Building and Environment 207 (2022) 108440

Contents lists available at ScienceDirect

Building and Environment

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

Occupant health in buildings: Impact of the COVID-19 pandemic on the opinions of building professionals and implications on research

Mohamad Awada [a], Burçin Becerik-Gerber [a,*], Elizabeth White [d], Simi Hoque [b], Zheng O'Neill [c], Giulia Pedrielli [d], Jin Wen [b], Teresa Wu [d]

[a] Department of Civil and Environmental Engineering, University of Southern California, United States
[b] Department of Civil, Environmental, and Architectural Engineering, Drexel University, United States
[c] Department of Mechanical Engineering, Texas A&M University, United States
[d] School of Computing Informatics and Decision Systems Engineering, Arizona State University, United States

A R T I C L E I N F O

Keywords:
Health
Buildings
Occupants
Professionals
State-of-the-art
COVID-19

A B S T R A C T

The objectives of this study are to investigate building professionals' experience, awareness, and interest in occupant health in buildings, and to assess the impact of the COVID-19 pandemic on their opinions, as well as to compare the research on occupant health in buildings to professionals' opinions. To address these objectives, a mixed research methodology, including a thorough review of the literature ($N_L = 190$) and an online survey ($N_S = 274$), was utilized. In general, there is an increasing research interest in occupant health and a heightened interest in health-related projects, among professionals, following the COVID-19 pandemic. Specifically, among the nine different building attributes examined, indoor air quality was the most researched building attribute with a focus on occupant health and was also presumed to be the most important by the professionals. Professionals considered fatigue and musculoskeletal pain to be the most important physical well-being issues, and stress, anxiety, and depression to be the most important mental well-being issues that need to be the focus of design, construction, and operation of buildings to support and promote occupant health, while eye-related symptoms and loss of concentration were the most researched physical and mental well-being symptoms in the literature, respectively. Finally, professionals indicated that COVID-19 pandemic had significant effect on their perspectives regarding buildings' impact on occupant health and they believed future building design, construction and operation will focus more on occupant health because of the pandemic experience.

1. Introduction

The World Health Organization (WHO) defines health as *"a state of complete physical, mental and social well-being"* [1]. Physical well-being is defined as the ability of our bodies to function appropriately and resist illness [2]. The modern definition of mental well-being transcends the traditional definition of "absence of mental illness" and is better defined as an individual's ability to realize his or her abilities and be productive while coping with the daily stresses of life [3]. Social well-being refers to a person's level of social engagement and sense of belonging [4]. According to the WHO, the concept of health is affected by the economic, social and personal factors as well as the physical built environment [5]. As such, Samet and Spengler stated that indoor environments should be designed with the aim of enhancing the physiological, psychological, and sociological functioning of occupants [6]. The literature thoroughly explains how different Indoor Environmental Quality (IEQ) factors such as lighting, acoustic and thermal conditions, indoor air quality, ventilation, humidity, spatial organization, ergonomics, and aesthetics can trigger various physical, mental and social responses among occupants [7–11]. Despite clear evidence showing the effect of IEQ on health [12], to date, other building-related areas of research such as energy efficiency and occupant comfort have received more attention [13].

Beyond the cause-effect relationship, the study of IEQ's effect on occupant health is complex and multi-layered. To assess health, researchers mainly rely on two major assessment schemes: subjective assessments through surveys [14] or interviews [15] and objective assessments through physiological measurements using sensors [16] or psychometric tests [17]. Other methods have also been employed in this area, such as conducting medical tests and examining sick leave reports [18,19], but these methods are less popular. Occupant health in

* Corresponding author.
E-mail address: becerik@usc.edu (B. Becerik-Gerber).

https://doi.org/10.1016/j.buildenv.2021.108440
Received 27 May 2021; Received in revised form 17 September 2021; Accepted 10 October 2021
Available online 16 October 2021

buildings depends on the type of building under study. For example, residential cooking is considered one of the most substantial sources of indoor air pollutants in households, exposing occupants to fine air particles that can lead to respiratory problems [20]. In office spaces, the goal remains to establish a more comfortable, productive, and healthier work environment for office workers who spend most of their time sitting. This makes the study of ergonomics and its effect on musculoskeletal disorders one of the most important topics in the context of healthy office spaces [21]. Additionally, in offices as well as in educational buildings, researchers have examined the relation between IEQ and fatigue, tiredness, headaches, attention and focus, to address student learning and worker productivity [22,23].

The objective of creating healthy buildings spans over the different lifecycle phases of a building: design, construction, and operation. For example, in the early design phases, building designers should consider the building orientation (whenever possible) to maximize access to daylight [24], create an interior design that reduces noise transmission [25] (especially in offices), consider natural ventilation when possible, and so on. Similarly, in the construction phase, contractors should avoid using materials with chemicals that can leach into the indoor environment and flush the building before occupancy to eliminate indoor air pollutants from newly installed systems [26]. During the operational phase, building owners and facility managers should commit to an occupant-centered approach that prioritizes health. Facility managers should continuously monitor the indoor air quality, thermal, acoustic, and luminous conditions and solicit occupant feedback since they are the end-users [27]. Given the stakes and the different stakeholders involved in creating healthy buildings, it is necessary to engage both building researchers and building practitioners and to understand their perspectives about the challenges to the healthy building movement [28].

In fact, many of the health problems related to a building can be avoided if building practitioners (e.g., designers, engineers, constructors, facility managers, etc.) establish occupant health as a functional objective in the design, construction, and operation of buildings [12]. The fact that numerous recently published studies show the negative impact of indoor environments on occupant health proves that the actual implementation of the concepts arising from research is limited. Clearly, research alone is not enough; research-to-practice is key for healthy buildings. This requires cultivating interest and awareness of this concept among building practitioners. Therefore, there is a need to understand and investigate the opinions of professionals *(here thereafter the word professionals refer to both researchers and practitioners)* about healthy buildings and compare their viewpoint to the state-of-the-art in this area. Given the interdisciplinary nature of the topic, these professionals should not be restricted to the building industry; health professionals also must be consulted to incorporate their knowledge about human health during the design, construction, and operation of a building. Similarly, data/computer scientists must be consulted to understand the data-related challenges for delivering buildings that support and promote occupant health.

Recently, the world witnessed the spread of the novel SARS-CoV-2 virus, which paralyzed all aspects of life and forced people to spend even longer periods of time indoors. This channeled much needed attention on the quality of indoor life and its consequences on occupant health. The COVID-19 pandemic is likely to precipitate a revolution in our thinking towards the design, construction, and operation of buildings and building professionals will play a vital role. The concept of healthy building is expected to drive the construction industry, facility management operations and academic research [29]. Lessons learned from this pandemic and concerns about future epidemics may encourage building professionals to rethink the spatial organization, human-building interactions, and human-human encounters within buildings. Additionally, because of the airborne nature of most viruses, researchers and practitioners likely will be thinking more carefully about indoor air quality and the proper operation of the Heating, Ventilation, and Air Conditioning (HVAC) systems including smart ventilation control and better humidity control. For what it's worth, the COVID-19 pandemic has laid the groundwork for a more holistic approach towards health in buildings, incorporating both research and practice [29].

In sum, if the impact of buildings on occupant health is not well understood and the benefits of healthy buildings are not clearly enumerated then integration of health objectives into the design, construction, and operation of healthy buildings is not formalized. Health objectives are therefore not widely adopted by building practitioners. The objectives of this study thus are to: (1) compare the literature related to occupant health assessment in buildings to professional opinions, (2) determine building professionals' experience, level of awareness, and interest regarding health in buildings, and (3) assess how the COVID-19 pandemic may have changed professionals' opinions. Section 2 outlines our research approach and methodology to address the above-mentioned objectives. Section 3 presents the results and a thorough discussion of our findings. Finally, Section 4 summarizes the conclusions.

2. Research approach and methodology

The following literature review focused on understanding the research to date on health in buildings. In addition, an online survey was administered to assess professionals' opinions, including changes in those opinions due to the pandemic. This study was approved as exempt research by the Institutional Review Board of the University of Southern California (UP-20-00246 IRB study number).

2.1. Literature review

Web of Science and PubMed databases were used to search for relevant articles published in peer-reviewed journals, conference proceedings, and books. In the initial screening phase, we focused on the title and abstract of every article and identified those that are relevant to the scope of this study. The search was based on keywords (TS = Topic) using "TS = (occupant*) AND TS = (building OR indoor OR built environment) AND TS = (health* OR wellbeing OR well-being)". This included all articles published in English with no time restriction. Since some entries of the search were phrases (e.g., well-being), even if only one word of this phrase (e.g., well or being) appeared in the title, abstract, or keywords of an article, that article was included in the results. The total number of articles screened after this search was 2575.

Next, we screened the studies that investigated the effects of buildings on health of occupants. After that, a full-paper screening was completed to decide whether a paper should be included in the study or not. Inclusion and exclusion criteria were predefined to create a more systematic procedure for the selection of research studies. Table 1 presents these criteria. The final number of studies included for analysis was 190 (184 journal papers and 6 conference papers) after the criteria were implemented.

Table 1
Inclusion and exclusion criteria used for paper selection.

Inclusion Criteria	Exclusion Criteria
Buildings such as office, educational, residential, hospital, retail, etc.	Outdoor built environment such as parks
Empirical studies	Review papers, theoretical studies, position papers
Independent variables are related to the buildings' physical attributes and are clearly stated and assessed	Independent variables are not related to the buildings' physical attributes (e.g., occupants demographics, occupant behavior, technological intervention)
Dependent variables are health effects of buildings (sick building syndrome, depression, anxiety, etc.) and are clearly stated and assessed	Dependent variables are not strictly related to health (productivity, performance, learning efficiency)

We developed a standardized form to systematically collect specific information from each paper. This form included the following fields (also see the **Appendix**): (1) identification information (title, authors, year of publication, type of article), (2) type of study (observational, intervention, laboratory studies), (3) physical attributes of the indoor environment (temperature, humidity, lighting, indoor air quality, ventilation, acoustics, spatial organization, ergonomics, biophilic design and aesthetics), (4) health area (physical, mental or social well-being) and more specifically the health issue under study (physical well-being: eye-, nose-, throat-, skin-, musculoskeletal-related symptoms, headache, nausea and fatigue; mental well-being: depression, mood, stress, anxiety, attention, concentration and attention), (5) methods for health assessment (surveys, interviews, sick leave reports, physiological/psychometric measurements, medical tests, complaints), and (6) type of building under study (office, educational, residential, hospital/health care centers, industrial, commercial (retail stores, malls)). Table 2 presents the distribution of the studies and the journals they are published. Due to space concerns, only the journals that had three or more studies are presented.

We identified three main research methodologies employed in the final list of articles: (1) observational studies in which researchers investigate the impact of buildings on health without an intervention (n = 135); (2) intervention studies in which researchers examine the effects of specific building parameter(s) on occupants health in buildings through exposure (n = 18) and (3) laboratory studies in which researchers study the effects of specific building parameter(s) on occupant health but in a controlled environment (n = 37). The distribution over the years is presented in Fig. 1. Research related to the effect of building indoor spaces on occupant health appears to be growing with more than 44% of the papers on this topic published in the last six years alone.

2.2. Online survey

An online survey was designed and administered to target a wide range of practitioners and researchers to determine their experience, level of awareness, and interest regarding health in buildings. The second objective of this survey was to understand how a global health crisis (the COVID-19 pandemic) impacted professional opinions regarding occupant health in buildings.

The survey was accessible through Qualtrics Panel Services between 15 May 2020 and 10 August 2020 (about 12 weeks). The distribution of the survey was directed to building professionals as well as others in relevant fields (computer science, medicine, public health). The survey was distributed through social media outlets (LinkedIn, etc.) and online networks of professional organizations, including the American Society of Civil Engineers (ASCE) Architectural Engineering Institute (AEI), ASCE Construction Institute (CI), ASCE Computing Division, Health in Buildings Roundtable (HiBR), Campus FM Technology Association (CFTA), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Technical Committees (TC) and local chapters. No personalized or direct emails were sent. In total, 284 responses were received, and 274 responses were included in the analysis, following a survey completeness assessment. However, it is worth mentioning that not all respondents answered all the survey questions thus, the number of answers for each question differ, as noted in the Results & Discussion Section.

Table 2
Collected studies distribution over the journals.

Journal Name	Most Recent Impact Factor	Number of studies
Building and Environment	4.971	23
Indoor Air	4.739	19
Journal of Environmental Psychology	3.301	9
Indoor and Built Environment	1.900	8
International Journal of Environmental Research and Public Health	2.849	8
Building Research &Information	5.202	7
Occupational and Environmental Medicine	3.824	6
Scandinavian Journal of Work, Environment & Health	4.127	4
Science of the Total Environment	6.551	4
Energy and Buildings	4.867	3
Environment and Behavior	5.141	3
International Archives of Occupational and Environmental Health	1.935	3
Journal of Work	1.132	3
Other	–	90

The online survey comprised of three areas corresponding to the research questions of this study with a total of 21 questions and an open comment question on health in buildings. The answers were multiple-choice, which were developed based on the literature in that area. The multiple-choice questions had no restrictions on the number of answers; a respondent could select more than one answer.

Questions related to professionals' opinion regarding health assessment in buildings:

- The most important general health categories to consider when examining occupant health in buildings (i.e., physical well-being, mental well-being, or social well-being).
- The most important physical and mental well-being issues that need to be the focus of research, design, construction, and operation of buildings to support and promote occupant health.
- The most important building attributes that need to be the focus of research, design, construction, and operation of buildings that support and promote occupant health.
- The most important method(s) to study and measure occupant health in buildings.

Questions related to professionals' level of awareness, experience, and interest regarding health in buildings:

- To what extent respondents think building professionals incorporate occupant health as an objective.
- Whether respondents believe they have an impact on the health of building occupants through the decisions they make professionally.
- Whether respondents worked on a project that aims to improve occupant health in buildings and if they did, what type of building they worked on.
- The different ways to enhance the design and operation of buildings that promote occupant health.
- General challenges facing the design and operation of buildings that promote occupant health.
- Data-related challenges for achieving design and operation of buildings that support and promote occupant health.
- Opportunities and research questions that need to be addressed in buildings to support and promote occupant health.

Questions regarding the effect of the recent COVID-19 pandemic on professionals' opinions regarding health in buildings:

- How much the recent pandemic affected perspectives on the impact of buildings on occupant health.
- Whether future building design, construction and operation will focus more on health and well-being with the experience of the pandemic.
- If respondents or their organization had any plans to focus on occupant health in buildings in the future.
- In the light of COVID-19 pandemic, what building attributes will be the most affected in the future.

Respondents were primarily from the building industry (51.00%); 29.23% from academia and 19.77% of the respondents indicated that they consider themselves to be from both academia and industry. A

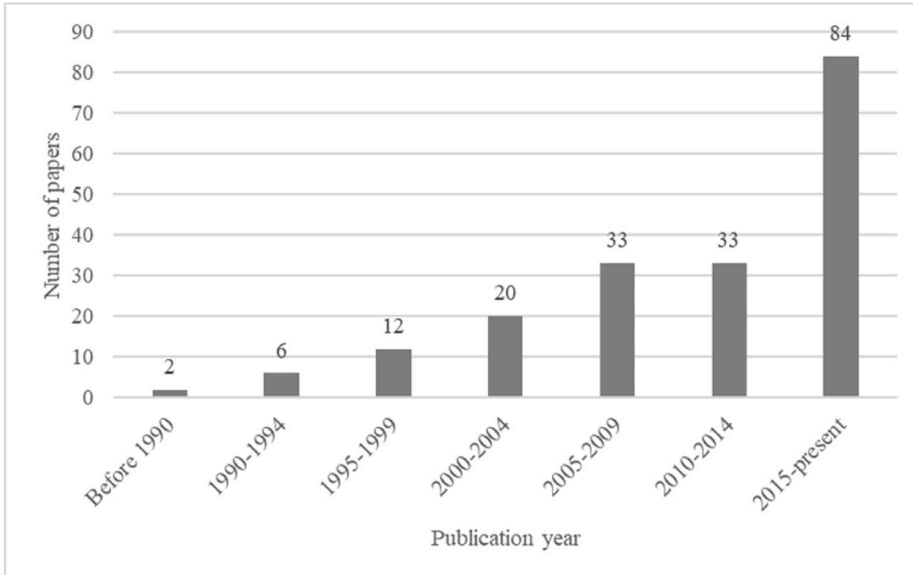

Fig. 1. Publication years of papers included in this study.

further distribution of the respondents by occupation shows that 26.75% of the respondents were engineers, 24.72% were facility managers, 16.71% were architects, 9.09% were building scientists, 5.63% were data or computer scientists, 4.03% were building service providers, 3.46% were doctors or public health workers, 8.79% were grouped under others which included social scientists, real estate developers, policymakers, building owners, interior design. The remaining 0.82% preferred not to answer this question.

