Building and Environment 229 (2023) 109964

Contents lists available at ScienceDirect

Building and Environment

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

Ten questions concerning the impact of environmental stress on office workers

Mohamad Awada [a], Burcin Becerik-Gerber [a,*], Ruying Liu [a], Mirmahdi Seyedrezaei [a], Zheng Lu [a], Matheos Xenakis [b], Gale Lucas [c], Shawn C. Roll [d], Shrikanth Narayanan [e]

[a] Department of Civil and Environmental Engineering, University of Southern California, USA
[b] Department of Industrial & Systems Engineering, University of Southern California, USA
[c] USC Institute for Creative Technologies, University of Southern California, Los Angeles, CA, USA
[d] Chan Division of Occupational Science and Occupational Therapy, University of Southern California, USA
[e] Signal Analysis and Interpretation Lab, University of Southern California, Los Angeles, CA, USA

A R T I C L E I N F O

Keywords:
Stress
Indoor environmental quality
Stress recovery
Office
Interior design

A B S T R A C T

We regularly face stress during our everyday activities, to the extent that stress is recognized by the World Health Organization as the epidemic of the 21st century. Stress is how humans respond physically and psychologically to adjustments, experiences, conditions, and circumstances in their lives. While there are many reasons for stress, work and job pressure remain the main cause. Thus, companies are increasingly interested in creating healthier, more comfortable, and stress-free offices for their workers. The indoor environment can induce environmental stress when it cannot satisfy the individual needs for health and comfort. In fact, office environmental conditions (e.g., thermal, and indoor air conditions, lighting, and noise) and interior design parameters (e.g., office layout, colors, furniture, access to views, distance to window, personal control and biophilic design) have been found to affect office workers' stress levels. A line of research based on the stress recovery theory offers new insights for establishing offices that limit environmental stress and help with work stress recovery. To that end, this paper answers ten questions that explore the relation between the indoor office-built environment and stress levels among workers. The answers to the ten questions are based on an extensive literature review to draw conclusions from what has been achieved to date. Thus, this study presents a foundation for future environmental stress related research in offices.

1. Introduction

The World Health Organization has recognized stress as the "global epidemic of the 21st century" [1]. Various factors–from geopolitical and societal to individual and interpersonal–can contribute to an individual's stress. Among all the stress factors, work has been identified as a key stressor for many individuals. It has been widely shown that work-related stress can negatively influence workers' physiological, psychological, and cognitive functions [2,3], thus leading to lower productivity and increased absenteeism [4]. Although many components of work-related stress are challenging to address, the physical work environment is a factor that research has shown can be altered to mitigate adverse impacts on stress [5–8].

Given that office and administrative work is the most common type of work in the U.S., accounting for over 18 million workers [9], it is often affected by a variety of stressors. In this paper, we define office workers as employees who spend most of their time working at a desk workstation performing activities such as reading, writing, and typing on their computers. Office work entails various job stressors that comprise a range of organizational (e.g., tight deadlines, heavy workload, unfamiliar duties) [10], social (e.g., lack of support, work surveillance) [11], and economic (e.g., inadequate income) [12] conditions that increase workers' stress levels. In addition, indoor environments and physical workspaces play a major role in work stress among office workers.

Rashid and Zimring [13] have advocated for acknowledging the contribution of the work environment to overall work-related stress through their proposed conceptual model. A core principle of this model is understanding ***environmental stress*** is distinct from ***work stress***. ***Environmental stress*** occurs when features of the workspace hinder personal needs for comfort and health and is manifested in physiological

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

https://doi.org/10.1016/j.buildenv.2022.109964
Received 19 October 2022; Received in revised form 27 December 2022; Accepted 28 December 2022
Available online 29 December 2022

and psychological responses to uncomfortable or unhealthy environmental conditions. Rashid and Zimring's model describes two categories of physical environmental variables: (1) Indoor Environmental Quality (IEQ) parameters such as noise, lighting, ambient temperature, and air quality, and (2) interior design parameters such as furniture, colors, biophilic design, access to views through windows and finishing material. Specifically, degraded indoor environmental quality and inappropriate space design have been associated with increased environmental stress, leading to elevated work stress and associated outcomes [13]. Lamb and Kwok [14] found that environmental stressors indirectly affect workers' performance by constraining motivation and increasing tiredness and distractibility. They argue that limiting the effect of these stressors by enhancing the IEQ conditions could result in improved productivity. Similarly, Singh et al. [15] demonstrated an average increase in productivity of 2.86 work hours every month due to reduced environmental stress when office workers were moved from traditional offices to LEED-rated buildings.

Accordingly, some companies are interested in optimizing the physical office spaces to reduce experiences of stress at work. In fact, in a survey of building professionals in 2020 on the development of healthy buildings [16], stress was rated as the most important problem for research, design, construction, and operation of healthier buildings in terms of mental well-being. Furthermore, respondents indicated that offices should be given high priority to promote comfortable and more productive work conditions. This serves as a call for companies to invest in office environments that reduce environmental stress, thus creating healthier and more productive work environments [17].

This paper aims to examine environmental stress, understand how the indoor office environment affects the psychophysiological state of office workers and determine how environmental stress perception varies between different populations in an effort to promote inclusive office design. Based on this, we proceed by presenting our vision of intelligent stress restorative office design that lies at the intersection of engineering, architecture, psychology, and computer science. We also provide rich and insightful future research directions for interested parties in the topic of environmental stress.

Fig. 1 provides a schematic overview of the investigation presented through detailed responses to ten questions. Questions 1 and 2 provide an overview of the general concept of stress and elaborate on the primary physiological and behavioral indicators of stress in office settings. Questions 3 to 6 provide an overview of causes and potential solutions for reducing environmental stress among office workers in physical and virtual spaces, including an emerging concept of nature contact. Questions 7 and 8 focus on the individualized needs of workers relative to physical office environments, including a rapidly growing neurodiverse workforce with unique sensory experiences within physical environments. Question 9 presents a vision for using technologies that support stress management and recovery within office workspaces. Finally, Question 10 identifies crucial gaps and challenges for environmental stress research in offices and lays the foundation for future research directions and advancements.

2. Ten questions

2.1. What is stress?

An early definition of biological stress was provided by Hans Selye in the 1930s: "stress is a non-specific response of the body to any demand" [18]. Selye established a three-stage stress model, the General Adaptation Syndrome (GAS). The GAS model explains how the human body reacts and adapts to stressors [19]. The first stage, called ***alarm reaction***, refers to the initial reactions the body when facing a stressor (e.g., increased heart rate, cortisol release, adrenaline boost). In the second stage, ***resistance***, the body tries to overcome the stress shock. If the stressful situation no longer exists, the body reduces the secretion of hormones and stabilizes the heart rate and blood pressure to pre-stress levels. However, if the stressful situation persists, the body cannot recover and restore pre-stress functioning levels, leading to the third stage: ***exhaustion***. Battling with stress for long periods can drain the body's energy by depleting its physical, emotional, and cognitive resources.

Thus, stress is defined differently depending on its duration. ***Acute stress*** is short-term stress due to a recent anticipated or unexpected event. During an episode of acute stress, people experience emotional distress and irritation as well as muscle tension, headaches, and back pain [20,21]. ***Episodic stress*** occurs when people experience acute stress repeatedly (e.g., repeated tight deadlines at work), which can lead to headaches, hypertension, and heart disease [21]. ***Chronic stress*** results from stressors that persist continuously over time (e.g., difficult marriage or job, health problems, poor living conditions). Chronic stress is associated with digestive issues, sleeping problems, and losing focus on daily tasks, and it can contribute to lifestyle diseases such as cardiovascular disease and type 2 diabetes [22].

