
[164] Gallup, Employee Engagement, 2019 [Online]. Available: https://www.gallup.com/access/239210/employee-engagement-survey.aspx?g_source=link_wwwv9&g_campaign=item_245024&g_medium=copy [Accessed 29 May 2019].
[165] R. Goetzel, R. Henke, M. Tabrizi, K. Pelletier, R. Loeppke, D. Ballard, J. Grossmeier, D. Anderson, D. Yach, R. Kelly, T. McCalister, S. Serxner, C. Selecky, L. Shallenberger, J. Fries, C. Baase, F. Isaac, K. Crighton, P. Wald, E. Exum, D. Shurney, R. Metz, Do workplace health promotion (wellness) programs work? J. Occup. Environ. Med. 56 (9) (2014) 927–934.
[166] Gresb, The GRESB Health & Well-Being Module, GRESB, 2019 [Online]. Available: https://gresb.com/health-well-being-module/ [Accessed 29 May 2019].
[167] Y. Al Horr, M. Arif, A. Kaushik, A. Mazroei, M. Katafygiotou, E. Elsarrag, Occupant productivity and office indoor environment quality: a review of the literature, Build. Environ. 105 (2016) 369–389.
[168] M. Hulin, M. Simoni, G. Viegi, I. Annesi-Maesano, Respiratory health and indoor air pollutants based on quantitative exposure assessments, Eur. Respir. J. 40 (4) (2012) 1033–1045.
[169] Institute for Health Metrics & Evaluation, Global Burden of Disease, 2019 [Online]. Available: http://www.healthdata.org/gbd [Accessed 29 May 2019].
[170] International WELL Building Institute, WELL Country Briefs. WELL V2, 2019 [Online]. Available: https://www.wellcertified.com/certification/v2/country-briefs [Accessed 29 May 2019].
[171] H. Frumkin, G. Bratman, S. Breslow, B. Cochran, P. Kahn, J. Lawler, P. Levin, P. Tandon, U. Varanasi, K. Wolf, S. Wood, Nature contact and human health: a research agenda, Environ. Health Perspect. 125 (7) (2017) 1–18.
[172] A. Loder, Small-Scale Urban Greening - Creating Places of Health, Creativity and Ecological Sustainability, Routledge, London, 2020.
[173] W. Churchill, House of Commons Rebuilding, 28 October 1943.
[174] V. Lee, M. Ho, C. Kai, X. Aguilera, Epidemic preparedness in urban settings: new challenges and opportunities, Lancet Infect. Dis. (27 March 2020), https://doi.org/10.1016/S1473-3099(20)30249-8.
[175] UN, Sustainable Development Goals, United Nations, 2015 [Online]. Available: https://www.un.org/sustainabledevelopment/sustainable-development-goals/ [Accessed 22 April 2020].
[176] T. Kuhn, The structure of scientific revolutions, in: International Encyclopedia of Unified Science vol. II, The University of Chicago Press, Chicago, 1962.