3. Results and discussion

As stated in Section 1, we have three objectives: (1) to compare the literature related to occupant health assessment in buildings to professional opinions, (2) to determine building professional experience, level of awareness, and interest regarding health in buildings, and (3) to assess the impact of COVID-19 pandemic on their opinions. First, a comparative analysis was performed between the literature and professional opinions regarding the physical attributes of the indoor environment, general and specific health issues, methods of assessment, and type of buildings to address objective 1. Then, further analysis of the survey was completed for determining the building professional experience, level of awareness, and interest regarding health in buildings to address objective 2 and for assessing the impact on COVID-19 pandemic on building professional opinions to address objective 3.

3.1. Assessment of occupant health in buildings: research efforts vs. professionals' opinions

To understand what aspects of health are most important in buildings from the professionals' perspective, we asked respondents which general health categories to consider when examining occupant health in buildings. Three options were provided based on the definition of health by the WHO [1]: physical, mental and, social well-being. To compare the literature in this field and the opinions of professionals, a similar classification of the papers collected ($N_L = 190$) through the literature review. The results, presented in Fig. 2, show that the respondents of the survey ($N_S = 270$) have given approximately equal importance to all three aspects of health (29.25%–35.93%). This demonstrates that

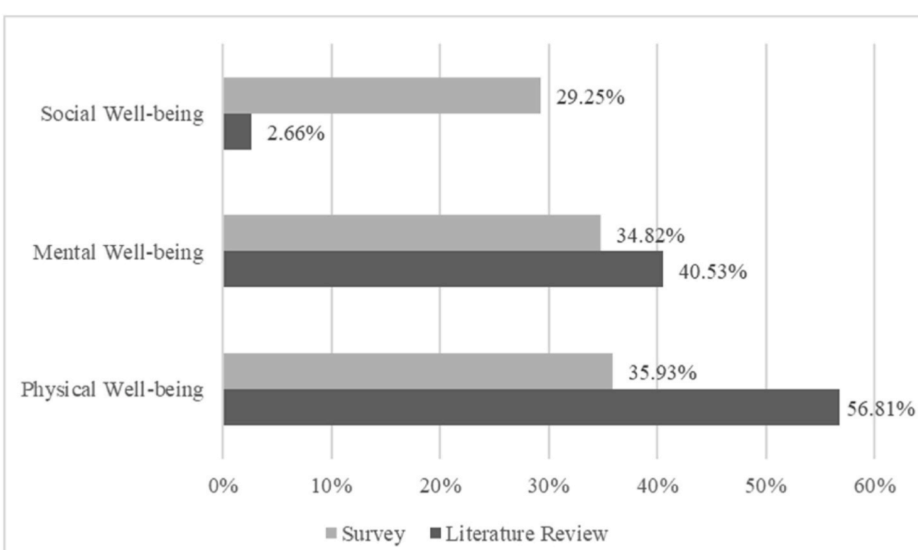

Fig. 2. Three aspects of health that are the most important in buildings based on survey and literature review results.

professionals believe that all three pillars of health (physical, mental and, social well-being) should be given equal importance and points towards professional interest in a more holistic approach to address healthy buildings. To further support our claim, a chi-square goodness of fit was conducted to test for any statistical differences between the three proportions. The results suggest that there is no significant difference between the proportion of professionals who consider physical, mental, or social well-being important ($\chi2 = 5.79$, df = 2 and $p = 0.06$). On the other hand, the published research has focused mainly on the physical well-being of occupants (56.81%), followed by mental well-being (40.53%), while only 2.66% of the studies investigated the social well-being aspect. The chi-square goodness of fit results ($\chi2 = 88.179$, df = 2 and $p < 0.001$) show that there is a significant difference between the proportion of papers which studied the physical, mental, or social well-being.

The disparity between the survey (29.25%) and literature review (2.66%) results in terms of social well-being is significantly noticeable. The results from the literature support the conclusion that although building professionals consider social well-being to be an important aspect of health in buildings, it is challenging to conduct research in this area. In comparison to physical and psychological well-being, both of which have been extensively measured quantitatively using physiological and psychometric measures, social well-being has not been investigated equally [30]. Furthermore, our literature review has focused on buildings as indoor spaces and not the built environment which could include neighborhood parks and green spaces. The built environment is often associated with enhanced social functioning and cohesion by improving the level of social interaction, trust, and reciprocity among the urban residents with access to such places [31]. Thus, future research should investigate the social well-being aspect from the built environment angle. To that end, Hillier suggested that building professionals should adapt to a "society first" approach where social interactions among humans are at the core of the built environment design [32]. Thus, Hillier urged the need for a collaborative effort between social and building scientists to study the impact of the built environment on social outcomes.

Additionally, given the limited number of research studies investigating social well-being returned by our review, and the ease of conducting research related to physical well-being, the results show a skewness with 56.81% of the studies in our literature review focusing on physical well-being. Considering the equal importance allocated by building professionals to all three aspects of health (~33%), the notable deviation in terms of physical well-being between the literature and survey results can be explained.

We found there is an agreement between the literature and professionals' opinions about the importance of three building attributes: indoor air quality, thermal conditions, and lighting. Respondents were asked about the most important building attributes, that should be the focus of the research, design, construction, and operation of buildings, to promote occupant health. The results presented in Fig. 3 ($N_S = 232$) show that ventilation (15.76%) and indoor air quality (15.41%) are the most important building attributes. This percentage distribution is expected; the survey was distributed following the spread of a highly infectious airborne virus; moreover, research on indoor air quality and ventilation over the last two decades has been fairly robust. Lighting and daylighting (12.37%) and thermal conditions (11.58%) were also of high interest to professionals. Numerous guidelines are established and widely adopted by practitioners that focus on the air quality and ventilation (ASHRAE standards 62.1 and 62.2 [33]) lighting (CEN 15251 [34], ASHRAE standard 90.1 [35]), and thermal conditions (ASHRAE standard 55 [36], International Standard ISO 7730 [37]) in buildings. Professionals may be more aware of the importance of these building parameters and their effect on occupant health in comparison to other attributes. The results from the literature ($N_L = 190$) indicate that indoor air quality (24.88%) is the most researched topic. From a research point of view, the topic of indoor air quality is the most diversified; pollutants such as volatile organic compounds, carbon monoxide, nitrogen dioxide, radon, particulates, etc., are harmful in the indoor environment. Investigating the health-related consequences of exposure to these various pollutants has and continues to garner considerable research effort. Thermal conditions (16.38%) and lighting and daylighting (15.53%) are also considered important research areas. It is noteworthy that while the literature has focused on the effect of the thermal environment on health more than that of ventilation, the recent COVID-19 pandemic might have a significant effect on future research directions, driving attention to ventilation and indoor air quality. At the same time, while neither the survey results nor the literature review results show an emphasis on topics like ergonomics and biophilia, as can be seen in the following paragraphs, both musculoskeletal pain (Fig. 4) and stress, depression, and anxiety (Fig. 5) were found to be important health issues, which could be alleviated by more focus on design and research efforts in these areas.

Sick building syndrome and the physical well-being consequences of buildings have been the focus of healthy building-related research.

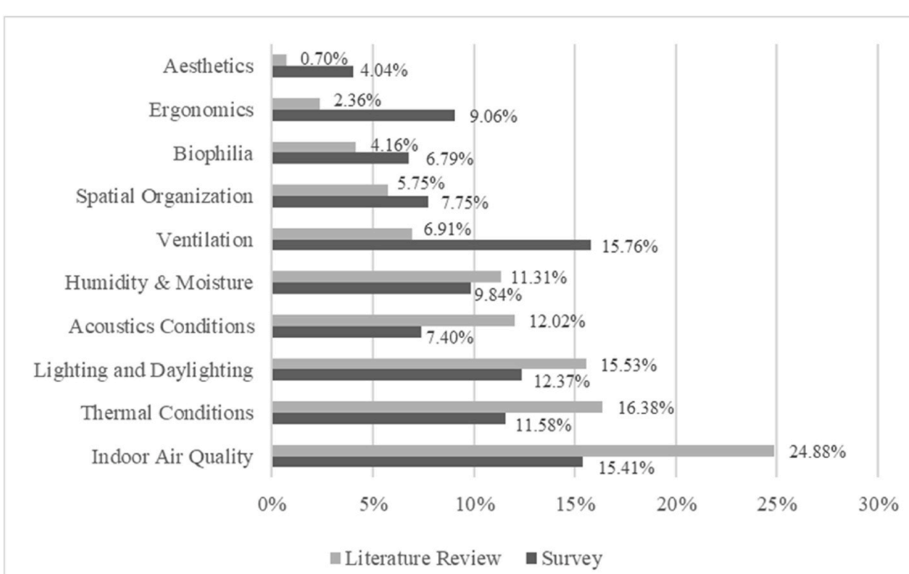

Fig. 3. Most important building attributes based on survey and literature review results.

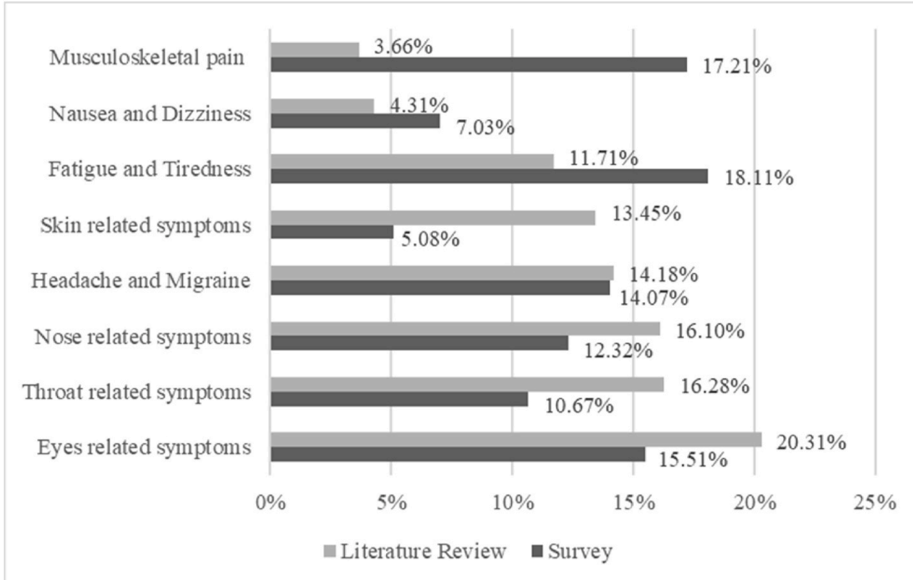

Fig. 4. Physical well-being symptoms based on survey and literature review results.

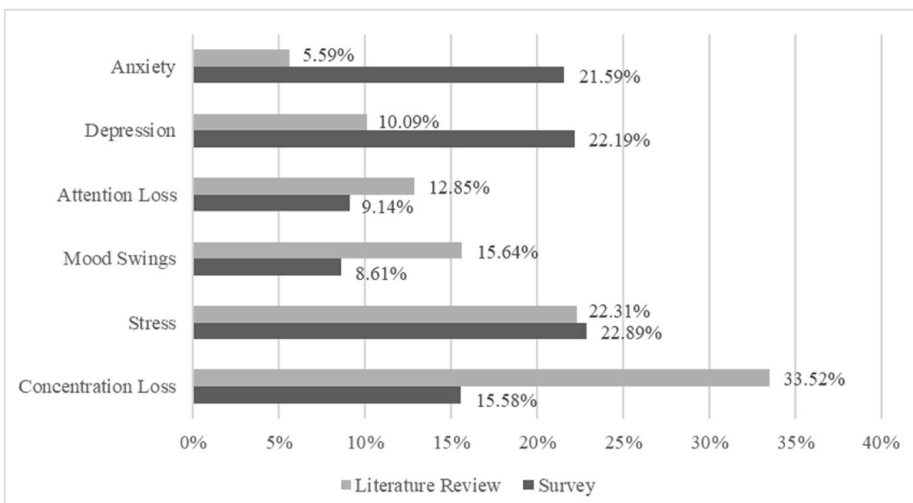

Fig. 5. Mental well-being problems based on survey and literature review results.

Therefore, we asked respondents about their opinion regarding the most important physical well-being symptoms for research, design, construction, and operation of buildings to support occupant health. The results are presented in Fig. 4. Respondents ($N_S = 263$) indicated that fatigue and tiredness (18.11%) and musculoskeletal disorders-related symptoms (17.21%) are the most important physical well-being issues, while skin-related symptoms (5.08%) are the least important. A reason behind this distribution might be that musculoskeletal disorders are a common problem in office environments. Furthermore, as previously mentioned, fatigue and tiredness are relatively easier to link to the indoor environmental conditions ranging from insufficient illumination to high noise levels to poor indoor air quality. Therefore, professionals might have selected the most important symptoms based on their personal experience during work hours and choosing the health issues that are detrimental to their productivity and performance. Given that the survey follows a worldwide shift towards working from home forcing workers from all professions to work at desks from their homes. On the other hand, the literature ($N_L = 165$) shows that eye-related (20.31%) and throat-related (16.28%) symptoms were among the most studied physical well-being symptoms, followed by nose-related and skin-related symptoms, headache, migraine, fatigue, and tiredness (ranging from 16.10% to 11.71%). Typically, researchers refer to the short-term physical well-being issues caused by degraded IEQ in buildings as sick building syndrome. The U.S. Environmental Protection Agency (EPA) defines sick building syndrome as the situation in which buildings' occupants are affected by acute health issues caused by the time spent in a certain building [38]. These issues comprise of eye (red, watery), nose (runny, blocked, stuffy), throat (dry, itchy), and skin (dry, itchy) related symptoms, as well as fatigue, and headaches. As these issues are scientifically defined and well-established under the notion of sick building syndrome, researchers examine these symptoms collectively to determine how healthy a building is, which explains why these symptoms were specifically the most researched acute symptoms in the literature. Surprisingly, musculoskeletal disorders were the least studied topic (3.66%). Looking back at Fig. 3, a reasonable explanation might be that the ergonomic attributes of buildings – which are directly linked to musculoskeletal disorders – were not researched as much as the other building attributes. This is due to the fact that this research area requires collaborative efforts between building scientists and occupational health professionals which limits the research about ergonomics settings in buildings and as such its musculoskeletal consequences on occupants [39]. Additionally, most engineering and built environment-related journals focus on the energy, thermal, acoustic, and visual performance as well as air quality in buildings which explains the lack of research related to ergonomics in the built environment. Yet, the discrepancy between the professionals' opinions about the prevalence of musculoskeletal pain and limited research focus in this area point to an important gap.

Throughout the COVID-19 stay-at-home mandates, the mental and psychological well-being of people has been given special interest, therefore, we asked respondents about the most important mental well-being problems for research, design, construction, and operation of buildings to support occupant health. Respondents ($N_S = 263$) indicated the top three concerns for the mental well-being to be stress (22.89%), depression (22.19%), and anxiety (21.59%). These mental well-being problems are the most common issues; millions of people suffer from these problems around the world [40], which indicates the significant impact of building professionals' understanding of these issues, as well as buildings' attributes, on preventing and mitigating them. Due to the stay-at-home mandates, lack of social connections, financial instabilities, and personal health concerns, depression, stress, and anxiety levels have increased in the overall population across the globe [41]. This might have changed professionals' opinions about the importance of these problems in built environments. On the other hand, the literature ($N_L = 108$) show that concentration loss (33.52%) and stress (22.31%) were the most studied by researchers. Fig. 5 presents the findings. Concentration loss can be examined using standardized psychometric tests such as the Stroop test [42], while stress can be studied through the analysis of physiological metrics (heart rate, skin conductance) [43]. Also, concentration loss and stress are considered a part of the sick building syndrome and are found in most of the related surveys. Such standard methods make these mental well-being related problems easier to study and explain the discrepancy between them and the rest of the studied mental well-being problems. In addition, if depression, mood, and anxiety are to be studied, collaboration efforts between building scientists and health professionals would be necessary, thus maybe limiting the number of research studies. Nevertheless, following the professionals' opinions and global health trends, more research is needed in these areas.