Though there is no unified definition for stress, most definitions include the primary tenet of exposure to an event, situation, or stimulus (i.e., stressor) that is manifested by a bodily reaction [23]. For instance, the Cleveland Clinic's definition described stress as "a normal reaction (physically, mentally, or emotionally) the body has when changes occur" [24], and the American Psychological Association defines stress as "the pattern of specific and nonspecific responses a person makes to stimulus events that disturb his or her equilibrium and tax or exceed his or her ability to cope" [25]. Engineering-based stress models focus on what happens to an individual rather than what happens within the individual [26]. In contrast, Lazarus and Folkman proposed the

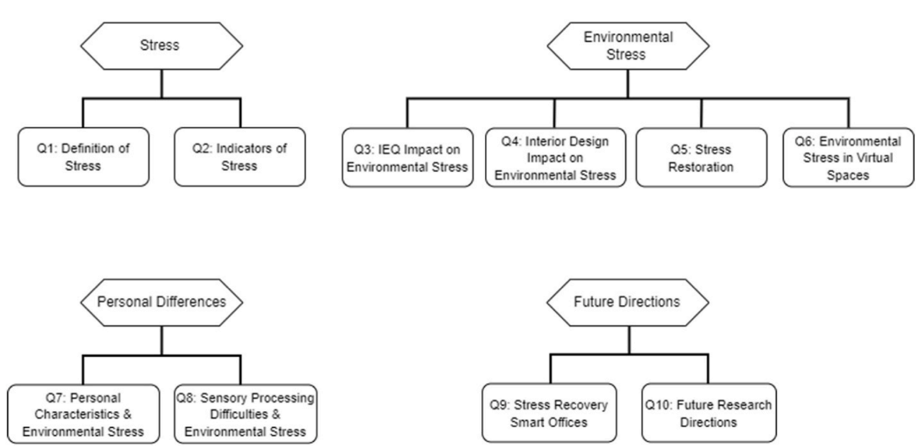

Fig. 1. Schematic overview of the ten questions concerning environmental stress in offices.

transactional model of stress in which they consider stress as an outcome of the interaction between an individual and the environment that can be moderated by individual perceptions [27].

The BioPsychoSocial (BPS) model of stress is a frequently referenced transactional model, explaining that how a bodily reaction manifests depends on how the stressor is appraised; specifically, whether an individual perceives the stressor as an opportunity/challenge or a threat [28]. Within this framework, a stressor is perceived as a challenge when the individual believes they have sufficient capabilities and personal resources to meet the demands of the stressful situation. Alternatively, a stressor is perceived as a threat when the individual believes they do *not* have sufficient capabilities or personal resources to meet the demands of the stressful situation. In the context of environmental stress, a similar analogy can be made; when the indoor office environment fails to meet workers' demands and expectations for a healthy and comfortable workplace, environmental stress starts to accumulate. On the other hand, a workplace that can meet these demands provides the worker with an opportunity to improve their productivity, health, and comfort thus reducing environmental stress.

2.2. What are the physiological and behavioral indicators of stress among office workers?

During a stressful situation, the body activates the sympathetic nervous system [28], which signals the adrenal glands to release cortisol and catecholamine hormones into the body, leading to physiological responses [28]. This fight or flight response prepares the body to face stressors by raising the blood pressure and increasing the heart rate to

Table 1
Physiological and behavioral indicators of stress in offices.

Physiological Indicators					
Indicator	Study Parameters	Data Collection	General Behavior under stress	Pros	Cons
Electrocardiogram (ECG)	Heart rate, Heart rate variability (HRV)	Cardiovascular activity using electrical sensors	Increased heart rate [29] High frequency in HRV decreases [11] Low frequency in HRV increases [11] Time domain metrics decrease [11]	Provides high accuracy in stress detection, Unobtrusive	Heart rate indicators are not unique to stress
Blood pressure (BP)	Mean, Minimum, Maximum	Cardiovascular activity using pressure sensors	Increased blood pressure [36]	Good indicator for strong stress reactions	Not accurate as other signals in detecting subtle stress responses
Skin Temperature	Mean, Minimum, Maximum	Surface temperature of the skin using skin temperature sensors	No consensus: in some studies skin temperature was found to increase [29], in others it was found to decrease [38]	Unobtrusive	No consensus on the effect of stress
Electro-Dermal Activity (EDA)	Skin conductance level, Skin conductance reaction	Electric conductivity of skin as an indicator of sweating using EDA sensors	Increased electro-dermal activity [30]	Provides high accuracy in stress detection, Unobtrusive	High electro-dermal activity is not unique to stress
Electroencephalography (EEG)	Frequency bands (alpha, beta, gamma, theta, and delta waves)	Brain electrical activity using scalp electrodes	High beta activity [39,40] Frontal alpha asymmetry [41,42]	Provides high accuracy in stress detection	Obtrusive
Electromyography (EMG)	Mean, Minimum, Maximum	Muscles contraction through electric signals	Increased muscle tension (upper back, shoulders, neck) [43,44]	Detects involuntary and minor facial reactions to stress	Obtrusive
Respiration	Respiration rate, Oxygen intake	Breathing activity using breathing sensors	Increased respiration rate [31]	Good indicator for strong stress reactions	Obtrusive, considered less reliable in comparison to other physiological signals
Eye Movement	Pupil dilations, Blinks, Fixations, Gaze	Eye-tracking sensors are used to measure eye-related features	Dilated pupils [45,46] Increased blinking rate [47,48]	Provides high accuracy in stress detection	Privacy and security concerns
Cortisol Hormone	Cortisol blood level	Salivary samples	Increased release of cortisol by adrenal glands [32]	Provides high accuracy in stress detection	Not suitable for real-time, obtrusive
Catecholamines Hormone	Catecholamines level	Urinary samples	Increased release of catecholamines by adrenal glands [49,50]	Provides high accuracy in stress detection	Not suitable for real-time, obtrusive
Behavioral Indicators					
Posture and Body Movement	Head and upper limbs movement, Posture, Movement pace	Computer vision is used to detect the skeleton of the human body	Increased head movements' frequency and speed [33,51], yet it remains difficult to generalize postural and movement reactions to stress, for that machine learning techniques are typically employed to detect stress using this data	Allows for integration of activity detection to further understand the stress context	Privacy and security concerns, expensive, requires intensive processing
Keyboard and Mouse Dynamics	Keystrokes, Mouse clicks, Mouse movement and wheel scroll, Click pressures	Computer applications can be installed to monitor this data	No consensus: Contradictory results are presented in many research studies, e.g. [30,33,35,52]	Unobtrusive data collection, Inexpensive	Privacy and security concerns, No consensus on the effect of stress
Facial Expressions	Facial action units	Computer vision used to extract facial features	It is difficult to generalize facial reactions to stress across people, for that machine learning techniques are typically employed to detect stress using facial expressions	Provides a wide range of data for accurate stress detection	Privacy and security concerns, expensive, requires intensive processing
Speech	Pitch, Speaking speed	Recorded using voice recorders	Voice pitch increases, speaking speed increases [53]	Can be used specifically for office call centers stress monitoring	Environmental noise interferes with the quality of data

push blood faster, increasing respiration rate to allow for more oxygen consumption, elevating perspiration rate to cool the body, and dilating pupils for more light intake to improve visual acuity. Given the direct association of physiological signals to human stress states, many studies have examined the relationship between psychological stress and these physiological responses [29–32]. Furthermore, stress induces behavioral reactions, some of which are the result of physiological changes. For instance, tense vocal muscles increase the voice pitch, irritability increases bodily movement [33] and changes facial expressions [34], and stress can alter how we interact with technological devices. In fact, several researchers have studied the feasibility of using keyboard and mouse dynamics as stress indicators among office workers [35].