Questionnaires and self-assessment have been widely adopted to study the level of comfort with the physical parameters of the built environment (thermal, visual, acoustical comfort) [44]. Therefore, we examined whether similar conclusions can be made to the assessment methods used by practitioners and researchers in the area of healthy buildings. We asked respondents about their opinions regarding the most important methods for studying and measuring occupant health in buildings. The responses ($N_S = 231$) – shown in Fig. 6 – suggest that questionnaires (23.19%) are the most important method, followed by occupant complaints (20.05%) and interviews (19.18%). One common trait for these three methods is that their combination creates a holistic post-occupancy evaluation method that relies on occupant assessments and judgments of the indoor environment. This kind of assessment scheme has been widely adopted in the industry and especially by facility managers to monitor building operations. The fact that professionals were enthusiastic about the use of physiological/psychometric measurements (18.76%) is promising. However, embracing the method in practice is difficult as it requires the continuous collection of personal data such as heart rate, respiration, skin conductance, gaze, etc. Leading to privacy concerns among building occupants. Furthermore, the effective collection of this data requires coordination with data scientists, the establishment of comprehensive data collection and analysis, and the availability of data storage. The results from the literature ($N_L = 190$) show that most studies rely on subjective questionnaires to assess the health of occupants in buildings (76.01%). Such outcome is expected since subjective assessments are widely adopted by researchers to examine occupant satisfaction, comfort, and health in buildings. Physiological/psychometric measurements came in second place with only 12.19% of the examined studies using this method to study occupant health. One reason behind this discrepancy in comparison to the adoption of questionnaires is related to the type of the study. As mentioned earlier, most of the studies collected through our literature review were observational, which makes questionnaires more suitable, while utilizing physiological/psychometric measurements can be difficult due to cost and feasibility. In addition, research surveys are currently designed to allow a snapshot evaluation of buildings and their effect on occupant health. This makes them more favorable for both researchers and occupants, in comparison to the long-term continuous monitoring through physiological data and psychometric tests. An interesting outcome is that objective measures which are direct indicators of health status (e.g., medical tests, sick leave reports) are among the least important methods according to building professionals and are also not widely used in research studies, which

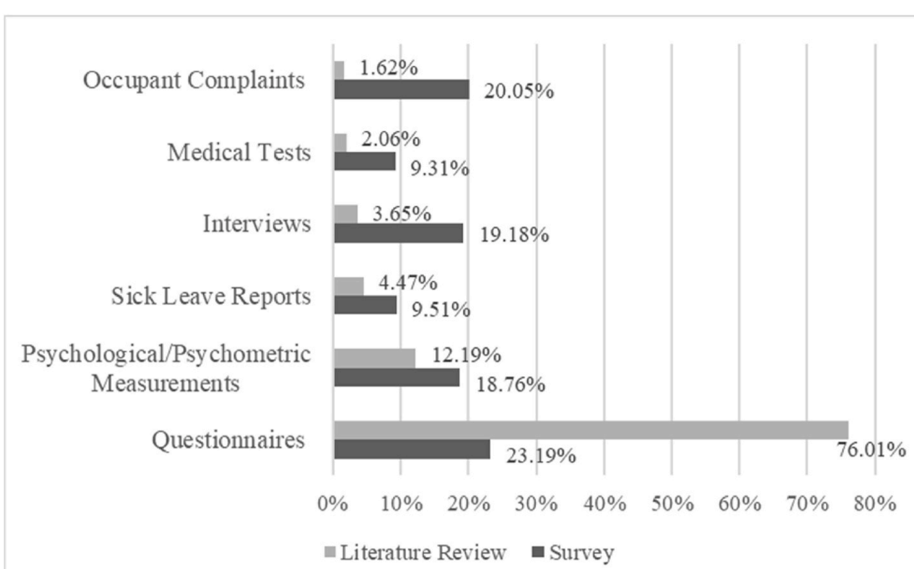

Fig. 6. Health assessment methods based on survey and literature review results.

could be related to the difficulty in accessing such data and privacy concerns. However, the difference between professionals' opinions of more balanced distribution of methods to be used versus the predominant use of questionnaires in research point out to the fact that we need to use a diverse set of research methods than just questionnaires to measure health in buildings.

3.2. Professionals' experience, level of awareness, and interest: opportunities & challenges related to healthy buildings

The survey also aimed at understanding how committed professionals are to the concept of healthy buildings, by examining their experience, level of awareness, and interest. It also aimed to identify the opportunities and challenges facing healthy buildings. We asked the respondents what type of building(s) (if any) they worked on with the objective of improving occupant health in buildings. The results (N_S = 169) show that office buildings (30.67%) were the building type that professionals had the most experience with regards to occupant health, followed by educational buildings (20.17%), residential buildings (17.21%), and hospitals and health care centers (15.98%). Professionals have less experience, on occupant health-related issues, with other building types such as commercial and industrial buildings. The literature (N_L = 173) results show that almost half of the studies about occupant health were conducted in office buildings (69.65%). Studies focusing on educational (11.94%), and residential (12.93%) buildings were less frequent, while the remaining studies were equally distributed over hospitals and health care centers, commercial, and industrial buildings. These results are presented in Fig. 7. One reason behind the importance given to office spaces in both research and practice can be explained through the significant financial return on investment associated with healthy office spaces. Office owners, companies and corporations are more aware of the financial benefits of healthy office spaces which range from lower absenteeism and presentism rates, higher productivity and reduced medical/pharmaceutical costs [29]. For the rest of the building types, health issues persist with degraded IEQ, but the associated financial costs are not as easily quantified. It is worth noting that studies conducted in laboratory settings were excluded from the analysis of the literature, as they do not represent a specific building type. Yet, the results show that more research is needed on different building types and their impact on occupant health.

Respondents were asked about the extent they think building professionals incorporate occupant health as an objective. Answers were provided using a 5-point Likert scale ranging between "Not at all" and "To a great extent." 11.30% of the respondents answered as "To a great extent," 16.32% answered "A lot," 38.08% answered "Somewhat," 28.45% answered "Very little," and 5.86% answered "Not at all" (N_S = 239). This is promising as the majority of the professionals think that health is incorporated as an objective. Fig. 8 presents these results.

We then asked the respondents whether they believe they have an impact on occupant health through the decisions they make professionally. Respondents were provided with 4 answers: "No," "Yes," "I don't know," "Maybe." The results show that (N_S = 272), many professionals (44.49%) believe that they can influence occupant health through their profession and only 4.78% admitted that they do not have an impact, while the rest answered either as "I don't know" (11.40%) or "Maybe" (39.34%). These results show that more effort should be invested in training, educating, teaching, and inspiring current and future building professionals about the topic of healthy buildings and what influence they have through their professions.

Respondents were asked about the best way to enhance the design of healthy buildings. The results (N_S = 227) show that professionals believe that collaboration between building practitioners, health professionals, and data scientists (39.81%) is necessary. They also advocate for the establishment of building design guidelines as a standard for the design of healthy buildings (40.89%). Yet only 19.30% believe that design professionals should acquire a professional certification for healthy building design. Fig. 9 presents these answers. The results suggest that to achieve effective healthy building design, there is a need to explore the possibilities for networking and collaboration between the different disciplines. Such collaborations can also further streamline common definitions, metrics, and measurement schemes for health in the context of buildings. It will go a long way towards building consensus between building practitioners, health professionals, and data scientists and to establishing building standards in the industry (i.e., WELL [45] and FitWel [46]). In addition, many professionals commented that design companies should administer healthy building design courses and webinars for their engineers and architects.

Similarly, the respondents were asked about the best ways to enhance the operation of healthy buildings (Fig. 10). The results (N_S = 220) show that professionals believed that the establishment of building guidelines to help facility managers monitor occupant health (41.10%) is the most important way to enhance the operation of healthy buildings. Once facility managers can monitor occupant health, they can make adjustments to the system operations that will mitigate adverse health outcomes. Additionally, 33.20% believed that facility managers should operate buildings with occupant health as a primary goal; this option

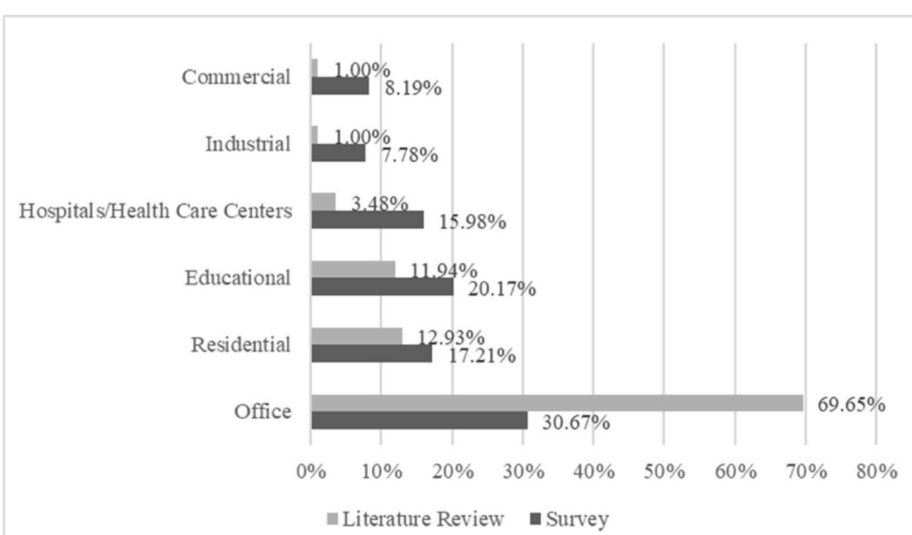

Fig. 7. Buildings' type distribution based on survey and literature review results.

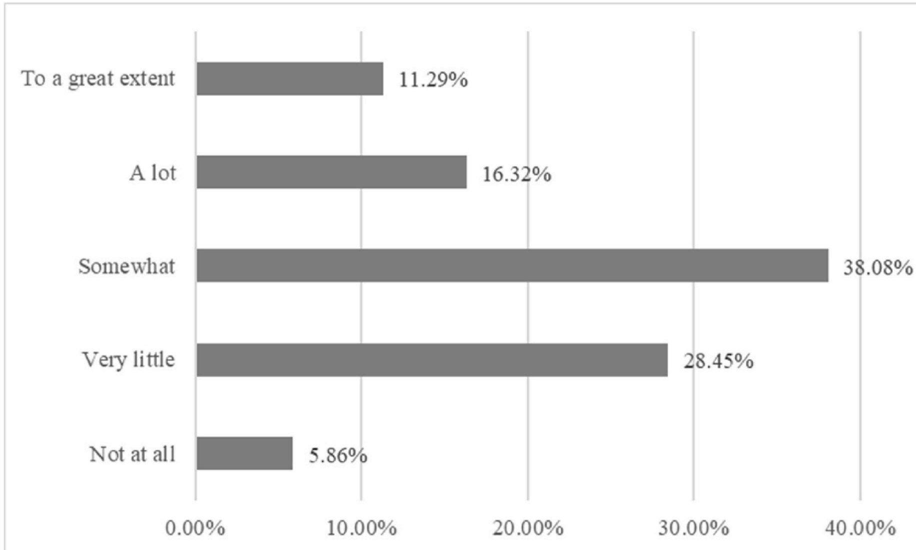

Fig. 8. Professionals' answers to the extent they incorporate occupant health as an objective for buildings design.

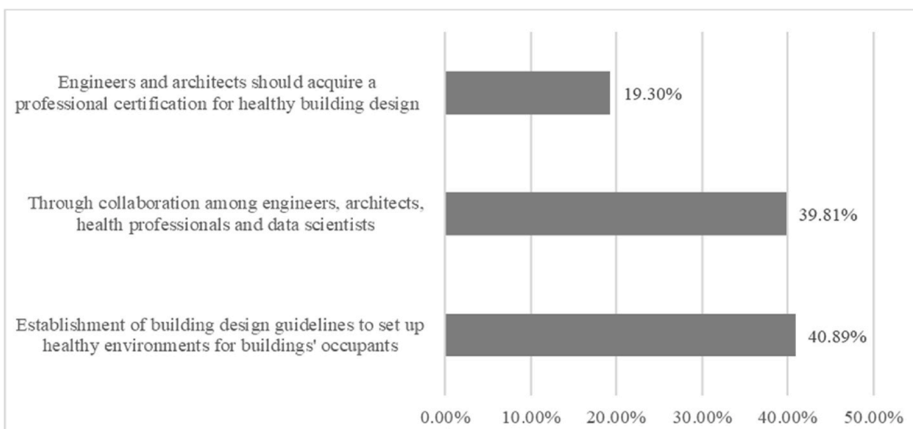

Fig. 9. Professionals' opinions about the best way to enhance the design of healthy buildings.

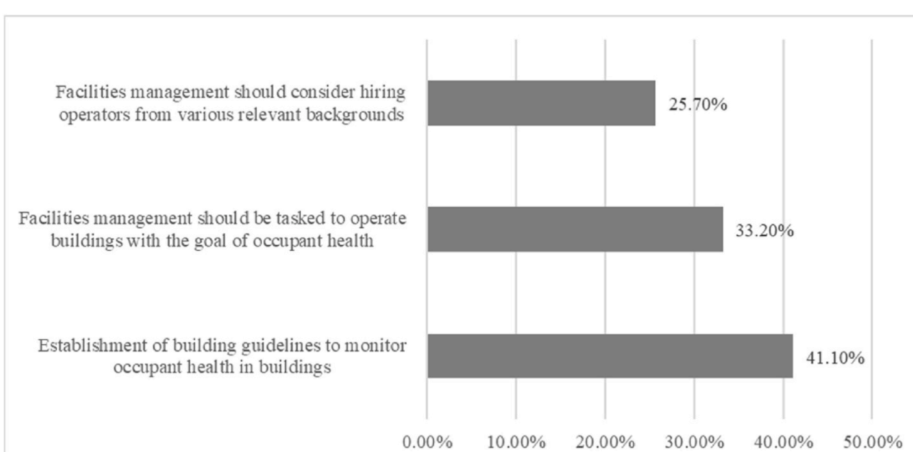

Fig. 10. Professionals' opinions about the best ways to enhance the operation of healthy buildings.

points to the importance of having occupant-centric building operation modules. Concerns about the effect of this approach on energy consumption and sustainability might arise; however, previous research studies have shown the tremendous co-benefits at the nexus of energy, sustainability, and health [47]. The remaining 25.70% thought hiring facility managers from relevant backgrounds is the best way to enhance the operation of healthy buildings. In the comments following this question, many professionals pointed out that facility managers can only operate with the final product (building) they are given; if a building has not been originally designed to promote occupant health, a facility manager's influence is limited.

Following the recommendations about the best ways to achieve healthy buildings, we asked the respondents about the challenges in the design and operation of buildings that promote occupant health (Fig. 11). The results ($N_S = 226$) show that the lack of understanding about the effects of buildings attributes on occupant health (23.66%) is a major challenge. Many respondents commented that to overcome this challenge, design and facility management companies must educate their staff about healthy buildings. Furthermore, universities play a vital role in raising awareness among future building professionals about the importance of this topic. An integrated curriculum that connects different fields of study (engineering, health, and data science) and focuses on streamlining the definition of health, as well as the means to promote occupant health, is needed. Lack of effective collaboration between the different project stakeholders was a major concern for professionals (17.17%), along with the lack of interest from employers and building owners (16.71%). Every new movement, in its early stages, faces similar problems because of the scarcity of real-world cases, which makes collaboration among stakeholders challenging, and owners reluctant to invest in untested solutions. Professionals found a lack of proof of positive return on investment (16.70%) and undefined fee structures for additional scope (11.65%) as significant financial challenges for the design and operation of healthy buildings. Quantification of return on investments for healthy buildings is not common or easy [48]; however, economic, and financial benefits from healthy buildings can be divided into 4 categories: (1) reduced costs due to health savings, (2) reduced operation costs as a result of efficient building systems, (3) increased rent and sale margins and (4) increased productivity levels of workers (commercial buildings) [29]. Moreover, professionals thought that the trade-off between energy consumption and maintaining a healthy indoor environment (14.11%) is a challenge; this is interesting as these two objectives do not need to be competing and more quantitative research in this area can prove these two objectives can co-exist and change professional opinions [47].

In this direction, we asked the professionals about the data-related challenges for achieving the design and operation of buildings that support and promote occupant health. The answers distribution is presented in Fig. 12. The results ($N_S = 226$) suggest that professionals believe that reluctance to share personal data (14.49%) is the most significant challenge, which is expected given the privacy issues. With the rise of smart buildings and the unprecedented integration of technologies into building operations, occupants are more aware of technology privacy breaches presenting a barrier for data collection. However, major research efforts are being established to ensure the security of the collected data by implementing innovative data collection and storage privacy design principles and protocols [49]. Additionally, professionals expressed their concerns about the difficulty of defining quantitative metrics that characterize occupant health in buildings (14.25%). This challenge circles back to the necessity for an integrated approach that combines the knowledge of all related fields. It foregrounds the need for a systematic methodology to quantitatively assess occupant health and identifies what data should be collected. This explains why professionals perceived the lack of effective collaboration between project stakeholders (11.93%), ambiguity in the type of data that should be collected (11.81%), and difficulty of linking building-related data to occupant health (10.58%) as other major data-related challenges. Other challenges were related to the lack of comprehensive data collection (8.76%) and analysis (7.67%), lack of resources (7.42%), organizational culture (6.82%), and storage of large data (6.21%). Such problems can be solved by employing data consultants and seeking guidance from and establishing protocols in collaboration with data scientists.