In general, physiological indicators provide high accuracy in stress detection. However, typical physiological responses seen during stress are, in fact, not unique to stress; thus, stress detection using physiological data can become problematic when it is isolated from a situational context [36]. Including situational context was supported by Liao et al. [33] who postulated that "*some physical symptoms such as fast heart rate are not unique to stress*." Unlike most physiological signals, behavioral data collection is unobtrusive and can be easily integrated with activity detection to further understand the stress context. For example, a Kinect camera can be installed at an office station to detect bodily movements and facial expressions associated with stress when used with a pre-trained algorithm for activity detection (writing, typing, talking, meeting). Yet, such behavioral data collection requires intensive processing and can raise privacy and security concerns [36].

A summary of the main physiological and behavioral indicators used in the literature is presented in Table 1. This summary was established after performing a literature review using the PRISMA framework [37] to understand the current state of research in the domain of stress detection in office spaces. PubMed, IEEE, and Web of Science databases were searched for articles published in peer-reviewed journals, books, and conference proceedings. The searches did not include any time restrictions. The following query (office OR workplace) AND (stress*) AND (detect* OR measure* OR recogn* OR monitor*) was used to search the title, abstract and keywords. Between the different databases, 5911 articles were acquired. Each article's title and abstract were screened for relevance to the investigation of physiological and behavioral indicators of stress in the workplace. Forward and backward snowballing methodology was also applied to capture all indicators of stress. It is worth noting that the list of indicators focuses on those that are feasible for the assessment of office workers' stress specifically. This is in contrast to non-feasible stress assessment methods for the office context include Functional Magnetic Resonance Imaging (fMRI), which requires special medical equipment, and the use of GPS data, which is not effective at the building scale. The table also details the primary study parameters used by researchers to determine stressful conditions and the most common data collection methods. The general behavior of each indicator is also described. Finally, the pros and cons of using each signal for stress detection and monitoring among office workers are presented.

2.3. How does indoor environmental quality (IEQ) affect office workers' environmental stress levels?

To answer this question, a literature review using the PRISMA framework [37] was performed to understand the effects of the IEQ parameters on the stress levels of office workers. Web of Science and PubMed databases were searched for articles published in peer-reviewed journals, books, and conference proceedings. The search did not include any time restrictions. The search was based on keywords (TS = Topic) using TS= (office OR workplace) AND TS= (*stress*) AND TS= (IEQ OR indoor environment OR indoor environmental quality). Each article's title and abstract were screened based on their relevance to the effect of different indoor environment quality on the environmental stress of office workers. A total of 59 articles were relevant. Next, a full paper screening was performed. Only papers presenting a causal or correlational analysis of IEQ influence on human stress in the office environment were included in our review. Forward and backward snowballing methodology was also applied to capture papers missed by the initial search. The final number of articles included to answer this question was 34. Table 2 presents a summary of these findings and key considerations are summarized below.

Ambient acoustic noise characteristics have various effects on workers' stress levels. Unpredictable noise (e.g., telephone rings, email/message notifications) is associated with increased levels of stress [13], and uncontrollable noise (e.g., background speech) leads to psychological tension resulting in elevated cortisol levels [54]. On the other hand, steady and constant noise is considered less frustrating and easier to get used to, which explains why white noise has been recommended as a masking sound to lessen the intelligibility level of intrusive speech in open-plan offices [55]. Although the dominant theory revolves around noise having a detrimental impact on workers' performance, psychology, and physiology [56], some studies found that an appropriate noise level matched to personal preferences can ease the anxiety that may result from silence. For instance, participants exposed to white noise at 45 dB showed lower electrodermal activity levels, thus indicating lower stress levels than those exposed to silence [57].

Thermal conditions in the workplace represent another major environmental stressor for office workers. Several studies have examined the effect of ambient air temperature in office settings on stress levels. For instance, Lan and Lian [58] found that participants presented more psychological tension and mood disturbance at 28 °C compared to 21 °C. On the other hand, Sepehri et al. [59] showed that ambient temperatures below 22 °C can cause a substantial increase in respiration rate, electrodermal activity, and skin temperature, which indicates elevated stress. Given that thermal preferences vary among office workers, control over the temperature–whenever possible–is preferred to ensure comfortable work conditions and, as such, reduce the stress associated with adverse environmental stimuli [60].

Lighting has numerous components that impact office workers' stress, each influencing physiological and psychological states differently. Poor distribution of light on vertical surfaces can create glare on computer screens, which leads to uncomfortable work settings and increased stress levels among office workers [61]. Color-correlated temperature is a metric used to describe the color of the light emitted by a source in degrees of Kelvin, with low Kelvin values indicating a warm yellow/red color and high Kelvin values indicating white/blue colors [62]. The literature suggests that low levels of color-correlated temperature provide a sense of relaxation for office workers within their workspace [63]. Illuminance has been associated with visual comfort. A cross-sectional study that included 464 full-time office workers found that non-comfortable illumination levels (e.g., too bright) increased self-reported annoyance and stress levels [6]. Finally, studies have shown that workers prefer to work in offices with access to natural light instead of electric lighting. In an experimental study, Ergan et al. [64] found that participants exposed to natural light showed lower electrodermal activity levels and reported lower subjective stress levels compared to participants who were not subjected to natural light.

Air quality has been identified as causing stress among office workers. In a laboratory study conducted by Choi et al. [65], participants demonstrated high beta-wave activity in the temporal lobe when they were exposed to air pollutants suggesting high environmental stress levels. Furthermore, Tu et al. [66] found that when carbon dioxide concentration increased from 8000 to 12,000 ppm, participants reported higher rates of headache and fatigue along with an increase in blood pressure indicating a higher level of stress and arousal. Thus, proper ventilation is a necessity in office spaces. In a comparative analysis of four buildings with different ventilation systems, Kamaruzzaman and Sabrani [67] showed that high indoor air quality maintained through adequate ventilation systems reduces self-reported stress levels among office workers.

Table 2
Studies examining the effect of IEQ parameters on the environmental stress of office workers.