To conclude this section of the survey, we gave the respondents the opportunity to express their thoughts about the opportunities and research questions that need to be addressed to support and promote occupant health. 66 respondents provided their opinions as comments. Professionals were interested in balancing well-being and sustainability throughout the building lifecycle, by highlighting potential conflicts and promoting research efforts that aim to address them. Others showed interest in creating an interdisciplinary network of experts from all related fields to streamline definitions, metrics, data collection and analysis methods and establishing comprehensive and quantitative measurements of the economic value of health. Some professionals pointed out that healthy building performance should not be solely considered during normal operations but also studied under extreme events to ensure robustness and resilience to buildings operations, thus securing and maintaining durable healthy conditions. Finally, some professionals expressed their interest in a healthy building movement that embraces equity and social justice; underrepresented minorities with disadvantaged socioeconomic statuses are likely to be living in unhealthy buildings, which develops disparities in health conditions based on income and race [50]. Thus, there is an urgent need to raise awareness about this topic. Such awareness may be achieved by listening to the affected populations, by pushing towards a political intervention, and by engaging experts to understand the means and methods necessary to promote and support social justice and healthy living conditions for everyone.

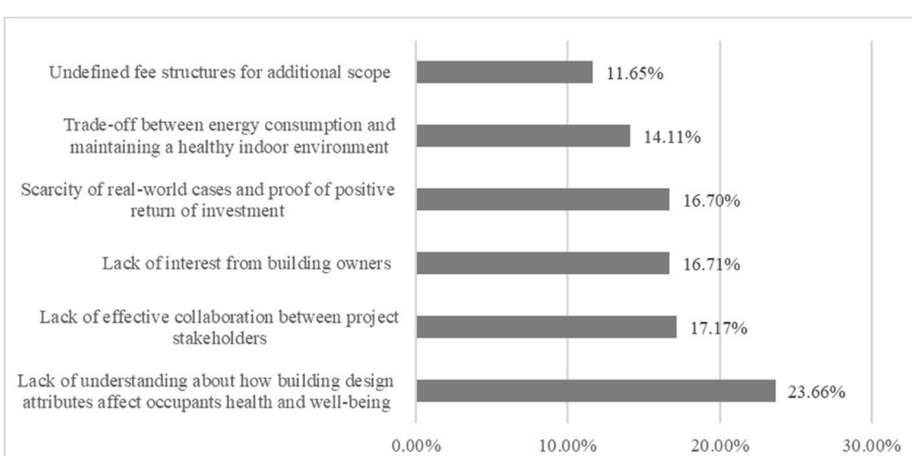

Fig. 11. Challenges in the design and operation of buildings to promote occupant health.

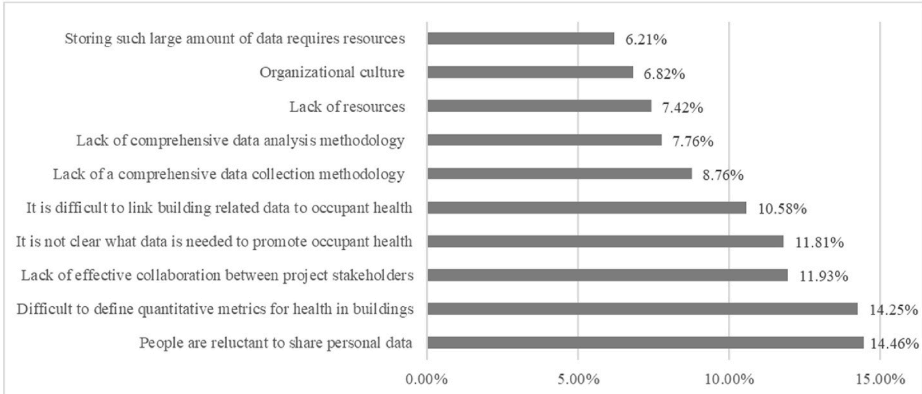

Fig. 12. Data-related challenges for achieving design and operation of healthy buildings.

3.3. Effects of COVID-19 pandemic on professionals' opinions regarding occupant health in buildings

The global COVID-19 pandemic raised public awareness of the important interrelationships between indoor environments and health. Healthy buildings have always been a necessity; however, during quarantine, when people spent extended time periods indoors, challenges surrounding buildings arose (e.g., adequate ventilation to limit virus transmission, optimal layouts to allow physical distancing.) This made people realize the critical importance of designing and operating buildings that can support and sustain occupant health and well-being. To that end, building facility managers and designers need to consider effective solutions to create healthier indoor environments. The recent pandemic will inevitably shape future design and operation guidelines [51], placing building professionals at the forefront of this movement. Therefore, the third objective of this paper completes our assessment of professional opinions with regard to healthy buildings through the lens of the recent pandemic.

We asked the respondents ($N_S = 274$) about the degree the recent pandemic affected their perspectives on the impact of buildings on occupant health. The results are presented in Fig. 13. Almost 75% of the responses showed a significant influence of the recent pandemic. This proves that the recent pandemic might create a revolution in the field of healthy buildings that researchers and practitioners from all related fields should benefit from to create a movement that will sustain even after the end of the pandemic. Of the remaining 25%, only 6.56% reported no change in their perspectives while the rest expressed a limited influence. A deeper analysis of those who answered that they do not expect any change revealed no common traits from the data collected. Needless to say, there needs to be more emphasis on designing, constructing and operating buildings with occupant health and well-being as an objective. Such initiatives necessitate continuous monitoring and development, codifying, and promoting for this movement, until building professionals endorse it [29]. The well-developed green building movement led by the USGBC could offer crucial insights to promote the healthy building movement among building professionals [52]. Resistance is inevitable, considering that nearly every new system, movement, or change in its early stages, faces similar problems because of the scarcity of real-world cases and lack of confidence in what is not evident yet [47]. However, this mentality will eventually evolve as abstract concepts are translated into concrete examples, and the benefits of the healthy buildings' movement become more tangible [47].

To emphasize the effect of the recent pandemic on healthy buildings, respondents were asked whether they believed future building design, construction and operation will focus more on occupant health as a result of the pandemic experience. The results ($N_S = 250$) indicate that most of the respondents (66.4%) believed so, while only 4.80% claimed that the pandemic will not have an effect and the remaining 28.8% were uncertain and responded "maybe." This suggests that the COVID-19 pandemic is a catalyst for the healthy building movement. It

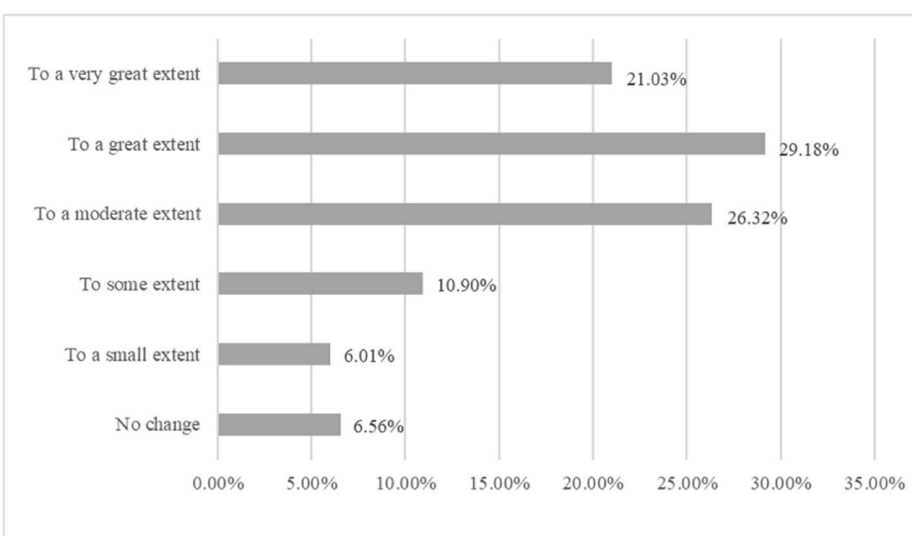

Fig. 13. The degree the recent pandemic affected professionals' perspective regarding buildings' impact on occupant health.

highlighted to building professionals that buildings were not well-equipped to counter an airborne virus or to sustain healthy conditions for occupants during the quarantine and/or stay-at-home period. The pandemic demonstrated that the integration of health considerations with the design, construction, and operation is not a luxury but rather an imperative necessity. These conclusions were further supported by the question of whether building professionals or their organization have any plans to focus on occupant health in buildings. The results (N_S = 212) show that a majority of 71.31% answered "yes," and only 28.69% responded with "no."

Finally, we asked the respondents about what building attributes will be most affected in the future, considering the pandemic. The multiple-choice answers provided in the survey to this question were based on a review of the literature to understand the most probable design changes that will occur following the pandemic. The results (N_S = 268) indicate that ventilation systems (21.22%) will be the center of attention; virus-laden droplets remain airborne for hours [53], which means that air replacement is necessary to combat and reduce infection within an indoor environment. Following the spread of COVID-19 indoors, it became clear that additional emphasis should be allocated to ventilation. Other solutions to control the airborne transmission of viruses can be through the adoption of less dense layouts (wider aisles for circulation, single offices instead of open-plan offices) (16.01%) and the use of operable windows (8.55%) when modernization of HVAC systems are not feasible. Aside from airborne transmission and infection, scientists warned that surface-touch contamination is another way for some viruses to spread among people [54]. Professionals' answers reflect the need for more touch-free systems such as automatic doors (17.21%), hands-free light switches and temperature controls (16.32%), antibacterial fabrics and finishes (12.14%), and voice-activated elevators (8.55%). A summary of these findings is presented in Fig. 14.

4. Limitations and future directions

While this study presents significant contributions to the field of healthy buildings, findings must be construed with certain limitations in mind. First, caution should be taken when generalizing the results of the questionnaire as almost two-thirds of our sample were engineers, architects, or facility managers, and the rest representing stakeholders with no direct building expertise. Also, this study could have benefited from asking the participants about their countries of work/residence, years of experience, and the number of healthy buildings related projects they worked on. As such, future research should aim for a better representation of all stakeholders and investigate the regional and expertise differences among building professionals' perspectives towards healthy buildings. In addition, the pandemic could have created a bias effect in some questions. According to professionals, ventilation and IAQ were the most important building attributes which could be attributed to the airborne nature of COVID-19. Similar reasoning could be applied to explain why stress, anxiety and depression were of higher importance to building professionals, given that such mental health symptoms were on the rise during the pandemic's stay-at-home mandates. To this end, future research directions should investigate the opinions of building professionals towards healthy buildings once the pandemic is over. In this case, academic publications could have lagged behind the current trends among professionals, and this could have driven the differences between our literature review and questionnaire results. Therefore, researchers in the field of healthy buildings should conduct a literature review covering the years following the pandemic and compare their results to the questionnaire results presented in our study.

5. Conclusions

This paper presented the results of our mixed-method analysis which aimed to investigate the topic of occupant health in buildings. A literature review was conducted to examine the literature and understand the status of research in this area, and an online survey targeting building professionals was administered to determine their level of awareness, experience, and interest regarding health in buildings and how the COVID-19 pandemic affected their opinions regarding this topic.

Results from this study show that research interest in the topic of healthy buildings is growing over the years, with almost half of the related studies published in the last six years. A comparison between the literature and professionals' opinions shows that professionals have given approximately equal importance to all three aspects of health (physical, mental, and social) while research has solely focused on the physical and mental well-being of occupants. Professionals indicated that fatigue and tiredness and musculoskeletal disorders-related symptoms are the most important physical well-being issues, while the literature has focused mainly on sick building syndrome symptoms: eye-, throat-, nose-, skin-related symptoms. For mental well-being effects of buildings, professionals indicated that stress, depression, and anxiety are the most important symptoms. On the other hand, the literature shows that mood swings and concentration loss were the most studied. Also, professionals' responses show that ventilation and indoor air quality are the most important building attributes. The results from the literature indicate that indoor air quality is the most researched topic followed by the thermal conditions and lighting and daylighting.

We asked respondents about their opinions regarding the most important methods for studying and measuring occupant health in buildings. Their responses suggest that questionnaires are the most important method, followed by occupant complaints and interviews, but

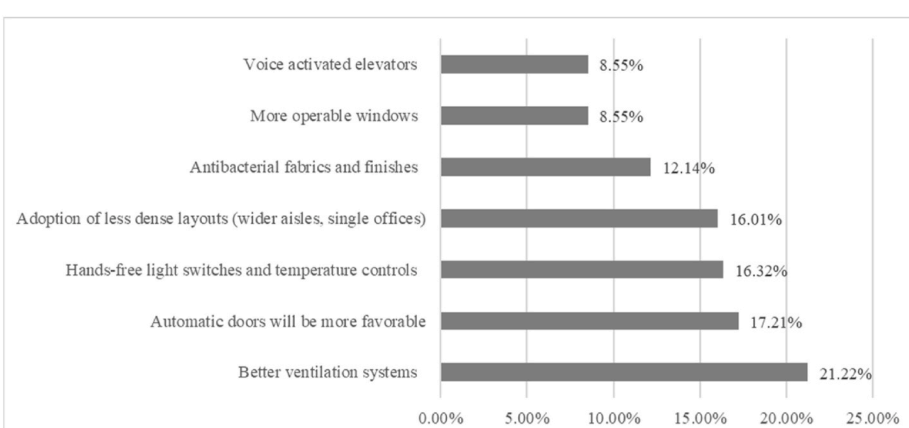

Fig. 14. Building attributes that will be most affected in the future considering the pandemic.

professionals favor a more balanced use of various methods. However, the analysis of the literature shows a major reliance on questionnaires to conduct research studies investigating occupant health in buildings. Upon asking them about what type of building(s) (if any) they worked on with the objective of improving occupant health, most of the respondents indicated that offices were the building type they had the most experience with. Assessment of the literature shows that almost half of the research studies also focus on occupant health in office buildings. There is a need to expand the research and practice-based efforts towards other types of buildings (e.g., educational, healthcare, etc.) that have a tremendous impact on occupant health.

The results of the survey show that professionals feel that they have a significant impact on occupant health through the decisions they make professionally. Also, they believed that building professionals should incorporate occupant health as an objective during the design, construction, and operation of buildings. However, respondents indicated that lack of understanding about the effect of building attributes on occupant health, the absence of an effective collaboration framework between the different stakeholders of a building were the major challenges facing the design and operation of buildings that promote occupant health. The suggested ways to enhance the design of healthy buildings are through the collaboration between building practitioners, health professionals, and data scientists as well as the establishment of design guidelines for healthy buildings. Similarly, they believe that the establishment of building guidelines to help facility managers monitor occupant health is crucial to enhance the operation of healthy buildings. When asked about the data-related challenges for achieving design and operation of buildings that support and promote occupant health, respondents pointed out that privacy concerns, reluctance to share data, and the difficulty in defining quantitative metrics that characterize occupant health in buildings were the most difficult data-related challenges.

The survey also examined the effects of the COVID-19 pandemic on professionals' opinions regarding health in buildings. Respondents indicated that the recent pandemic had a significant influence on their perspectives regarding the impact of buildings on health. They suggested that future building design, construction and operation will focus more on occupant health and predicted that they and their organizations will have plans to focus on occupant health in buildings. Finally, respondents believe that following this pandemic, professionals will more closely attend to ventilation systems to maintain high indoor quality and limit infection in indoor spaces. Additional design changes such as adopting less dense layouts, using hand-free systems (elevators, light switches, etc.), and installing antibacterial fabrics and finishes were found to be important.

Conclusions from this study provide a foundation for future research related to occupant health in buildings. Researchers should invest more in the study of social well-being, rely on quantitative measurements of health rather than focusing on the subjective assessment through surveys, widen their scope beyond sick building syndrome symptoms, and focus their studies on residential, educational buildings, and hospitals. Professional opinions were highly influenced by the recent COVID-19 pandemic which explains why they gave high importance to the indoor air quality and ventilation compared to other building attributes and suggested that healthy buildings should prevent depression, anxiety, and stress among occupants, as these mental symptoms have increased during the pandemic. The COVID-19 pandemic may well revolutionize the design, construction, and operation of healthy buildings with researchers and practitioners from all related fields playing a vital role in shaping this movement. Furthermore, future research directions should investigate the challenges facing healthy buildings, and professionals are advised to engage in discussions about the means to promote effective collaboration between building practitioners, health professionals, and data scientists. This effort should focus on developing a common vocabulary (definitions, metrics), data collection protocols, and analysis methods related to occupant health in buildings. Also, following the professional suggestions, researchers are advised to invest in examining the trade-off and synergies between energy efficiency, sustainability, and occupant health and to consider the effect of extreme events on occupant well-being. Also, professionals indicated the need for educational organizations to establish an integrated curriculum that connects different fields of study (engineering, health, and data science) to train, educate, teach, and inspire current and future building professionals about the topic of healthy buildings and what influence they have through their professions.

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.

Acknowledgements

This material is based upon the work supported by the National Science Foundation under Grants No. 1931226, 2009754, 1931238, 1856032, and 1931254. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.buildenv.2021.108440.

Appendix

Ref	Health Category	Mental well-being Investigated	Physical well-being Investigated	Health Assessment Methods	Building Attributes	Building Type
[55]	Mental	Mood	–	Survey, Physiological/ Psychometric measurements	Aesthetics	*
[56]	Mental	Mood	–	Survey	Biophilic design	*
[57]	Mental	Mood	–	Survey, Sick leave reports	Acoustics, Lighting, Thermal, Humidity, IAQ	Office
[58]	Mental, Physical	Stress	MSD, Nose, Throat	Survey, Sick leave reports	Biophilic design	Office
[59]	Mental	Mood	–	Survey	Thermal, Lighting	Office
[60]	Mental, Physical	Anxiety, Stress	MSD	Survey, Sick leave reports	Ergonomics	Office

(continued on next page)

(*continued*)

Ref	Health Category	Mental well-being Investigated	Physical well-being Investigated	Health Assessment Methods	Building Attributes	Building Type
[61]	Mental, Physical	Concentration	Eye, Fatigue, Headache, Throat, Skin, Nausea	Survey	Lighting, Spatial Organization	Office
[62]	Social	–	–	Survey	Biophilic design	*
[63]	Mental	Attention	–	Physiological/Psychometric measurements	Biophilic design	*
[64]	Mental	Stress	–	Survey	Lighting, Ventilation	Office
[65]	Mental	Stress	–	Survey	Biophilic design	Office
[66]	Mental, Physical	Anxiety, Stress	Fatigue	Survey	Lighting	Commercial
[67]	Physical	–	Eyes, Nose, Throat, Headache, Fatigue	Survey	Thermal, Lighting	Office
[68]	Physical	–	Throat, Headache, Fatigue	Survey	Thermal, Humidity, IAQ	Office
[69]	Mental, Physical, Social	Mood, Concentration, Stress	Fatigue, Headache	Survey	Acoustics, Spatial organization	Office
[70]	Mental	Attention, Concentration	–	Survey, Physiological/ Psychometric measurements	Acoustics	*
[7]	Social	–	–	Physiological/Psychometric measurements	Spatial Organization	Office
[71]	Mental	Stress	–	Survey	Ergonomics	Office
[72]	Physical	–	MSD, Eyes, Nose, Throat, Skin, Headache, Nausea	Survey	Lighting, Thermal, IAQ, Ergonomics	Office
[73]	Physical	–	Eyes, Nose, Throat, Skin, Headache, Fatigue Nausea	Survey, Physiological/ Psychometric measurements	Acoustics, Lighting, Thermal, IAQ	Office
[74]	Physical	–	MSD, Eye, Nose, Throat, Skin, Headache, Nausea	Survey	Acoustics, Lighting, Thermal, Humidity, IAQ	Office
[75]	Physical	–	Eye, Nose, Throat, Skin, Headache Nausea	Survey	Acoustics, Lighting, Thermal, IAQ, Spatial organization	Office
[76]	Physical	–	MSD	Survey, Medical Test	Ergonomics	Office
[77]	Physical	–	Eye, Nose, Throat, Skin, Headache, Fatigue, Nausea	Survey, Complaints	Thermal, Acoustics, Lighting, IAQ, Humidity	Office
[78]	Physical	–	Eye, Nose, Throat, Headache	Survey	Thermal, Acoustics, Lighting	Office
[79]	Mental, Physical	Depression, Concentration	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey, Physiological/ Psychometric measurements	Humidity & Moisture, IAQ, Thermal, Acoustics	Office
[80]	Mental	Stress	–	Survey	Acoustics	Office
[81]	Mental	Concentration, Attention	–	Physiological/Psychometric measurements	Spatial Organization	Office
[82]	Physical	–	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey, Interviews, Sick leave reports	IAQ, Humidity, Lighting, Acoustics, Thermal	Office
[83]	Social	–	–	Survey	Spatial Organization	Office
[84]	Physical	–	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey, Sick leave Reports	Spatial Organization	Office
[85]	Mental, Physical	Mood	Overall health	Survey, Physiological/ Psychometric measurements	Lighting	Office
[86]	Physical	–	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey	Acoustics, Lighting, Thermal, IAQ	Office
[87]	Mental	Mood, Attention	–	Survey - Physiological/ Psychometric measurements	Lighting	*
[88]	Mental, Physical	Stress	Fatigue	Physiological/Psychometric measurements	Acoustics	*
[89]	Physical	–	Eye, Nose, Throat, skin, Headache, Fatigue, Nausea	Survey	Thermal, IAQ	Office
[90]	Mental	Attention, Concentration	–	Survey, Physiological/ Psychometric measurements	Lighting, Acoustics	*
[91]	Physical	–	Overall Health	Survey, Sick leave Reports	Spatial Organization	Office
[92]	Mental, Physical	Stress, Concentration	Fatigue	Survey, Physiological/ Psychometric measurements	Acoustics	*
[93]	Mental, Physical	Anxiety, Depression	Eye, Nose, Throat, Skin	Survey	IAQ, Biophilic design	Office
[94]	Mental	Stress	–	Survey, Physiological/ Psychometric measurements	Acoustics, spatial organization, IAQ, ventilation, Lighting	Office
[95]	Mental, Physical	Anxiety, Stress	MSD, Eye, Nose, Throat, Skin, Headache, Fatigue	Survey	Lighting	Office
[96]	Mental, Physical	Depression	Overall Health	Survey, Sick leave reports	Spatial Organization	Office
[97]	Mental, Physical	Attention, Mood Concentration	Fatigue, Eye, Headache	Survey	Lighting	Office
[98]	Physical	–	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey	IAQ	Office
[99]	Physical	–		Survey		Office

(*continued on next page*)

(*continued*)

Ref	Health Category	Mental well-being Investigated	Physical well-being Investigated	Health Assessment Methods	Building Attributes	Building Type
			MSD, Eye, Nose, Throat, Headache		Ergonomics, Acoustics, Lighting, Thermal, Spatial organization	
[100]	Mental, Physical	Depression, Concentration	Eye, Nose, Throat, Skin, Headache, Fatigue, Nausea	Survey	IAQ	Office
[101]	Mental, Physical	Stress	MSD, Eye, Nose, Throat, Skin, Headache, Fatigue	Survey	Acoustics	Office
[102]	Physical	–	Eye, Nose, Throat, Skin, Headache, Fatigue, Nausea	Survey	Ventilation	Office
[103]	Mental	Attention	–	Physiological/Psychometric measurements	Lighting	*
[104]	Mental, Physical	Concentration	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey	Biophilic design	Office
[105]	Mental, Physical	Concentration	MSD, Eye, Nose, Throat, Skin, Headache, Fatigue	Survey	Ventilation	Office
[106]	Mental, Physical	Stress, Mood	Fatigue	Survey	Spatial Organization, IAQ, Acoustics, Lighting	Office
[107]	Mental, Physical	Concentration	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey	Ventilation	Office
[108]	Mental, Physical	Depression, Concentration	Eye, Nose, Throat, Skin, Headache, Fatigue, Nausea	Survey	IAQ	Office
[109]	Mental	Stress, Depression, Mood	–	Survey	Lighting	Office
[110]	Mental, Physical	Concentration	Fatigue	Physiological/Psychometric measurements	Lighting, Thermal	Office
[111]	Mental	Concentration	–	Survey	Acoustics, Lighting, Spatial organization, Ergonomics, Biophilic design	Educational
[112]	Mental	Concentration, Attention	–	Physiological/Psychometric measurements	Acoustics	*
[113]	Physical	–	MSD	Survey	Ergonomics	Office
[114]	Mental, Physical	Mood, Stress	Fatigue	Survey, Interviews	Biophilic design	Office
[115]	Mental	Concentration, Attention, Mood	–	Survey, Physiological/ Psychometric measurements	Biophilic design	*
[116]	Physical	–	Overall health	Medical Test	Moisture & Humidity	Residential
[117]	Mental	Concentration, Mood	–	Physiological/Psychometric measurements	Thermal, Moisture & Humidity, IAQ, Acoustics, Ventilation	Hospitals/Health care centers
[118]	Mental	Attention, Concentration	–	Survey, Physiological/ Psychometric measurements	Spatial organization, Acoustics	Educational
[119]	Mental	Anxiety - Mood	–	Survey	Aesthetics	*
[120]	Physical	–	Eye, Nose, Throat, Skin, Headache, Fatigue, Nausea	Survey	Ventilation	Office
[121]	Physical	–	Eye, Nose, Throat, Skin, Headache, Fatigue, Nausea	Survey	Ventilation	*
[122]	Mental	Mood, Concentration, Attention	–	Survey, Physiological/ Psychometric measurements	Lighting	*
[123]	Mental	Mood, Stress, Anxiety	–	Survey	Lighting, Biophilic design	Office
[124]	Physical	–	Nose, throat	Survey	Moisture & Humidity	Residential
[125]	Mental	Stress	–	Survey	Acoustics, IAQ, Lighting, Thermal	Residential
[126]	Mental, Physical	Attention, Concentration	Fatigue	Survey	Lighting	Office
[127]	Physical	–	Eye, Skin, Headaches	Survey	Lighting	Office
[128]	Mental, Physical	Concentration	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey	Ventilation	Office
[129]	Physical	–	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey	Ventilation, Moisture & Humidity	Hospitals/Health care centers
[9]	Physical	–	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey, Complaints	IAQ, Acoustics, Lighting, Thermal	Office
[130]	Mental	Stress, Attention, Concentration	–	Survey	Thermal, IAQ	Office, Educational
[131]	Mental	Stress, Attention	–	Survey	Biophilic design	Office
[132]	Mental, Physical	Mood, attention, concentration, stress	Eye	Survey, Physiological/ Psychometric measurements	Biophilic design, Lighting	*
[133]	Mental, Physical	Concentration	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey	IAQ	Office
[134]	Mental, Physical	Mood, Concentration	Headache, Eye	Survey	IAQ, Lighting, Thermal	Office
[135]	Physical	–	Overall health	Survey, Sick leave reports	Ventilation	Residential
[136]					Lighting	Office

(*continued on next page*)

(continued)

Ref	Health Category	Mental well-being Investigated	Physical well-being Investigated	Health Assessment Methods	Building Attributes	Building Type
	Mental, Physical	Concentration, Attention	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey, Physiological/ Psychometric measurements		
[137]	Mental	Stress	–	Survey - Medical Test	Aesthetics	*
[138]	Mental, Physical	Concentration	Fatigue	Survey, Medical Test, Physiological/Psychometric measurements	Biophilic design, Lighting	*
[139]	Mental	Stress	–	Survey	IAQ, Acoustics, Lighting, Thermal	Office
[140]	Mental	Stress	–	Survey	IAQ	Educational
[141]	Physical	–	Eye, Nose, Throat, Skin	Survey	IAQ	Residential
[142]	Physical	–	Headache, Fatigue, Nausea	Survey	Spatial organization, IAQ, Thermal, Lighting, Acoustics	Office
[143]	Physical	–	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey	Moisture & Humidity	Residential
[144]	Mental, Physical	Stress	MSD, Headache, Eye	Survey	Lighting	Office
[145]	Mental, Physical	Concentration	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey	Humidity & Moisture, IAQ, Thermal, Acoustics	Office
[146]	Mental, Physical	Depression	Eye, Nose, Throat, Skin, Headache	Survey	IAQ	Office
[147]	Physical	–	Eye, Nose, Throat, Skin, Headache	Survey	IAQ, Humidity & Moisture, Lighting	Residential
[148]	Physical	–	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey	IAQ	Office
[149]	Physical	–	Eye, Nose, Throat, Skin, Headache	Survey	IAQ, Thermal, Lighting, Acoustics	Residential, Office
[150]	Physical	–	Eye, Throat, Nose Headache, MSD	Survey	IAQ, Thermal, Lighting, Acoustics, Ergonomics	Educational
[151]	Mental, Physical	Stress, Depression	Skin, Eye, Throat, Nose, MSD	Survey	Ventilation, IAQ, thermal	Residential
[152]	Mental, Physical	Concentration	Eye, Throat, Nose Headache, Fatigue	Survey	IAQ, Humidity & Moisture	Educational
[153]	Physical	–	Nose, Eye, Fatigue, Headache	Survey	IAQ, Humidity & Moisture, Thermal	Office
[154]	Mental, Physical	Depression, Concentration	Eye, Throat, Nose Headache, Fatigue	Survey	IAQ, Humidity & Moisture	Office
[155]	Mental, Physical	Depression, Concentration	Eye, Throat, Skin, Nose, Headache	Survey, Physiological/ Psychometric measurements	IAQ	*
[156]	Mental, Physical	Anxiety, Mood, Concentration	Nose, Eyes, Throat, Headache, Nausea	Survey	IAQ, Ventilation	Residential
[157]	Mental, Physical	Concentration	Eye, Throat, Nose Headache, Fatigue	Survey, Interviews	Thermal, IAQ, Acoustics, Lighting	Educational
[158]	Mental, Physical	Anxiety, Concentration	Nose, Eyes, Throat, Headache, Nausea	Survey	Thermal, IAQ, Lighting, Acoustic	Residential
[159]	Physical	–	Eye, Nose, Throat, Skin, Headache, Fatigue	Survey	IAQ, Humidity & Moisture	Residential
[160]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Nausea	Survey	IAQ, Thermal, Acoustics, Lighting	Office
[161]	Mental, Physical	Depression, Anxiety	Overall health	Survey	Thermal, Acoustics, Lighting, Humidity & Moisture, IAQ	Residential
[162]	Mental	Attention	–	Survey	Lighting	*
[163]	Mental, Physical	Concentration	Headache	Survey	IAQ, Lighting, Thermal, Acoustics, Ergonomics, Spatial organization	Office
[164]	Mental, Physical	Concentration	Nose, Throat, Skin, Eye, Fatigue, Nausea	Survey	Humidity & Moisture, Ventilation	Residential
[165]	Physical	–	Overall health	Physiological/Psychometric measurements	IAQ, Thermal	*
[166]	Physical	–	Overall health	Survey	Thermal, IAQ, Lighting, Acoustics, Spatial organization	Office, Educational
[167]	Mental, Physical	Mood	Eye, Nose, Throat Skin, Headache	Survey, Sick leave reports	Acoustics, Spatial organization, Thermal, IAQ, Lighting	Hospitals/Health care centers
[168]	Mental, Physical, Social	–	Overall Health	Survey	Thermal, IAQ, Lighting, Acoustics, Spatial organization	Office
[169]	Physical	–	Overall Health	Survey	Thermal, IAQ, Acoustics, Lighting, spatial organization	Office
[170]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey, Complaints	Ventilation, Thermal, Acoustics, Lighting, spatial organization	Office
[171]	Physical	–	Overall Health	Survey	Spatial organization, IAQ, Thermal, Acoustics, Lighting	Office
[172]	Physical	–	Overall Health	Survey	Spatial organization, IAQ, Thermal, Acoustics, Lighting	office
[173]	Mental, Physical		Nose, Throat, Skin, Eye, Fatigue, Headache	Survey, Physiological/ Psychometric measurements	Thermal, IAQ	Office

(continued on next page)

(*continued*)

Ref	Health Category	Mental well-being Investigated	Physical well-being Investigated	Health Assessment Methods	Building Attributes	Building Type
		Mood, Stress, Depression, Concentration				
[174]	Mental, Physical	Depression, Attention, Concentration	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ, Humidity & Moisture, Thermal	Office
[175]	Mental, Physical	Depression, Attention, Concentration	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	Ventilation, IAQ	Office
[176]	Mental, Physical	Depression, Attention, Concentration	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ	Office
[177]	Physical	–	Nose, Throat, Skin, Eye, Headache	Survey	Moisture & Humidity, IAQ	Residential
[178]	Mental, Physical	Concentration	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ, Thermal, Moisture & Humidity, Ventilation	Hospitals/Health care centers
[179]	Mental, Physical	Depression, Concentration	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ	Commercial
[180]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ, Thermal, Humidity & Moisture	Office
[181]	Physical	–	Skin, Nose, Eyes, Headache	Survey	Humidity & Moisture, IAQ, Thermal	Office
[182]	Mental, Physical	Concentration	Eye, Skin, Nose, Headache	Survey	IAQ	Office
[183]	Physical	–	Overall Health	Sick leave reports, Complaints	Ventilation, Spatial organization, Moisture & Humidity	Office
[184]	Physical	–	Nose, Throat	Survey	IAQ, Humidity & Moisture	Educational
[185]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	Thermal, IAQ, Humidity & Moisture	Educational
[186]	Mental, Physical	Concentration	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey, Physiological/ Psychometric measurements	IAQ	Educational
[187]	Physical	–	Overall health	Sick leave reports	Humidity & Moisture, Ventilation, IAQ	Educational
[188]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache, Nausea	Survey	IAQ, Humidity & Moisture	Educational
[189]	Mental, Physical	Concentration	Nose, Throat, Skin, Eye, Fatigue	Survey	Humidity & Moisture, IAQ	Educational
[190]	Physical	–	Nose, Throat, Skin, Eye, Fatigue	Survey	IAQ, Thermal, Humidity & Moisture	Residential
[191]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ	Office
[192]	Physical	–	Nose, Throat, Skin, Eye, Headache, Nausea	Survey, Medical Test	Humidity & Moisture	Office
[193]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ	Educational, Residential
[194]	Mental, Physical	Stress	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey, Interview	IAQ, Thermal, Ventilation	Office
[195]	Physical	Concentration, Depression	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ, Thermal, Humidity & Moisture	Office
[196]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ	Office
[197]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ, Humidity & Moisture, Thermal	Office
[198]	Mental, Physical	Concentration, Stress	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ, Ventilation	Educational
[199]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	Thermal, Humidity & Moisture, IAQ, Ventilation	Office
[200]	Mental, Physical	Concentration	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ	Residential
[201]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ	Office
[202]	Physical	–	Overall Health	Survey	IAQ	Residential
[203]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ, Thermal	Office
[204]	Mental, Physical	Concentration	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	Thermal, IAQ, Noise, Lighting, Biophilic design	Office
[205]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ	Residential
[206]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache, Nausea	Survey	IAQ	Industrial
[207]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache, Nausea	Survey	Noise, Lighting, Ventilation	Residential
[208]	Physical	–		Survey	IAQ, Thermal, Humidity & Moisture	Office