Paper	Stress Assessment Method	Physiological/ Behavioral Signals	IEQ Parameters Under Study	Type of Study	Participant Number	Results
[70]	Questionnaires	–	Lighting	Experimental	24	High CCT (6500 K) reduces stress levels
[71]	Physiological	HR	Noise	Experimental	25	Low-frequency multi-tonal noise, and low-frequency stationary noise with regular amplitude modulation results in increased heart rate
[66]	Physiological	HR, BP	IAQ, Temperature	Experimental	30	Blood pressure increases at a CO_2 level of 12,000
[72]	Physiological	BP	IAQ	Experimental	22	When the operative temperature increased from below 20.5 °C-25 °C, systolic blood pressure and diastolic blood pressure decreased
[73]	Questionnaires, Physiological	HR	IAQ	Experimental	4	Elevated CO2 concentration leads to changes in heart rate variation, and an increase of peripheral blood circulation.
[6]	Questionnaire	–	IAQ, Temperature, Noise, Lighting	Observational	464	Higher satisfaction levels of perceived air quality, thermal comfort, noise, and lighting, were significantly associated with a reduction in stress at work.
[74]	Physiological, Questionnaire	HR, ST, EDA	Lighting	Experimental	15	There was no significant change in physiological stress indicators or subjective perceived stress between static lighting and dynamic lighting conditions
[5]	Questionnaire	–	Temperature, IAQ	Observational	19	A ML model reached an 88% accuracy detecting stress using environmental temperature, humidity, air pressure, and CO2 data
[58]	Questionnaire	–	Temperature	Experimental	21	Participants presented more psychological tension and mood disturbance at 28 °C compared to 21 °C
[65]	Physiological, Questionnaire	BEA	Temperature, IAQ, Noise	Experimental	12	Occupants' stress was maximized when they were exposed to a temperature of 30 C, odor irritants (VOCs) and to road traffic noises
[63]	Questionnaire	–	Lighting	Experimental	56	2700K color-correlated temperature provides a sense of relaxation for office workers
[75]	Physiological	HR, EDA	Lighting	Experimental	72	Participants showed a larger decrease in heart rate while exposed to a façade with non-uniform distribution of openings, in comparison to venetian blinds
[76]	Questionnaire	–	IAQ, Lighting	Observational	779	Stress is associated with self-reported physical symptoms caused by the physical environment
[77]	Questionnaire	–	Noise	Observational	128	Lower levels of ambient noise were found to buffer the negative impact of psychosocial job stress upon job satisfaction, well-being, or organizational commitment
[49]	Hormone test	Cortisol, Catecholamines	Noise	Experimental	47	There was no statistically significant effect of noise on the stress hormones.
[78]	Questionnaire	–	Noise	Observational	145	Enhanced acoustical conditions (absorbing tiles & wall absorbents) were associated with lower cognitive stress
[50]	Hormone test	Cortisol, Catecholamines	Noise	Experimental	38	Hearing impaired participants showed higher stress hormone levels during the high noise compared to the low noise condition
[79]	Questionnaire	–	IAQ, Noise, Lighting	Observational	1830	The results indicate that poor air quality and noise affect the mental state of office workers and increase their stress
[80]	Physiological, Questionnaire	Cortisol, BP, HR	IAQ	Experimental	10	Inhaling emissions of volatile constituents from cedar timber showed no significant effect on the psychological and physiological factors
[64]	Physiological, Questionnaire	BEA, EDA, BP, MT	Lighting	Experimental	40	Poor lighting leads to increased psychophysiological stress arousal
[81]	Physiological, Behavioral	BEA, HR, MT, ST, EDA, BP	Temperature, Noise	Experimental	35	In the presence of high noise levels, the rise in air temperature aggravated the mean value of neurophysiological responses.
[54]	Hormone test, physiological	Cortisol, HR, BP	Noise	Experimental	59	Working during speech background noise leads to elevated HRV LF/HF ratio with time and increased cortisol levels
[57]	Physiological	EDA	Noise	Experimental	39	White noise level at 45 dB resulted in reduced electrodermal activity in comparison to ambient noise and white noise at 65 dB
[59]	Physiological	BP, HR, ST, EDA	Temperature	Experimental	24	Blood pressures, heart rate, galvanic skin response, and respiration rate increased as the air temperature decreased
[82]	Physiological	BEA, HR	Noise	Experimental	12	Heart rate and heart rate variability increased significantly in a louder noise condition 65 dB(A), in comparison to a 45 dB condition.
[83]	Physiological, Hormone test	MT, BP, HR, Cortisol	Noise	Experimental	10	Simulated open-plan office noise at 65 dB has no effect on the physiological state of people
[84]	Physiological, Hormone test	HR, BP, Cortisol	Noise	Experimental	10	Reductions in HRV (LF and RMSSD) were observed during noise exposure. No significant changes in blood pressure, salivary cortisol or amylase were observed.
[85]	Questionnaire	–	Lighting	Experimental	64	There was an association between reduced job stress severity and direct lighting
[86]	Questionnaire	–	Temperature	Observational	46	Perceived thermal comfort was associated with employees' stress
[87]	Questionnaire	–	Lighting	Experimental	90	There was no difference in job stress between a parabolic downlighting system and a ceiling suspended, lensed-indirect up lighting system

(continued on next page)

Table 2 (*continued*)

Paper	Stress Assessment Method	Physiological/ Behavioral Signals	IEQ Parameters Under Study	Type of Study	Participant Number	Results
[67]	Questionnaire	–	IAQ	Observational	394	High indoor air quality maintained through adequate ventilation systems reduces self-reported stress levels among office workers
[88]	Questionnaire, Physiological, Behavioral	HR, EDA, Facial expressions	Noise	Experimental	40	Open plan office noise reduces the psychological stress, increases heart rate, and increases phasic skin conductance
[68]	Questionnaire	–	IAQ, Temperature, Noise, Lighting	Observational	988	Low satisfaction with indoor air quality and noise predicts higher levels of mental stress, rumination, or worry
[69]	Questionnaire	–	IAQ, Temperature, Noise, Lighting	Observational	393	Low levels of stress were significantly predicted by higher satisfaction with indoor thermal conditions

HR: Heart Rate, BP: Blood Pressure, ST: Skin Temperature, EDA: Electro-Dermal Activity, BEA: Brain Electrical Activity, MT: Muscle Tension, RR: Respiration Rate.

Finally, studying environmental stress relative to IEQ among office workers should not be restricted to traditional office spaces. A recent study that investigated the influence of IEQ on workers' well-being during the work-from-home period due to the COVID-19 pandemic concluded that mental stress, rumination, and worry were predicted by low satisfaction levels with noise and indoor air quality [68]. Furthermore, Bergefurt et al. [69] found that while working from home, low levels of stress were significantly predicted by higher satisfaction with indoor thermal conditions.

2.4. How does interior design affect office workers' environmental stress levels?

To answer this question, a literature review using the PRISMA framework [37] was performed to examine the effect of interior design on occupants' stress levels. Web of Science and PubMed databases were searched for articles published in peer-reviewed journals, books, and conference proceedings. The searches did not include any time restrictions. The following query (office OR workplace) AND (*stress*) AND (design* OR indoor). Each article's title and abstract were screened based on their relevance to the effect of different interior design parameters on the environmental stress of office workers. 104 articles were relevant. Next, a full paper screening was performed. Only papers presenting causal or correlational analysis on the influence of interior design parameters on human stress in the office environment were included in our review. Forward and backward snowballing methodology was also applied to capture papers missed by the initial search. The final number of articles included to answer this question was 29. A standardized form was used to gather information from each paper. Table 3 presents a summary of these findings and key considerations are summarized below.

Finishing materials and furniture are primary components of the interior design of office spaces linked to workers' environmental stress levels. Visual stimulation from wood wall panels has been found to result in lower tension and fatigue compared to non-wooden indoor environments, such as white steel panels or painted plaster [89] When working in wooden rooms, workers show lower heart rate and heart rate variability, which indicates a more relaxed state [7]. In a similar study, salivary cortisol concentration was lower in workers engaging in an office-like environment with oak wood furniture than when engaging in spaces with non-wood furniture [90]. Uncomfortable chairs and workstations are considered ergonomic stressors, and low satisfaction with the workstation's ergonomic setup is associated with elevated levels of distress [79]. Among all office furniture studies, sit-stand desks have been a predominant focus of recent investigations on the perceived stress levels of workers, mostly failing to identify any difference between effects on stress levels between standard and sit-stand office desks [91, 92].

Personal control over the indoor environment moderates the psychological stress associated with negative environmental stimuli. Most studies in this area have focused on the consequences of privacy and work satisfaction based on control of an ergonomic office setup, as these factors relate to workers' psychological stress [93]. Paciuk [94] postulated that a work environment should be adjustable and provide the worker with the flexibility to adapt to different work needs, requirements, and conditions. To that end, Huang et al. [95] found that providing office workers with control over the ergonomic settings of their workstations allowed them to use their workspace more effectively, resulting in better performance, environmental satisfaction, and communication with their peers. These positive outcomes were associated with reduced psychological stress reactions. In another study, Robertson and O'Neill [96] demonstrated that more adjustable features in a workstation resulted in enhanced group collaboration, decreased stress, and limited physical health problems.

Office interior color is another factor that can influence workers' moods and stress levels. This influence is thought to be based on synesthesia, which occurs when people experience one of their senses through another [97]. For instance, some color-related literature argues that red is often associated with anger, aggression, and anxiety, while blue is associated with tranquility and calmness [98]. Such conclusions were further supported by an experimental study by Kwallek et al. [99] that showed office workers who worked in a red room had higher anxiety and stress levels than those who worked in a blue room. Another study examining virtual work environments showed that incorporating dark-colored surfaces increased stress levels [64].