(*continued on next page*)

(*continued*)

Ref	Health Category	Mental well-being Investigated	Physical well-being Investigated	Health Assessment Methods	Building Attributes	Building Type
			Nose, Throat, Skin, Eye, Fatigue, Headache, Nausea			
[209]	Physical	–	Nose, Throat, Eye Headache	Survey	IAQ, Thermal, Humidity & Moisture	Office
[210]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	IAQ	Office
[211]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache, Nausea	Survey	IAQ	Educational
[212]	Physical	–	Nose, Throat, Skin, Eye, Fatigue, Headache	Survey	Humidity & Moisture, Ventilation, IAQ	Residential
[213]	Mental, Physical	Concentration	Nose, Throat, Skin, Eye, Headache, Fatigue, Nausea	Survey	IAQ	Residential
[214]	Mental, Physical	Concentration, Attention, Stress	Nose, Throat, Skin, Eye, Headache, Fatigue, Nausea	Survey	IAQ	Office
[215]	Physical	–	Skin, Eye, Throat	Survey	IAQ	Office, Residential
[216]	Mental, Physical	Overall Health	Overall Health	Survey	Biophilic design	*
[217]	Mental	Stress	–	Survey	IAQ	Office
[218]	Mental	Stress, Concentration	–	Survey	Acoustics	Office
[219]	Mental	Mood	–	Survey	Biophilic design	Office
[220]	Mental, Physical	Attention, Stress, Mood, Concentration	Nose, Throat, Skin, Eye, Headache, Fatigue, Nausea	Survey, Physiological/ Psychometric measurements	Biophilic design	Educational
[221]	Mental	Stress	–	Survey	Lighting, Humidity, Acoustics, Thermal, IAQ	Office
[222]	Mental, Physical, Social	Concentration, Attention, Mood, Anxiety	Nose, Throat, Skin, Eye, Headache, Fatigue	Survey, Interview	IAQ, Acoustics, Lighting, Thermal, Humidity & Moisture	Educational
[223]	Physical	–	Nose, Throat, Skin, Eye, Headache, Fatigue, MSD	Survey	IAQ, Acoustics, Lighting, Thermal, Humidity & Moisture, Ergonomics	Office
[224]	Mental, Physical	Mood	Nose, Throat, Skin, Eye, Headache, Fatigue	Survey, Physiological/ Psychometric measurements	Thermal	*
[225]	Physical	–	Skin, Eye, Nose, Fatigue, Headache	Survey	Thermal, Humidity & Moisture	Office
[226]	Physical	–	Nose, Eye, Skin	Survey	Ventilation	Residential
[227]	Mental, Physical	Concentration	Eye, Nose, Nausea, Throat, Skin, Fatigue	Survey	Thermal, Acoustics, Lighting, IAQ	Office
[228]	Mental, Physical	Concentration	Nose, Skin, Nausea, Throat, Eye, Fatigue	Survey	IAQ, Lighting, Thermal, Acoustics	Office
[229]	Mental, Physical	Concentration	Nose, Skin, Throat, Eye, Fatigue	Survey	IAQ, Lighting, Thermal, Acoustics,	Office
[230]	Mental, Physical	Stress	Nose, Throat, Skin, Eye, Headache, Fatigue, MSD	Survey	IAQ, Acoustics, Ventilation, Thermal, Humidity & Moisture	Office, Hospitals/Health care centers, Educational
[231]	Physical	–	Nose, Throat, Skin, Eye, Headache, Fatigue	Survey	Thermal, Humidity & Moisture, IAQ, Lighting, Noise, Ventilation	Office
[232]	Mental, Physical	Stress, Mood	Nose, Throat, Skin, Eye, Headache, Fatigue	Survey	IAQ, Ventilation, Humidity & Moisture, Thermal	Office
[233]	Physical	–	Nose, Throat, Skin, Eye, Headache, Fatigue	Survey	Thermal, Humidity & Moisture, IAQ, Acoustics, Ventilation	Office
[234]	Physical	–	Nose, Throat, Skin, Eye, Headache, Fatigue	Survey	Thermal, Humidity & Moisture, IAQ	Office
[235]	Physical	–	Eye	Survey	Thermal, Humidity & Moisture, IAQ, Lighting	Office
[236]	Mental, Physical	Concentration, Stress, Mood	Eye, Skin, Throat, Fatigue	Survey	Thermal, Lighting, IAQ, Humidity & Moisture, Acoustics	Hospitals/Health care centers
[237]	Mental	Stress, Mood	–	Survey, Physiological/ Psychometric measurements	Lighting	Office
[238]	Physical	–	Skin, Nose, Fatigue, Headache	Survey	Ventilation	Residential
[239]	Social	–	–	Survey	Spatial Organization	Hospitals/Health care centers
[240]	Mental, Physical	Concentration	Fatigue	Survey	Acoustics	Educational
[241]	Physical	–	Eyes, Nose, Throat	Survey	IAQ	Office
[242]	Mental, Physical	Depression Stress	Eye, Nose, Nausea, Throat, Skin, Fatigue, Headache	Survey	IAQ	Office

Note: * is used for an "*experimental/laboratory study*" for which a specific type of building is not specified.

References

[1] World Health Organization, The Constitution of the World Health Organization, 1947.
[2] World Health Organization, Management of Physical Health Conditions in Adults with Severe Mental Disorders: WHO Guidelines, 2018.
[3] World Health Organization, Promoting Mental Health: Concepts, Emerging Evidence, Practice: Summary Report, 2004.
[4] L.J. Waite, Social well-being and health in the older population: moving beyond social relationships, in: In *Future Directions For the Demography of Aging: Proceedings of a Workshop*, National Academies Press, 2018.
[5] World Health Organization, Indoor Environment: Health Aspects of Air Quality, Thermal Environment, Light and Noise, 1990.
[6] J.M. Samet, J.D. Spengler, Indoor environments and health: moving into the 21st century, Am. J. Publ. Health (2003) 1489–1493.
[7] E.S. Bernstein, S. Turban, The impact of the 'open'workspace on human collaboration, Philos. Trans. R. Soc. B Biol. Sci. (2018).
[8] E. Oldham, H. Kim, IEQ field investigation in high-performance, urban elementary schools, Atmosphere (2020).
[9] D.H. Kim, P.M. Bluyssen, Clustering of office workers from the OFFICAIR study in The Netherlands based on their self-reported health and comfort, Build. Environ (2020).
[10] R.K. Raanaas, K.H. Evensen, D. Rich, G. Sjøstrøm, G. Patil, Benefits of indoor plants on attention capacity in an office setting, J. Environ. Psychol. (2011) 99–105.
[11] P. Leather, D. Beale, L. Sullivan, Noise, psychosocial stress and their interaction in the workplace, J. Environ. Psychol. (2003) 213–222.
[12] M. Arif, M. Katafygiotou, A. Mazroei, A. Kaushik, E. Elsarrag, Impact of indoor environmental quality on occupant well-being and comfort: a review of the literature, Int. J. Sustain. Built Environ. (2016) 1–11.
[13] L. Rohde, T.S. Larsen, R.L. Jensen, O.K. Larsen, Framing holistic indoor environment: definitions of comfort, health and well-being, Indoor Built Environ. (2020) 1118–1136.
[14] S.K. Wong, L.W.C. Lai, D.C.W. Ho, K.W. Chau, C.L.K. Lam, C.H.F. Ng, Sick building syndrome and perceived indoor environmental quality: a survey of apartment buildings in Hong Kong, Habitat Int. (2009) 463–471.
[15] H. Belachew, et al., Sick building syndrome and associated risk factors among the population of Gondar town, northwest Ethiopia, Environ. Health Prev. Med. (2018) 1–9.
[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. (2016) 138–144.
[17] S. Hammond, Using psychometric tests, in: In *Research methods in Psychology*, 2006, pp. 182–209.
[18] J. Pekkanen, A. Hyvärinen, U. Haverinen-Shaughnessy, M. Korppi, T. Putus, A. Nevalainen, Moisture damage and childhood asthma: a population-based incident case–control study, Eur. Respir. J. (2007) 509–515.
[19] E. Simons, S.A. Hwang, E.F. Fitzgerald, C. Kielb, S. Lin, The impact of school building conditions on student absenteeism in upstate New York, Am. J. Publ. Health (2010) 1679–1686.
[20] L. Sun, L.A. Wallace, Residential cooking and use of kitchen ventilation: the impact on exposure, J. Air Waste Manag. Assoc. (2020).
[21] M.S.A. Rodrigues, R.D.V. Leite, C.M. Lelis, T.C. Chaves, Differences in ergonomic and workstation factors between computer office workers with and without reported musculoskeletal pain, Work (2017) 563–572.
[22] K. Savelieva, T. Marttila, J. Lampi, S. Ung-Lanki, M. Elovainio, J. Pekkanen, Associations between indoor environmental quality in schools and symptom reporting in pupil-administered questionnaires, Environ. Health (Lond.) (2019) 1–12.
[23] D. Lukcso, T.L. Guidotti, D.E. Franklin, A. Burt, Indoor environmental and air quality characteristics, building-related health symptoms, and worker productivity in a federal government building complex, Arch. Environ. Occup. Health (2016) 85–101.
[24] M. Donn, E. Braasch, M. Woodbury, E. Novak, A. Banks, Design Research: Optimising Row-House Orientation, 2015.
[25] M.A. Mujeebu, Introductory chapter: indoor environmental quality, in: In *Indoor Environmental Quality.*, 2019.
[26] S.S. Kim, D.H. Kang, D.H. Choi, M.S. Yeo, K.W. Kim, Comparison of strategies to improve indoor air quality at the pre-occupancy stage in new apartment buildings, Build. Environ. (2008) 320–328.
[27] J. Pašek, V. Sojková, Facility management of smart buildings, Int. Rev. Appl. Sci. Eng. (2018) 181–187.
[28] L. Carmichael, et al., Healthy buildings for a healthy city: is the public health evidence base informing current building policies? Sci. Total Environ. (2020).
[29] M. Awada, et al., Ten questions concerning occupant health in buildings during normal operations and extreme events including the COVID-19 pandemic, Build. Environ. (2021).
[30] E.A. Hahn, et al., Measuring social health in the patient-reported outcomes measurement information system (PROMIS): item bank development and testing, Qual. Life Res. (2010) 1035–1044.
[31] D.H. Kim, S. Yoo, How does the built environment in compact metropolitan cities affect health? A systematic review of Korean studies, Int. J. Environ. Res. Publ. Health (2019).
[32] B. Hillier, Space and spatiality: what the built environment needs from social theory, Build. Res. Inf. (2008).
[33] ASHRAE, The standards for ventilation and indoor air quality, Standards 62.1 and,adverse health effects for occupants, https://www.ashrae.org/technical-resources/bookstore/standards-62-1-62-2#:~:text=ANSI%2FASHRAE, 2019.
[34] B.W. Olesen, Revision of EN 15251: indoor environmental criteria, REHVA J. (2012).
[35] ASHRAE, ANSI/ASHRAE/IES standard 90.1-2019 – energy standard for buildings except low-rise residential buildings [Online]. Available: https://www.ashrae.org/technical-resources/bookstore/standard-90-1, 2019.
[36] ASHRAE, Standard 55 – thermal environmental conditions for human occupancy [Online]. Available, https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy, 2020.
[37] ISO, ISO 7730:2005 Ergonomics of the thermal environment — analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria [Online]. Available: https://www.iso.org/standard/39155.html, 2015.
[38] United States Environmental Protection Agency, Indoor air pollution: an introduction for health professionals. https://www.epa.gov/indoor-air-quality-iaq/indoor-air-pollution-introduction-health-professionals#health-sbs, 2020.
[39] L.B. Hall-Andersen, O. Broberg, Integrating ergonomics into engineering design: the role of objects, Appl. Ergon (2014).
[40] J. Lee, E.H. Lee, S.H. Moon, Systematic review of the measurement properties of the depression anxiety stress Scales–21 by applying updated COSMIN methodology, Qual. Life Res. (2019) 2325–2339.
[41] N. Salari, et al., Prevalence of stress, anxiety, depression among the general population during the COVID-19 pandemic: a systematic review and meta-analysis, Glob. Health (2020) 1–11.
[42] C. Wang, et al., How indoor environmental quality affects occupants' cognitive functions: a systematic review, Build. Environ. (2021).
[43] A. Fernandes, R. Helawar, R. Lokesh, T. Tari, A.V. Shahapurkar, Determination of Stress Using Blood Pressure and Galvanic Skin Response, 2014.
[44] R.F. Rupp, N.G. Vásquez, R. Lamberts, A review of human thermal comfort in the built environment, Energy Build. (2015).
[45] WELL, WELL health-safety rating. https://www.wellcertified.com/.
[46] fitwel, "FITWEL." .
[47] J.G. Allen, J.D. Macomber, Healthy Buildings: How Indoor Spaces Drive Performance and Productivity, Harvard University Press., 2020.
[48] B. Birkenfeld, P. Brown, N. Kresse, J. Sullivan, P. Thiam, Quantifying the hidden benefits of high-performance building, Int. Soc. Sustain. Prof. (2011).
[49] F. McCreary, A. Zafiroglu, H. Patterson, The contextual complexity of privacy in smart homes and smart buildings, in: In Nternational Conference on HCI in Business, Government, and Organizations, 2016, pp. 67–78.
[50] A.E. Gold, No home for justice: how eviction perpetuates health inequity among low-income and minority tenants, Geo. J. Poverty L. Pol'y (2016).
[51] ASHRAE, ASHRAE offers COVID-19 building readiness/reopening guidance. https://www.ashrae.org/about/news/2020/ashrae-offers-covid-19-building-readiness-reopening-guidance, 2020.
[52] J.M. Taylor, Sustainable Building Practices: Legislative and Economic Incentives, 2011.
[53] R. Mittal, R. Ni, J.H. Seo, The flow physics of COVID-19, J. Fluid Mech. (2020).
[54] V.A. Mouchtouri, et al., Environmental contamination of SARS-CoV-2 on surfaces, air-conditioner and ventilation systems, Int. J. Hyg Environ. Health (2020).
[55] R. Küller, B. Mikellides, J. Janssens, Color, arousal, and performance—a comparison of three experiments, Color Res. Appl. (2009).
[56] E. van Esch, R. Minjock, S.M. Colarelli, S. Hirsch, Office window views: view features trump nature in predicting employee well-being, J. Environ. Psychol. (2019) 56–64.
[57] B.C. Dreyer, S. Coulombe, S. Whitney, M. Riemer, D. Labbé, Beyond exposure to outdoor nature: exploration of the benefits of a green building's indoor environment on wellbeing, Front. Psychol. (2018).
[58] S. Bjørnstad, G.G. Patil, R.K. Raanaas, Nature contact and organizational support during office working hours: benefits relating to stress reduction, subjective health complaints, and sick leave, Work (2016).
[59] G.R. Newsham, et al., Do 'green'buildings have better indoor environments? New evidence, Build. Res. Inf. (2013).
[60] E. Schell, T. Theorell, H. Saraste, Workplace aesthetics: impact of environments upon employee health as compared to ergonomics, Work (2012).
[61] M.B. Aries, J.A. Veitch, G.R. Newsham, Windows, view, and office characteristics predict physical and psychological discomfort, J. Environ. Psychol. (2010) 533–541.
[62] N. Weinstein, A.K. Przybylski, R.M. Ryan, Can nature make us more caring? Effects of immersion in nature on intrinsic aspirations and generosity, Pers. Soc. Psychol. Bull. (2009).
[63] R.K. Raanaas, K.H. Evensen, D. Rich, G. Sjøstrøm, G. Patil, Benefits of indoor plants on attention capacity in an office setting, J. Environ. Psychol. (2011).
[64] G. Newsham, J. Brand, C. Donnelly, J. Veitch, M. Aries, K. Charles, Linking indoor environment conditions to job satisfaction: a field study, Build. Res. Inf. (2009).
[65] W. Sop Shin, The influence of forest view through a window on job satisfaction and job stress, Scand. J. For. Res. (2007) 248–253.
[66] P. Leather, M. Pyrgas, D. Beale, C. Lawrence, Windows in the workplace: sunlight, view, and occupational stress, Environ. Behav. (1998) 739–762.
[67] I. Sakellaris, et al., Personal control of the indoor environment in offices: relations with building characteristics, influence on occupant perception and reported symptoms related to the building—the officair project, Appl. Sci. (2019).