Office layout choices relative to a workspace's physical and social use are also important. Open-plan offices are often associated with increased noise levels, lack of privacy, and inability to control the indoor environment [100], all of which tend to be related to increased environmental stress levels. For instance, Sander et al. [88] showed that the auditory environment of open-plan offices reduces psychological well-being compared to a quieter, private office acoustic environment. Furthermore, Rashid et al. [101] argue that uncontrollable visual and physical work settings in open-plan offices negatively affect employees by decreasing their concentration and increasing their stress levels, thus leading to degraded productivity. These results were further supported by Haapakangas et al. [102] who found that work distractions caused by the layout of open-plan offices are a central source of environmental stress. Similarly, sharing the workspace with other adults or children while working from home during the COVID-19 pandemic was considered a major environmental distractor associated with stress [103].

Finally, access to ***natural views and nature integration*** in office spaces are two interior design parameters that have benefits in moderating and reducing office workers' stress levels while working. These effects have been supported by the stress reduction theory [104], which states that exposure to natural elements leads to a positive emotional state and promotes recovery by easing the alert state following a stressful situation. More insights about this theory are discussed in question 5.

Table 3
Studies examining the effect of interior design parameters on the environmental stress of office workers.

Paper	Stress Assessment Method	Physiological/ Behavioral Signals	Interior Design Parameters Under Study	Study Type	Participant Number	Results
[7]	Physiological	BP, EDA, HR, ST	Finishing Material	Experimental	20	When working in wooden rooms, workers show lower heart rate and heart rate variability, which indicates a more relaxed state
[90]	Physiological	HR, Cortisol	Furniture	Experimental	61	Salivary cortisol was lower in workers engaging in an office-like environment with oak wood furniture than when engaging in spaces with non-wood furniture
[105]	Physiological	EDA, HR	Distance to Window	Experimental	32	Decreases in physiological stress levels were found when participants were closer to the window
[106]	Questionnaire	–	Natural Views	Experimental	86	The reports from participants regarding perceived stress level did not show a significant difference between having and not having a window with natural views
[107]	Physiological, Questionnaire	BEA, HR, EDA	Natural Views	Experimental	30	Viewing green space through a high-rise window resulted in a significant increase in alpha wave power and a significant decrease in the skin conductance.
[99]	Questionnaire	–	Colors	Experimental	36	Office workers who worked in a red room had higher anxiety and stress levels than those who worked in a blue room
[89]	Physiological, Questionnaire	BP	Finishing Material	Experimental	14	Visual stimulation from wood wall panels has been found to result in lower tension and fatigue compared to non-wooden indoor environments
[108]	Physiological, questionnaire	MT, BP, BEA	Natural Views, Biophilic Design	Experimental	38	When neither the window view nor the indoor plants were shown, participants suffered the highest degree of tension and anxiety
[95]	Questionnaire	–	Personal Control	Observational	89	Providing office workers with control over the ergonomic settings of their workstations reduced psychological stress
[109]	Questionnaire	–	Biophilic Design	Experimental	385	Window scenes and the presence of indoor plants can significantly reduce the psychophysiological arousal
[110]	Hormone test, physiological	HR, Cortisol	Office Layout	Observational	60	Individuals in old offices had lower HRV at night, and a larger rise in cortisol upon awakening compared with those in renovated (more illuminance, lower noise) office spaces
[111]	Questionnaire	–	Natural Views	Observational	931	Office workers with forest views reported lower job stress in comparison to workers without the forest views
[79]	Questionnaire	–	Furniture	Observational	1830	Uncomfortable chairs and workstations are considered ergonomic stressors, and is associated with elevated levels of distress
[64]	Physiological	BEA, EDA, BP, MT	Colors	Experimental	40	Dark-colored surfaces in an office space increased stress levels
[96]	Questionnaire, Interviews	–	Personal Control	Experimental	40	More adjustable features in a workstation resulted in enhanced group collaboration, decreased stress, and limited physical health problems
[112]	Physiological	BEA, EDA, BP	Biophilic Design	Experimental	30	Viewing blue and purple flowers resulted in a significant increase in alpha relative waves, and a significant increase in parasympathetic nervous activity.
[113]	Physiological, Questionnaire	HR, EDA, BP	Biophilic Design	Experimental	100	Biophilic indoor environments had consistently better recovery responses after stressor compared to those in the non-biophilic environment.
[114]	Physiological, Questionnaire	HR, EDA, BP	Biophilic Design	Experimental	28	Biophilic elements led to a drop of 8.6 mmHg in systolic and 3.6 mmHg in diastolic blood pressure resulting in reduced stress
[8]	Physiological, Questionnaire	BP, BEA	Biophilic Design	Experimental	50	Observing indoor ornamental plants in a working environment for 5 min can decrease mental stress by enhancing brainwave activity and lowering anxiety.
[115]	Physiological, Questionnaire	HR	Biophilic Design	Experimental	63	Gazing intentionally at nearby plants on a daily basis in the work environment can reduce the psychological and physiological stress of office workers.
[116]	Physiological	HR	Biophilic Design	Experimental	24	Active interaction with indoor plants reduces psychological stress and results in reduction of total log [LF/(LF + HF)]
[117]	Physiological	HR, BP	Office Layout	Observational	231	Workers in open bench seating experienced lower perceived stress at the office than those in cubicles
[118]	Physiological	HR, BP, SC	Biophilic Design	Experimental	30	Biophilic interventions reduces physiological (heart rate, blood pressure) and psychological stress
[119]	Questionnaire	–	Biophilic Design	Observational	565	A greater amount of indoor nature contact at work was significantly associated with less job stress
[88]	Questionnaire, Physiological, Behavioral	HR, EDA, Facial expressions	Office Layout	Experimental	40	The auditory environment of open-plan offices reduces psychological well-being compared to a quieter, private office acoustic environment
[91]	Hormone test, Physiological	HR, Cortisol	Furniture	Experimental	18	No differences in stress noted between standard and sit-stand office desks
[92]	Questionnaire	–	Furniture	Experimental	18	No differences in stress noted between standard and sit-stand office desks
[102]	Questionnaire	–	Office Layout	Observational	158	Work distractions caused by the layout of open-plan offices are a central source of environmental stress
[103]	Questionnaire	–	Office Layout	Observational	209	Sharing the workspace with other adults or children while working from home was considered a major environmental distractor associated with stress

HR: Heart Rate, BP: Blood Pressure, ST: Skin Temperature, EDA: Electro-Dermal Activity, BEA: Brain Electrical Activity, MT: Muscle Tension, RR: Respiration Rate.

2.5. How can nature contact reduce stress or promote stress recovery among office workers?

In addition to removing direct environmental stressors, it is also important to dedicate efforts toward environmental solutions that promote stress recovery, that is, assisting workers in returning to baseline psychophysiological conditions after experiencing a stressor. Stress Reduction Theory (SRT), proposed by Ulrich et al. [104] suggests that nature-related settings can facilitate stress recovery. This theory is supported by evolutionary perspectives suggesting that our early human ancestors have formed a predisposition towards natural elements such as plants and water to help them survive. However, human-nature interaction is greatly limited in contemporary social life due to urbanization and modern lifestyle [120]. As people spend 90% of their time indoors [121], new efforts have been made to incorporate natural features into buildings. This concept, known as biophilic design, provides building occupants with essential exposure to nature. Building professionals –practitioners and researchers– aware of its importance have been pushing toward adopting biophilic design in office spaces [16]. The literature provides a range of studies discussing biophilic design's positive effects on workers' cognitive performance, health, and well-being [120]. More specifically, research shows that nature contact can actively help office workers recover from work stress [122].

Biophilic design includes many naturistic features (e.g., lighting, fresh air, water, plants, animals) and can be achieved through visual, auditory, and olfactory stimuli [120]. For example, biophilic office environments with stress recovery effects can be created by visual stimuli, including not only live plants but also greenery scenes displayed through projection and artworks [123,124]. Auditory stimuli can be achieved by playing ambient sounds, such as wind, streams, birds, and chirping crickets [125,126]. Olfactory stimuli can reduce stress but are less often incorporated in the biophilic design of office spaces [120]. Aromatherapy using essential oils is widely used for olfactory interventions in other settings [127]. For example, lavender has been reported by many researchers as a sedative odor with the capability to reduce mental stress, demonstrated by decreased heart rate and skin conductance [128]. Other scents, such as odors from herbs, fruits, flowers, leaves, and woods, can support stress reduction, considering the pleasantness, happiness, and calmness induced by the scent [129].

Although biophilic design can be beneficial, there are potential limitations and negative consequences. Visual and auditory stimuli may interrupt office workers' tasks and disturb productivity or workflow. Olfactory stimuli added to an environment can negatively impact indoor air quality, and certain scents that may help some workers feel less stressed may harm others, such as those with sensitivities to fragrances [130]. In an ongoing experimental study by our research team, we found that the stress recovery effect of bergamot scent depends on gender; the change in heart rate variability revealed that bergamot scent increased stress among males but not among females [131]. Particular elements of a natural scene may also determine the effect on stress; for example, a moderate density of tree cover may be better for stress recovery than low or high density [132]. However, like the effect of scent, this may also vary across individuals; while an inverted-U shape stress recovery function was observed for men, there was no relationship between the density of tree cover and stress recovery among women.

Most studies examining sensory experiences have focused on one stimulus at a time for stress recovery, disregarding the fact that humans perceive their surroundings as a multisensory experience. Hedblom et al. [133] argue that incorporating olfactory stimuli into auditory and visual features enhances the overall stress recovery effects due to the potential multisensory benefits. Similarly, other researchers show that adding birds or water sounds to visual nature features can strengthen the recovery effects of human-nature interactions [49,134].

2.6. How can virtual spaces assist in understanding and reducing environmental stress?

The recent pandemic forced many organizations and workers to conduct work remotely from their homes to control the spread of the virus. In their study, Xiao et al. [135] suggest that a successful work-from-home strategy necessitates a healthy separation between the home environment and its distractions while still working at home. Remote, telework, and hybrid work arrangements are likely to continue. There is a need for a solution that appropriately supports these emerging work arrangements that separate home life from work life while providing social interaction and collaboration opportunities with co-workers. One solution is the use of virtual workspaces. Virtual Reality (VR) creates an immersive experience allowing workers to, perceptually and psychologically, leave their physical home environment and enter their virtual office space [136]. The Metaverse made headlines in 2021 following the pandemic work disruption. The Metaverse office is a virtual office space that mimics the physical office space, where office workers can virtually meet, work, and collaborate [137].

Like the physical space, the virtual space can have significant psychophysiological effects on office workers [138]. Researchers have been studying how the architectural design of virtual spaces can affect environmental stress. VR enables researchers to manipulate architectural components that are not easily adjustable in a physical office space (e.g., walls, color, finishing material). For instance, Yeom et al. [139] tracked the psychological and physiological responses of 27 subjects when the wall in their VR environment changed from non-green to small and large green wall conditions. The results showed that the small green wall condition resulted in lower self-reported stress levels and decreased electrodermal activity compared to the large green wall condition.

Importantly, VR allows for examining the combined effects of multiple IEQ and interior design features on the environmental stress experience. For instance, Ergan et al. [140] used VR to show that spaces with natural daylight, accompanied by a standard level of luminance and bright colors on the interior walls led to relaxation, reduced electrodermal activity, and more stable heart rate variability. In another example, Zhang et al. [141] examined the simultaneous effect of room size, ceiling height, light temperature, visual complexity, room layout symmetry, window-to-wall ratio, window aspect ratio, finish color scheme, and spatial alignment, by creating 32 VR rooms with different design attributes. The authors used the Perceived Restorativeness Scale (PRS) by Hartig et al. [142] to subjectively assess the stress recovery capacity of the different VR rooms. Their results suggest that the main effects of window aspect ratio, room size, and light temperature and the 2-way interaction effects of ceiling height with window-to-wall ratio, room size with finish color scheme, room size with visual complexity, and light temperature with window aspect ratio were significantly beneficial to the recovery experience.

VR also provides a reliable method for nature access. 3-D simulated virtual environments allow office workers to engage in an immersive experience of nature [133]. Several studies have examined the effectiveness of virtual offices with biophilic design features in reducing stress among office workers [113,118]. The results suggest that virtual offices with plants, water, biomorphic materials and shapes, nature views through windows, natural lights, furniture, and decorations with patterns analog to nature help reduce work stress. Yin et al. [143] replicated a real biophilic office environment into virtual reality and found that the virtual office can trigger similar psychological and physiological responses as the real office.

2.7. What personal and demographic factors impact environmental stress among office workers?

A plethora of research studies have examined relationships among environmental discomfort, unhealthy indoor conditions, and environmental stress [59,75,80,144]. Workers' characteristics are critical to how the physical office environment is perceived as comfortable or healthy and, as such, the overall environmental stress experience [5, 145]. Mahbub and Zimring proposed a conceptual framework explaining that stress develops when individual needs for comfort and health are thwarted by offices' environmental features [13]. This framework accounts for personal differences and suggests that motives, attitudes, and demographic factors present a moderating effect between individual needs and environmental stress. Despite the lack of studies examining the direct relationship between personal characteristics and environmental stress, several researchers have investigated the impact of individual factors on comfort, health, and physiological responses.

Gender and/or biological sex may be important demographic factors that contribute to different experiences in the physical office space [146]. Self-report of stress, comfort, and other factors may be influenced by gender, such as the fact that women are socialized to be more comfortable expressing negative emotions than men (except anger), and they can experience additional stress from engaging in emotional suppression. In addition to differential experiences (or reporting) of stress based on gender, Havenith and Middendorps [147] argue that differences in responses to temperature (i.e., heat strain) could also (at least in part) be caused by differences in physiology based on biological sex. They report that psychophysiological responses to warm and cold are related to the percentage of body fat and the surface-to-mass ratio. This sex difference may also impact other physiological measures, such as pulse rate. In one study, females exhibited significantly lower pulse rate during cold stress in comparison to a thermally comfortable state, while male pulse rates did not exhibit any changes with temperature variation [148]. Gender also affects the environmental stress caused by noise and lighting. Abassi et al. found that the noise-induced stress effect in women was more intense than in men. Their results showed that a combination of increased noise level and workload resulted in increased LF/HF (a frequency domain HRV metric) compared to men indicating higher stress [149]. In another study, it was found that women showed significantly lower heart rate levels compared to men when placed in a room with an illuminance of 325 lux and a color temperature of 3400 K [150]. Future work examining environmental stress in office settings must measure biological sex and gender to arrive at nuanced understandings and conclusions.

Age is another demographic factor that affects environmental stress experiences. Older individuals prefer higher ambient temperatures due to their lower activity level and metabolic rate compared to young adults [151]. Carrillo et al. [152] found that during a heat wave, older individuals showed less change in heart rate variability compared to young individuals. Their analysis suggests that the younger age group experienced greater sympathetic activity during the heat stress period than the older group, suggesting higher physiological stress. High illumination in offices was found to induce physiological arousal among older employees but resulted in a relaxing atmosphere for young office workers [153]. Another study found that cortisol levels were increased among old individuals compared to the young when exposed to blue-enriched white light [98].