[68] J.Y. Lee, P. Wargocki, Y.H. Chan, L. Chen, K.W. Tham, Indoor environmental quality, occupant satisfaction, and acute building-related health symptoms in Green Mark-certified compared with non-certified office buildings, Indoor Air (2019).
[69] S. Di Blasio, L. Shtrepi, G.E. Puglisi, A. Astolfi, A cross-sectional survey on the impact of irrelevant speech noise on annoyance, mental health and well-being, performance and occupants' behavior in shared and open-plan offices, Int. J. Environ. Res. Publ. Health (2019).
[70] A.M. Abbasi, M. Motamedzade, M. Aliabadi, R. Golmohammadi, L. Tapak, Study of the physiological and mental health effects caused by exposure to low-frequency noise in a simulated control room, Build. Acoust. (2018).
[71] V. Schellewald, J. Kleinert, R. Ellegast, Introducing a dynamic workstation in the office: insights in characteristics of use and short-term changes of well-being in a 12 week observational study, Int. J. Environ. Res. Publ. Health (2018).
[72] S. Lee, M.H. Park, B.Y. Jeong, Gender differences in public office workers' satisfaction, subjective symptoms and musculoskeletal complaints in workplace and office environments, Int. J. Occup. Saf. Ergon. (2018).
[73] P. MacNaughton, et al., The impact of working in a green certified building on cognitive function and health, Build. Environ. (2017).
[74] D.S. Shin, B.Y. Jeong, M.H. Park, Structural equation modeling of office environment quality, sick building syndrome, and musculoskeletal complaints on aggregate satisfaction of office workers, Hum. Factors Ergon. Manuf. Serv. Ind. (2018).
[75] K. Azuma, K. Ikeda, N. Kagi, U. Yanagi, H. Osawa, Evaluating prevalence and risk factors of building-related symptoms among office workers: seasonal characteristics of symptoms and psychosocial and physical environmental factors, Environ. Health Prev. Med. (2017).
[76] M.J. Pereira, et al., An investigation of self-reported health-related productivity loss in office workers and associations with individual and work-related factors using an Employer's perspective, J. Occup. Environ. Med. (2017).
[77] M. Mulville, N. Callaghan, D. Isaac, The impact of the ambient environment and building configuration on occupant productivity in open-plan commercial offices, J. Corp. Real Estate (2016).
[78] P.M. Bluyssen, et al., Self-reported health and comfort in 'modern'office buildings: first results from the European OFFICAIR study, Indoor Air (2016).
[79] 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. (2016).
[80] A. Seddigh, E. Berntson, F. Jönsson, C.B. Danielson, H. Westerlund, The effect of noise absorption variation in open-plan offices: a field study with a cross-over design, J. Environ. Psychol. (2015) 34–44.
[81] A. Seddigh, C. Stenfors, E. Berntsson, R. Bååth, S. Sikström, H. Westerlund, The association between office design and performance on demanding cognitive tasks, J. Environ. Psychol. (2015).
[82] K.W. Tham, P. Wargocki, Y.F. Tan, Indoor environmental quality, occupant perception, prevalence of sick building syndrome symptoms, and sick leave in a Green Mark Platinum-rated versus a non-Green Mark-rated building: a case study, Sci. Technol. Built Environ. (2015).
[83] C.B. Danielsson, L. Bodin, C. Wulff, T. Theorell, The relation between office type and workplace conflict: a gender and noise perspective, J. Environ. Psychol. (2015).
[84] C. Bodin Danielsson, H.S. Chungkham, C. Wulff, H. Westerlund, Office design's impact on sick leave rates, Ergonomics (2014).
[85] M. Boubekri, I.N. Cheung, K.J. Reid, C.H. Wang, P.C. Zee, Impact of windows and daylight exposure on overall health and sleep quality of office workers: a case-control pilot study, J. Clin. sleep Med. (2014).
[86] A. Boerstra, T. Beuker, M. Loomans, J. Hensen, Impact of available and perceived control on comfort and health in European offices, Architect. Sci. Rev. (2013).
[87] G. Newsham, C. Arsenault, J. Veitch, A.M. Tosco, C. Duval, Task lighting effects on office worker satisfaction and performance, and energy efficiency, Leukos (2005).
[88] H. Jahncke, N. Halin, Performance, fatigue and stress in open-plan offices: the effects of noise and restoration on hearing impaired and normal hearing individuals, Noise Health (2012).
[89] A. Chen, V.W.C. Chang, Human health and thermal comfort of office workers in Singapore, Build. Environ. (2012).
[90] A. Liebl, J. Haller, B. Jödicke, H. Baumgartner, S. Schlittmeier, J. Hellbrück, Combined effects of acoustic and visual distraction on cognitive performance and well-being, Appl. Ergon. (2012).
[91] J.H. Pejtersen, H. Feveile, K.B. Christensen, H. Burr, Sickness absence associated with shared and open-plan offices—a national cross sectional questionnaire survey, Scand. J. Work. Environ. Health (2011).
[92] H. Jahncke, S. Hygge, N. Halin, A.M. Green, K. Dimberg, Open-plan office noise: cognitive performance and restoration, J. Environ. Psychol. (2011).
[93] H.H. Kim, et al., Evaluation of indoor air quality and health related parameters in office buildings with or without indoor plants, J. Japanese Soc. Hortic. Sci. (2011).
[94] J.F. Thayer, et al., Effects of the physical work environment on physiological measures of stress, Eur. J. Prev. Cardiol. (2010).
[95] K.I. Fostervold, J. Nersveen, Proportions of direct and indirect indoor lighting—the effect on health, well-being and cognitive performance of office workers, Light. Res. Technol. (2008).
[96] C.B. Danielsson, L. Bodin, Office type in relation to health, well-being, and job satisfaction among employees, Environ. Behav. (2008).
[97] A.U. Viola, L.M. James, L.J. Schlangen, D.J. Dijk, Blue-enriched white light in the workplace improves self-reported alertness, performance and sleep quality, Scand. J. Work. Environ. Health (2008).
[98] H.P. Hutter, H. Moshammer, P. Wallner, B. Damberger, P. Tappler, M. Kundi, Health complaints and annoyances after moving into a new office building A multidisciplinary approach including analysis of questionnaires air and house dust sample, Int. J. Hyg Environ. Health (2006).
[99] A. Mahdavi, U. Unzeitig, Occupancy implications of spatial, indoor-environmental, and organizational features of office spaces, Build. Environ. (2005).
[100] H.J. Chao, J. Schwartz, D.K. Milton, H.A. Burge, The work environment and workers' health in four large office buildings, Environ. Health Perspect. (2003).
[101] P. Leather, D. Beale, L. Sullivan, Noise, psychosocial stress and their interaction in the workplace, J. Environ. Psychol. (2003).
[102] R. Bholah, I. Fagoonee, A.H. Subratty, Sick building syndrome in Mauritius: are symptoms associated with the office environment? Indoor Built Environ. (2000).
[103] C. Cajochen, J.M. Zeitzer, C.A. Czeisler, D.J. Dijk, Dose-response relationship for light intensity and ocular and electroencephalographic correlates of human alertness, Behav. Brain Res. (2000).
[104] T. Fjeld, B. Veiersted, L. Sandvik, G. Riise, F. Levy, The effect of indoor foliage plants on health and discomfort symptoms among office workers, Indoor Built Environ. (1998).
[105] D. Menzies, J. Pasztor, F. Nunes, J. Leduc, C.H. Chan, Effect of a new ventilation system on health and well-being of office workers, Arch. Environ. Health (1997).
[106] S. Klitzman, J.M. Stellman, The impact OF the physical environment ON the psychological well-being OF office workers, Soc. Sci. Med. (1989).
[107] A. Hedge, T.D. Sterling, E.M. Sterling, C.W. Collett, D.A. Sterling, V. Nie, Indoor air quality and health in two office buildings with different ventilation systems, Environ. Int. (1989).
[108] K. Azuma, K. Ikeda, N. Kagi, U. Yanagi, H. Osawa, Physicochemical risk factors for building-related symptoms in air-conditioned office buildings: ambient particles and combined exposure to indoor air pollutants, Sci. Total Environ. (2018).
[109] M.G. Figueiro, et al., The impact of daytime light exposures on sleep and mood in office workers, Sleep Heal (2017).
[110] K. Vimalanathan, T.R. Babu, The effect of indoor office environment on the work performance, health and well-being of office workers, J. Environ. Heal. Sci. Eng. (2014).
[111] C. Tufvesson, J. Tufvesson, The building process as a tool towards an all-inclusive school. A Swedish example focusing on children with defined concentration difficulties such as ADHD, autism and Down's syndrome, J. Hous. Built Environ. (2009).
[112] F. Khajenasiri, A. Zamanian, Z. Zamanian, The effect of exposure to high noise levels on the performance and rate of error in manual activities, Electron. Physician (2016).
[113] M.M. Robertson, M.J. O'Neill, Reducing musculoskeletal discomfort: effects of an office ergonomics workplace and training intervention, Int. J. Occup. Saf. Ergon. (2003).
[114] T. Gray, C. Birrell, Are biophilic-designed site office buildings linked to health benefits and high performing occupants? Int. J. Environ. Res. Publ. Health (2014).
[115] M.G. Berman, J. Jonides, S. Kaplan, The cognitive benefits of interacting with nature, Psychol. Sci. (2008).
[116] J. Pekkanen, A. Hyvärinen, U. Haverinen-Shaughnessy, M. Korppi, T. Putus, A. Nevalainen, Moisture damage and childhood asthma: a population-based incident case–control study, Eur. Respir. J. (2007).
[117] A.E. van den Berg, C.G. Van den Berg, A comparison of children with ADHD in a natural and built setting, Child Care Health Dev. (2011).
[118] M. Mostafa, An architecture for autism: concepts of design intervention for the autistic user, Int. J. Archit. Res. (2008).
[119] J.W. Verhoeven, M.E. Pieterse, A.T. Pruyn, Effects of interior color on health care consumers: a 360 degree photo simulation experiment, ACR North Am. Adv. (2006).
[120] J.J. Jaakkola, O.P. Heinoneon, O. Seppänen, Mechanical ventilation in office buildings and the sick building syndrome. An experimental and epidemiological study, Indoor Air (1991).
[121] D. Norbäck, K. Nordström, Sick building syndrome in relation to air exchange rate, CO 2, room temperature and relative air humidity in university computer classrooms: an experimental study, Int. Arch. Occup. Environ. Health (2008).
[122] I. Knez, C. Kers, Effects of indoor lighting, gender, and age on mood and cognitive performance, Environ. Behav. (2000).
[123] M. An, S.M. Colarelli, K. O'Brien, M.E. Boyajian, Why we need more nature at work: effects of natural elements and sunlight on employee mental health and work attitudes, PLoS One (2016).
[124] M.D. Keall, J. Crane, M.G. Baker, K. Wickens, P. Howden-Chapman, M. Cunningham, A measure for quantifying the impact of housing quality on respiratory health: a cross-sectional study, Environ. Health (Lond.) (2012).
[125] P. Xue, C.M. Mak, Z.T. Ai, A structured approach to overall environmental satisfaction in high-rise residential buildings, Energy Build. (2016).
[126] P.R. Mills, S.C. Tomkins, L.J. Schlangen, The effect of high correlated colour temperature office lighting on employee wellbeing and work performance, J. Circadian Rhythms (2007) 1–9.
[127] T. Hwang, J.T. Kim, Effects of indoor lighting on occupants' visual comfort and eye health in a green building, Indoor Built Environ. (2011).
[128] J. Bourbeau, C. Brisson, S. Allaire, Prevalence of the sick building syndrome symptoms in office workers before and six months and three years after being