Other personal factors, such as thermal adaptation and personality, have been found to affect the perception of the indoor thermal environment. Luo et al. [154] have shown that subjects living in a cold climate presented a decreased range of physiological responses when exposed to cold indoor environments, indicative of the physiological acclimatization to this thermal stressor. Clothing level is another factor that affects the thermal sensation. Usually, differences between gender in terms of thermal comfort, have been explained in terms of clothing differences. For example, this fact has pushed the Government of Japan to introduce cool biz and warm biz initiatives in 2005 allowing office occupants to wear flexible clothing in summer and winter [155].

Kallio et al. [5] concluded that extroverted office workers are more likely to be stressed by uncomfortable IEQ. Other research has demonstrated that introverted workers care primarily about privacy and personal space [156], while extroverted workers appreciate and feel less pressured by direct communication with co-workers than introverted workers; thus, extroverted workers do better in open-plan offices [157]. Lastly, in a controlled laboratory experiment, in a low-intensity noise environment, neurotic (personality dimension) participants felt more noise annoyance and more distress than non-neurotic individuals [158].

In summary, studies have demonstrated the significance of demographics and personal factors such as gender, age, and personality in shaping the environmental stress experience. However, more research remains necessary to determine the interaction effect among these factors on the environmental stress level of office workers.

2.8. How can office environments assist people with sensory processing differences in reducing environmental stress?

Sensory processing disorder is defined as "a disruption in the organization of sensory input, which shapes our perception of the world and impacts our responses to it" [159]. Statistics show that 5%–16.5% of the general population have some type of sensory processing disorder [160]. Such occurrences are even higher among the neurodivergent population, such as individuals with ASD (Autism Spectrum Disorder) or ADHD (Attention Deficit Hyperactivity Disorder) [160]. Unfortunately, the neurodivergent population remains significantly underrepresented in the workplace with a low employment rate [161,162], and the lack of a supportive physical work environment is a major cause [163].

People with sensory processing differences usually find it challenging to adapt to the work environment in a typical office space [164]. Failing to cope with the environmental stimuli can cause alarm and stimulation leading to distress. People with sensory differences can feel overwhelmed by coworkers, agitated by uncontrollable noise, annoyed by bright or flickering lights, startled by the texture of their surroundings, or even uncomfortable with intense odors [165]. Clements-Croome et al. [166] argue that designing better indoor environments requires a comprehensive analysis of the multi-modal sensory relationship between occupants and their spaces. In a recent study conducted by Caniato et al. [167], it was found that uncomfortable acoustic conditions significantly increased environmental stress among individuals with ASD. Other environmental parameters (thermal and visual conditions and indoor air quality) were less disturbing but also induced environmental stress. Furthermore, the authors highlighted that acoustic sensitivity depended on the severity of autism, which was higher when the autism severity was higher.

Several accommodations can be made to create inclusive offices where people with sensory differences can thrive. These accommodations can reduce the distress associated with environmental stimuli [168]. For instance, providing indoor break rooms in workspaces to disconnect from uncomfortable environmental conditions can facilitate the recovery of personal resources (mood, fatigue, arousal) and hence decrease the stress level [169]. To help people with fragrance sensitivity, it is recommended to maintain good indoor air quality through proper ventilation and air purification systems [170]. People with a sensitivity to light should have access to personalized lighting control systems to adjust the brightness and color temperature to their preferences. When it comes to noise, installing sound absorption panels or sound masking systems is important to reduce annoyance caused by distracting sounds [171]. On the other hand, utter silence can also be disturbing for some. In fact, research shows that people with sensory differences show higher cognitive capabilities and are less stressed when exposed to white noise [172].

Despite the extensive research conducted around sensory processing disorders and a substantial number of studies examining the effect of the physical workspace on the general population, systematic research that links both areas remains limited [164]. However, the debate around redesigning the physical workspace to include people with sensory differences is now gaining importance.

2.9. How can technologies be leveraged to establish stress-recovery smart offices?

The concept of smart spaces has been gaining traction in the last decade. Smart indoor environments are equipped with technological systems to automatically adjust indoor environmental settings to optimize a particular goal [173]. In office settings, researchers have focused on establishing automated systems that control personal equipment (e.g., fans, windows, blinds, heaters) to maximize comfort among office workers [174] or reduce energy consumption [175]. However, an opportunity exists to establish smart offices that aim at lowering work and environmental stress among office workers through the lens of the stress reduction theory.

With the rapid technological advancements, researchers strive to use Machine Learning (ML) models for a scalable, continuous, accurate, automated, and early detection of stress. ML algorithms employ mathematical computations to analyze physiological and behavioral data and identify the stress levels of an office worker. The main goal of these algorithms is to maximize the accuracy of the stress detection model, i.e., the ability of the model to identify a stressed worker correctly. The literature provides a wide range of studies that have successfully established ML automated systems for stress detection purposes [176].

These systems can be installed to inform smart offices about the appropriate indoor environmental intervention necessary to maintain a non-stressful work environment. When the worker feels relaxed, there might be no need for environmental intervention. However, when the worker is stressed, this system could identify the necessary adjustments that bring the worker to a relaxed state. These adjustments –as per the stress reduction theory– promote nature contact through auditory (e.g., bird sounds, wind sounds, waterfalls, leaves rustling) [125], visual (e.g., nature videos, images) [177], or olfactory (e.g., bergamot, wood, grass) stimuli [129]. It is important to underscore the opportunities for personalization.

To our knowledge, only one attempt has been made to establish such a comprehensive framework. Zhao et al. [178] have presented a responsive office that can change its ambiance driven by a group of physiological sensors. The office was equipped with a projector where different nature scenes were presented according to the personal preferences of the worker to restore their stress levels. Additionally, a sound system would emit nature sounds to help with recovery. Their results show that the responsive office helped office workers double the speed of high-stress recovery compared to the baseline condition.

Nevertheless, such systems are difficult to deploy using the "one size fits all" approach to the office environment targeted interventions. Personal preferences must be taken into consideration when adjusting the indoor environment. Therefore, feedback about the adjustments is crucial for effective results; if the worker feels that the adjustments were not satisfactory, they should be allowed to send feedback to the automated system signaling that the latest adjustments did not meet their expectations for stress recovery. The AI system might look for other suitable adjustments by processing this feedback. In summary, the smart office can coevolve with the worker to adapt the workspace in a way that reduces environmental and work stress and promotes productivity through the appropriate interventions, as depicted in Fig. 2.

2.10. What are the future directions and challenges of environmental stress research in offices?

Despite the research efforts reviewed in this paper, the building community lacks well-established design guidelines focused on minimizing workplace environmental stress or promoting recovery. General

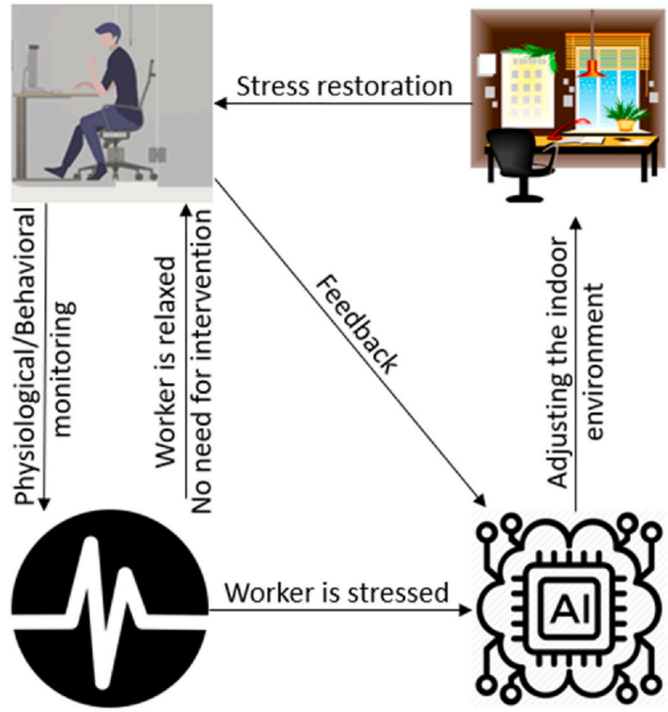

Fig. 2. Stress-recovery smart office framework.