exposed to a building with an improved ventilation system, Occup. Environ. Med. (1997).
[129] K. Nordström, D. Norbäck, R. Akselsson, Effect of air humidification on the sick building syndrome and perceived indoor air quality in hospitals: a four month longitudinal study, Occup. Environ. Med. (1994).
[130] J. Kallio, et al., Assessment of perceived indoor environmental quality, stress and productivity based on environmental sensor data and personality categorization, Build. Environ. (2020).
[131] N. Hähn, E. Essah, T. Blanusa, Biophilic design and office planting: a case study of effects on perceived health, well-being and performance metrics in the workplace, Intell. Build. Int. (2020).
[132] W.H. Ko, et al., The impact of a view from a window on thermal comfort, emotion, and cognitive performance, Build. Environ (2020).
[133] H. Fahad Alomirah, H.M. Moda, Assessment of indoor air quality and users perception of a renovated office building in manchester, Int. J. Environ. Res. Publ. Health (2020).
[134] J.H. Choi, V. Loftness, D. Nou, B. Tinianov, D. Yeom, Multi-Season assessment of occupant responses to manual shading and dynamic glass in a workplace environment, Energies (2020).
[135] P. Howden-Chapman, et al., Effects of improved home heating on asthma in community dwelling children: randomised controlled trial, BMJ (2008).
[136] A. Jamrozik, et al., Access to daylight and view in an office improves cognitive performance and satisfaction and reduces eyestrain: a controlled crossover study, Build. Environ (2019).
[137] M.D. Burnard, A. Kutnar, Human stress responses in office-like environments with wood furniture, Build. Res. Inf. (2020).
[138] J.A. Sanchez, T. Ikaga, S.V. Sanchez, Quantitative improvement in workplace performance through biophilic design: a pilot experiment case study, Energy Build. (2018).
[139] T.Q. Thach, et al., Associations of perceived indoor environmental quality with stress in the workplace, Indoor Air (2020).
[140] U. Surahman, H.R.D. Ray, Sick Building Syndrome and its Effect on Health of Students and Teachers in Selected Educational Buildings in Bandung, 2020.
[141] M.A. Mohammed, et al., Psychosocial perception of the effects of harmattan dust on the environment and health of building occupants in Maiduguri, Nigeria, Facilities (2020).
[142] C. Aigbavboa, W.D. Thwala, Performance of a green building's indoor environmental quality on building occupants in South Africa, J. Green Build (2019).
[143] X. Huo, et al., Sick building syndrome symptoms among young parents in Chinese homes, Build. Environ. (2020).
[144] J.M. Katabaro, Y. Yan, Effects of lighting quality on working efficiency of workers in office building in Tanzania, J. Environ. Public Health (2019).
[145] M. Lahtinen, C. Sundman-Digert, K. Reijula, Psychosocial work environment and indoor air problems: a questionnaire as a means of problem diagnosis, Occup. Environ. Med. (2004).
[146] N.A. Nelson, J.D. Kaufman, J. Burt, C. Karr, Health symptoms and the work environment in four nonproblem United States office buildings, Scand. J. Work. Environ. Health (1995).
[147] H.M. Al Momani, H.H. Ali, Sick building syndrome in apartment buildings in Jordan, Jordan J. Civ. Eng. (2008).
[148] M.J. Mendell, Q. Lei-Gomez, A. Mirer, O. Seppanen, M.G. Brunner, Risk factors for occupant symptoms in heating, ventilating, and air-conditioning systems in US office buildings: the US EPA BASE study, Int. J. Indoor Air Qual. Clim. (2007).
[149] C.A. Roulet, et al., Perceived health and comfort in relation to energy use and building characteristics, Build. Res. Inf. (2006).
[150] A. Hedge, L. Miller, J.A. Dorsey, Occupant comfort and health in green and conventional university buildings, Work (2014).
[151] K. Hasegawa, H. Yoshino, National survey on ventilation systems and the health of occupants in Japanese homes, Int. J. Vent. (2014).
[152] C. Kielb, S. Lin, N. Muscatiello, W. Hord, J. Rogers-Harrington, J. Healy, Building-related health symptoms and classroom indoor air quality: a survey of school teachers in New York State, Indoor Air (2015).
[153] M.J. Mendell, et al., A longitudinal study of ventilation rates in California office buildings and self-reported occupant outcomes including respiratory illness absence, Build. Environ. (2015).
[154] D. Lukcso, T.L. Guidotti, D.E. Franklin, A. Burt, Indoor environmental and air quality characteristics, building-related health symptoms, and worker productivity in a federal government building complex, Arch. Environ. Occup. Health (2016).
[155] X. Zhang, P. Wargocki, Z. Lian, C. Thyregod, Effects of exposure to carbon dioxide and bioeffluents on perceived air quality, self-assessed acute health symptoms, and cognitive performance, Indoor Air (2017).
[156] P. Wallner, et al., Health and wellbeing of occupants in highly energy efficient buildings: a field study, Int. J. Environ. Res. Publ. Health (2017).
[157] S. Vilcekova, L. Meciarova, E.K. Burdova, J. Katunska, D. Kosicanova, S. Doroudiani, Indoor environmental quality of classrooms and occupants' comfort in a special education school in Slovak Republic, Build. Environ. (2017).
[158] S.N. Kamaruzzaman, A.M. Azmal, Evaluation of occupants' well-being and perception towards indoor environmental quality in Malaysia affordable housing, J. Facil. Manag. (2019).
[159] T. Nitmetawong, S. Boonvisut, K. Kallawicha, H.J. Chao, Effect of indoor environmental quality on building-related symptoms among the residents of apartment-type buildings in Bangkok area, Hum. Ecol. Risk Assess. (2020).
[160] T.Q. Thach, et al., Prevalence of sick building syndrome and its association with perceived indoor environmental quality in an Asian multi-ethnic working population, Build. Environ. (2019).
[161] Y. Chen, B. Chen, Modeling of effect of residential indoor environment on health based on a questionnaire survey of selected China cities, Build. Environ. (2019).
[162] C. de Bakker, M. Aarts, H. Kort, E. van Loenen, A. Rosemann, Preferred luminance distributions in open-plan offices in relation to time of day and subjective alertness, Leukos (2019).
[163] M. Franke, C. Nadler, Towards a holistic approach for assessing the impact of IEQ on satisfaction, health, and productivity, Build. Res. Inf. (2020).
[164] X. Huo, et al., Sick building syndrome symptoms among young parents in Chinese homes, Build. Environ. (2020).
[165] J. Kim, T. Hong, M. Kong, K. Jeong, Building occupants' psycho-physiological response to indoor climate and CO2 concentration changes in office buildings, Build. Environ. (2020).
[166] M. Khoshbakht, G. Baird, E.O. Rasheed, The influence of work group size and space sharing on the perceived productivity, overall comfort and health of occupants in commercial and academic buildings, Indoor Built Environ. (2020).
[167] A. Eijkelenboom, D.H. Kim, P.M. Bluyssen, First results of self-reported health and comfort of staff in outpatient areas of hospitals in The Netherlands, Build. Environ (2020).
[168] C. Candido, L. Thomas, S. Haddad, F. Zhang, M. Mackey, W. Ye, Designing activity-based workspaces: satisfaction, productivity and physical activity, Build. Res. Inf (2019).
[169] S. Bae, A. Asojo, D. Guerin, C. Martin, A post-occupancy evaluation of the impact of indoor environmental quality on health and well-being in office buildings, J. Organ. Psychol. (2017).
[170] I.A. Meir, M. Schwartz, Y. Davara, Y. Garb, A window of one's own: a public office post-occupancy evaluation, Build. Res. Inf (2019).
[171] C. Candido, et al., Impact of Workspace Layout on Occupant Satisfaction, Perceived Health and Productivity, 2016.
[172] C. Candido, J. Kim, R. de Dear, L. Thomas, BOSSA: a multidimensional post-occupancy evaluation tool, Build. Res. Inf. (2016).
[173] L. Lan, P. Wargocki, D.P. Wyon, Z. Lian, Effects of thermal discomfort in an office on perceived air quality, SBS symptoms, physiological responses, and human performance, Indoor Air (2011).
[174] L. Fang, D.P. Wyon, G. Clausen, P.O. Fanger, Impact of indoor air temperature and humidity in an office on perceived air quality, SBS symptoms and performance, Indoor Air (2004).
[175] P. Wargocki, D.P. Wyon, J. Sundell, G. Clausen, P.O. Fanger, The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity, Indoor Air (2000).
[176] P. Wargocki, D.P. Wyon, Y.K. Baik, G. Clausen, P.O. Fanger, Perceived air quality, sick building syndrome (SBS) symptoms and productivity in an office with two different pollution loads, Indoor Air (1999).
[177] G. Smedje, J. Wang, D. Norbäck, H. Nilsson, K. Engvall, SBS symptoms in relation to dampness and ventilation in inspected single-family houses in Sweden, Int. Arch. Occup. Environ. Health (2017).
[178] K. Nordström, D. Norbäck, R. Akselsson, Influence of indoor air quality and personal factors on the sick building syndrome (SBS) in Swedish geriatric hospitals, Occup. Environ. Med. (1995).
[179] J. Kim, M. Jang, K. Choi, K. Kim, Perception of indoor air quality (IAQ) by workers in underground shopping centers in relation to sick-building syndrome (SBS) and store type: a cross-sectional study in Korea, BMC Publ. Health (2019).
[180] M.G. Apte, W.J. Fisk, J.M. Daisey, Indoor Carbon Dioxide Concentrations and SBS in Office Workers, 2000.
[181] J.J. Jaakkola, P. Tuomaala, O. Seppänen, Air recirculation and sick building syndrome: a blinded crossover trial, Am. J. Publ. Health (1994).
[182] J.J. Jaakkola, P. Miettinen, Ventilation rate in office buildings and sick building syndrome, Occup. Environ. Med. (1995).
[183] D.K. Milton, P.M. Glencross, M.D. Wafrers, Risk of sick leave associated with outdoor air supply rate, humidification, and occupant complaints, Indoor Air (2000).
[184] T. Meklin, et al., Indoor air microbes and respiratory symptoms of children in moisture damaged and reference schools, Indoor Air (2002).
[185] H.W. Meyer, H. Würtz, P. Suadicani, O. Valbjørn, T. Sigsgaard, F. Gyntelberg, Molds in floor dust and building-related symptoms in adolescent school children, Indoor Air (2004).
[186] A.N. Myhrvold, E. Olsen, O. Lauridsen, Indoor environment in schools–pupils health and performance in regard to CO2 concentrations, Indoor Air (1996).
[187] E. Simons, S.A. Hwang, E.F. Fitzgerald, C. Kielb, S. Lin, The impact of school building conditions on student absenteeism in upstate New York, Am. J. Publ. Health (2010).
[188] D. Norbäck, M. Torgen, C. Edling, Volatile organic compounds, respirable dust, and personal factors related to prevalence and incidence of sick building syndrome in primary schools, Occup. Environ. Med. (1990).
[189] N.E. Ebbehøj, et al., Molds in floor dust, building-related symptoms, and lung function among male and female schoolteachers, Indoor Air (2005).
[190] N.H. Wong, B. Huang, Comparative study of the indoor air quality of naturally ventilated and air-conditioned bedrooms of residential buildings in Singapore, Build. Environ. (2004).
[191] M.J. Jafari, et al., Association of sick building syndrome with indoor air parameters, Tanaffos (2015).
[192] X. Zhang, B. Sahlberg, G. Wieslander, C. Janson, T. Gislason, D. Norback, Dampness and moulds in workplace buildings: associations with incidence and

remission of sick building syndrome (SBS) and biomarkers of inflammation in a 10 year follow-up study, Sci. Total Environ (2012).
[193] S. Mentese, D. Tasdibi, Airborne bacteria levels in indoor urban environments: the influence of season and prevalence of sick building syndrome (SBS), *Indoor Built Environ.* (2016).
[194] R. Nur Fadilah, J. Juliana, Indoor air quality (IAQ) and sick buildings syndrome (SBS) among office workers in new and old building in Universiti Putra Malaysia, Serdang, Heal. Environ. J. (2012).
[195] D.H. Tsai, J.S. Lin, C.C. Chan, Office workers' sick building syndrome and indoor carbon dioxide concentrations, J. Occup. Environ. Hyg. (2012).
[196] M.E. Zamani, J. Jalaludin, N. Shaharom, Indoor air quality and prevalence of sick building syndrome among office workers in two different offices in Selangor, Am. J. Appl. Sci. (2013).
[197] K. Gladyszewska-Fiedoruk, Survey research of selected issues the sick building syndrome (SBS) in an office building, Environ. Clim. Technol. (2019).
[198] N.H. Fauzan, J. Jalaludin, P. Chua, Indoor air quality and sick building syndrome (SBS) among staff in two different private higher learning institution settings in kuala lumpur and selangor, Int. J. Appl. Chem. (2016).
[199] H. Nakaoka, et al., Correlating the symptoms of sick-building syndrome to indoor VOCs concentration levels and odour, Indoor Built Environ. (2014).
[200] Y. Sun, J. Hou, R. Cheng, Y. Sheng, X. Zhang, J. Sundell, Indoor air quality, ventilation and their associations with sick building syndrome in Chinese homes, Energy Build (2019).
[201] C.Y. Lu, J.M. Lin, Y.Y. Chen, Y.C. Chen, Building-related symptoms among office employees associated with indoor carbon dioxide and total volatile organic compounds, Int. J. Environ. Res. Publ. Health (2015).
[202] S. Mentese, et al., Association between respiratory health and indoor air pollution exposure in Canakkale, Turkey, Build. Environ (2015).
[203] C.Y. Lu, M.C. Tsai, C.H. Muo, Y.H. Kuo, F.C. Sung, C.C. Wu, Personal, psychosocial and environmental factors related to sick building syndrome in official employees of Taiwan, Int. J. Environ. Res. Publ. Health (2018).
[204] Z. Gou, S.S.Y. Lau, Sick building syndrome in open-plan offices, J. Facil. Manag (2012).
[205] P. Guo, et al., Sick building syndrome by indoor air pollution in Dalian, China, Int. J. Environ. Res. Publ. Health (2013).
[206] U. Reuben, A.F. Ismail, A.L. Ahmad, H.M. Maina, A. Daud, Indoor air quality and sick building syndrome among Nigerian laboratory university workers, J. Phys. Sci. (2019).
[207] S.K. Wong, L.W.C. Lai, D.C.W. Ho, K.W. Chau, C.L.K. Lam, C.H.F. Ng, Sick building syndrome and perceived indoor environmental quality: a survey of apartment buildings in Hong Kong, Habitat Int (2009).
[208] M.G. Apte, Associations between indoor CO2 concentrations and sick building syndrome symptoms in US office buildings: an analysis of the 1994-1996 BASE study data, Indoor Air (2000).
[209] I. Syazwan Aizat, J. Juliana, O. Norhafizalina, Z.A. Azman, J. Kamaruzaman, Indoor air quality and sick building syndrome in Malaysian buildings, Global J. Health Sci. (2009).
[210] S. Gupta, M. Khare, R. Goyal, Sick building syndrome—a case study in a multistory centrally air-conditioned building in the Delhi City, Build. Environ. (2007).
[211] B. Sahlberg, G. Smedje, D. Norback, Sick building syndrome (SBS) among school employees in the county of uppsala, Sweden, Indoor Air (2002).
[212] K. Engvall, C. Norrby, D. Norbäck, Sick building syndrome in relation to building dampness in multi-family residential buildings in Stockholm, Int. Arch. Occup. Environ. Health (2001).
[213] T. Takigawa, B.L. Wang, N. Sakano, D.H. Wang, K. Ogino, R. Kishi, A longitudinal study of environmental risk factors for subjective symptoms associated with sick building syndrome in new dwellings, Sci. Total Environ (2009).
[214] B. Stenberg, N. Eriksson, J. Höög, J. Sundell, S. Wall, The sick building syndrome (SBS) in office workers. A case-referent study of personal, psychosocial and building-related risk indicators, Int. J. Epidemiol. (1994).
[215] D. Norbäck, G. Wieslander, E. Björnsson, C. Janson, G. Boman, Eye irritation, nasal congestion, and facial skin itching in relation to emissions from newly painted indoor surfaces, Indoor Built Environ. (1996).
[216] A. Thatcher, K. Adamson, L. Bloch, A. Kalantzis, Do indoor plants improve performance and well-being in offices? Divergent results from laboratory and field studies, J. Environ. Psychol. (2020).
[217] S.N. Kamaruzzaman, N.A. Sabrani, The effect of indoor air quality (IAQ) towards occupants' psychological performance in office buildings, J. Des. Built (2011).
[218] A. Haapakangas, R. Helenius, E. Keskinen, V. Hongisto, Perceived Acoustic Environment, Work Performance and Well-Being–Survey Results from Finnish Offices, 2008.
[219] K. Korpela, J. De Bloom, M. Sianoja, T. Pasanen, U. Kinnunen, Nature at home and at work: naturally good? Links between window views, indoor plants, outdoor activities and employee well-being over one year, Landsc. Urban Plann. (2017).
[220] N. van den Bogerd, et al., Greening the classroom: three field experiments on the effects of indoor nature on students' attention, well-being, and perceived environmental quality, Build. Environ. (2020).
[221] Q. Jin, H. Wallbaum, Improving Indoor Environmental Quality (IEQ) for Occupant Health and Well-Being: A Case Study of Swedish Office Building, 2020.
[222] A.M. Sadick, M.H. Issa, Occupants' indoor environmental quality satisfaction factors as measures of school teachers' well-being, Build. Environ. (2017).
[223] W. Bischof, M. Bullinger, Indoor conditions and well-being: interim results from the ProKlimA study, Indoor Built Environ. (1998).
[224] L. Lan, Z. Lian, L. Pan, The effects of air temperature on office workers' well-being, workload and productivity-evaluated with subjective ratings, Appl. Ergon. (2010).
[225] L.M. Reinikainen, J.J. Jaakkola, Effects of temperature and humidification in the office environment, Arch. Environ. Health (2001).
[226] C.G. Bornehag, J. Sundell, L. Hägerhed-Engman, T. Sigsgaard, Association between ventilation rates in 390 Swedish homes and allergic symptoms in children, Indoor Air (2005).
[227] P. Dhungana, M. Chalise, Prevalence of sick building syndrome symptoms and its associated factors among bank employees in Pokhara Metropolitan, Nepal, Indoor Air (2020).
[228] K. Reijula, C. Sundman-Digert, Assessment of indoor air problems at work with a questionnaire, Occup. Environ. Med. (2004).
[229] C. Herr, Health and indoor climate-related complaints in office workers reporting toner-related health problems, Epidemiology (2007).
[230] K. Tähtinen, J. Remes, K. Karvala, K. Salmi, M. Lahtinen, K. Reijula, Perceived indoor air quality and psychosocial work environment in office, school and health care environments in Finland, Int. J. Occup. Med. Environ. Health (2020).
[231] P. Skov, O. Valbjørn, B.V. Pedersen, Influence of indoor climate on the sick building syndrome in an office environment, Scand. J. Work. Environ. Health (1990).
[232] S. Muhič, V. Butala, The influence of indoor environment in office buildings on their occupants: expected–unexpected, Build. Environ (2004).
[233] J.L. de Magalhães Rios, J.L. Boechat, A. Gioda, C.Y. dos Santos, F.R. de Aquino Neto, J.R.L. e Silva, Symptoms prevalence among office workers of a sealed versus a non-sealed building: associations to indoor air quality, Environ. Int. (2009).
[234] S.J. Reynolds, et al., Indoor environmental quality in six commercial office buildings in the midwest United States, Appl. Occup. Environ. Hyg (2001).
[235] Y. de Kluizenaar, et al., Office characteristics and dry eye complaints in European workers–The OFFICAIR study, Build. Environ. (2016).
[236] S. Kalender Smajlović, A. Kukec, M. Dovjak, Association between sick building syndrome and indoor environmental quality in Slovenian hospitals: a cross-sectional study, Int. J. Environ. Res. Publ. Health (2019).
[237] R. Zhang, et al., Impacts of dynamic LED lighting on the well-being and experience of office occupants, Int. J. Environ. Res. Publ. Health (2020).
[238] R.M. Ketema, A. Araki, Y.A. Bamai, T. Saito, R. Kishi, Lifestyle behaviors and home and school environment in association with sick building syndrome among elementary school children: a cross-sectional study, Environ. Health Prev. Med. (2020).
[239] G. Lacanna, C. Wagenaar, T. Avermaete, V. Swami, Evaluating the psychosocial impact of indoor public spaces in complex healthcare settings, HERD Heal. Environ. Res. Des. J. (2019).
[240] G.R. Ana, D.G. Shendell, G.E. Brown, M.K.C. Sridhar, Assessment of noise and associated health impacts at selected secondary schools in Ibadan, Nigeria, J. Environ. Public Health (2009).
[241] C.A. Erdmann, M.G. Apte, Mucous Membrane and Lower Respiratory Building Related Symptoms in Relation to Indoor Carbon Dioxide Concentrations in the 100-building BASE Dataset, 2004.
[242] N.A. Nelson, J.D. Kaufman, J. Burt, C. Karr, Health symptoms and the work environment in four nonproblem United States office buildings, Scand. J. Work. Environ. Health (1995).