healthy building guidelines (e.g., WELL standard [179]) exist, but they lack comprehensive design strategies for stress and focus on the overall physical, mental, and social well-being of building occupants. To that end, interdisciplinary joint efforts between psychologists, architects, engineers, and work management professionals are required to integrate these research findings into tangible design and operational standards that aim at reducing environmental stress and overall work-related stress among office workers. Furthermore, in their review of the built environment's effect on mental health, Hoisington et al. [180] argue that the general U.S. policy does not fully consider the mental health consequences of office space design. Thus, there is a need to engage policymakers in the discussion about potential stress-recovery effects of the indoor built environment and promote stress-oriented design guidelines for buildings in general and offices more specifically. Finally, designing stress-recovery smart offices necessitates the expertise of data scientists and information technology professionals to establish the necessary technological infrastructure and control systems for real-time data collection, storage, analysis, and response generation.

To establish these guidelines, we need a more in-depth analysis of the effect of indoor environmental conditions on workers' stress levels. Tables 2 and 3 show that experimental studies are dominant compared to real-world observational studies. However, despite their importance, controlled experimental studies might not fully represent realistic office work, and results from these experiments might not generalize well to actual office environments. For instance, lab studies do not reflect on prolonged exposure to environmental stressors but rather focus on creating intense conditions over short periods. Also, participants are usually assigned predesigned tasks to perform during these experimental procedures, which do not mimic the dynamics and complexity of office work, hence failing to accurately examine the interplay between office work and the effect of environmental stressors. In contrast, observational studies allow for mapping the effects of environmental stressors over longer periods and under more ecologically valid office work conditions. However, as seen in Tables 2 and 3, all observational studies rely on the subjective assessment of stress; questionnaires are the most convenient means of data collection, whereas collecting objective data through sensors requires more resources and might be challenging, especially for longitudinal studies, nevertheless conducting these observational studies might be crucial to understand stress in workspaces.

Furthermore, none of the studies presented in Tables 2 and 3 examined the effect of the duration or frequency of environmental exposure on the environmental stress experience. On that note, several research questions can be posed: How do repetitive and long exposures to environmental stressors affect the psychophysiological state of office workers? Do adaptation and personal resilience play a role in limiting the negative impact of long and repetitive exposures to environmental stressors? To answer these questions, future research should perform intervention studies in real offices; researchers can monitor the environmental settings (e.g., temperature, lighting) over long periods while tracking office workers' psychophysiological indicators in real-time. These studies could also help us understand the interrelation between work stress and environmental stress.

More research is needed to understand how personal and demographic factors impact environmental stress among office workers. In most of the studies presented in Tables 2 and 3, the authors discuss their results but end up mentioning that a major limitation of their work is that they are missing the analysis of personal characteristics. A primary reason could be that the study of personal differences usually necessitates a large number of participants to cover all possible variations and reach sufficient statistical power. Also, some populations (e.g., people with ASD or ADHD) require special accommodations during data collection to ensure they are not overwhelmed by the environmental conditions, which makes it difficult to conduct these studies.

Most studies focus on one environmental factor rather than studying the interaction effect of multiple IEQ or design parameters on stress. With the recent technological advancements, machine learning techniques offer a powerful tool to solve this problem. Using low cost sensors, researchers can collect data about the indoor office environment and apply machine learning methods to map the indoor environmental conditions (IEQ and interior design attributes) to the stress state of a worker. To our knowledge, only one study applied such a framework [5]. Thus, future research should focus on understanding the indoor environment's collective effect on office workers' stress. Additionally, results from Tables 2 and 3 show that IEQ parameters and interior design characteristics are studied separately, however an interactive effect between these categories could exist. For example, some materials or choice of furniture/carpeting can affect air quality, and the perception of IEQ parameters can change with colors or selection of materials (wood, vs. metal). Thus, researchers should consider studying the interplay effect of IEQ and interior design parameters on environmental stress among office workers.

The literature presents numerous studies that have investigated the effect of nature contact via visual, auditory, and olfactory stimuli on the work stress of office workers. However, limited attention has been allocated to comparing the recovery effects of these different sensory stimuli [54]. In addition, future research directions should examine the optimal means to integrate recovery interventions without interrupting the work. For office workers, preferable stress recovery strategies would be those that do not hinder their work progress, especially with the pressure of tight deadlines and demanding workload. Therefore, a stress recovery environment that does not sacrifice office workers' productivity should be prioritized. Finally, limited attention has been allocated to developing assistive office environments for people with sensory difference and sensory disorders. Therefore, future studies with empirical data should be conducted to better understand how the indoor office environment affects this population.

Lastly, the literature mainly focused on studying stress among office workers working in traditional office spaces. However, the pandemic demonstrated the feasibility of working from home, with companies and organizations aiming to define the work, workforce, and workplace in a new system that recognizes the work as a set of tasks to be achieved rather than linking it with a specific location. Thus, future research should not limit the study of work and environmental stress to traditional office spaces but identify how workers' stress varies across different workplaces, including virtual workspaces. Additionally, the COVID-19 pandemic will have drastic effects on the way we design our spaces (e.g., ventilation rates, office spaces distribution, finishing materials, etc.). Thus, researchers should investigate how these changes affect occupants' environmental stress and determine the best design practices that reduce environmental stress and transmission of indoor diseases.

Built on what preceded, it is crucial to investigate the economic implications of environmental stress at the worker and organization levels. Thus, future research directions should aim to better quantify the associated financial losses by considering the impact of environmental stress on workers' productivity and absenteeism. On that note, researchers should perform a return-on-investment analysis to determine the financial feasibility of any solution aiming at reducing environmental stress.

3. Conclusion

The topic of healthy buildings has recently been gaining momentum, even more so during the COVID-19 pandemic. There is particular interest in the effect of buildings on the environmental stress of occupants. More specifically, companies and researchers are considering how the indoor environment of office spaces affects office workers' stress. As outlined in this paper, there is growing evidence that suboptimal IEQ and interior design conditions in office spaces result in increased environmental stress. However, different groups perceive these indoor conditions uniquely; gender and/or biological sex, age, and sensory needs are personal factors that affect the preferences towards the indoor environment and thus can affect environmental stress, but more work needs to be done to understand the unique contribution of each factor.

There remain several challenges and opportunities for environmental stress research in offices. Our literature analysis shows a need to better understand how different IEQ and interior design conditions interact to impact environmental stress. Future research should consider how to better design and operate office spaces to reduce environmental stress. Stress-oriented design approaches based on the stress reduction theory represent a promising solution. However, an interdisciplinary effort that brings together building scientists, biomedical scientists, psychologists, work management professionals, policymakers, engineers, and data scientists would help to establish standardized stress-oriented office design and operation guidelines and thereby optimize future offices to promote stress reduction and recovery.

CRediT authorship contribution statement

Mohamad Awada: Writing – original draft, Methodology, Investigation, Conceptualization. **Burcin Becerik-Gerber:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization. **Ruying Liu:** Writing – original draft. **Mirmahdi Seyedrezaei:** Writing – original draft. **Zheng Lu:** Writing – original draft. **Matheos Xenakis:** Writing – original draft. **Gale Lucas:** Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization. **Shawn C. Roll:** Writing – review & editing, Writing – original draft, Funding acquisition. **Shrikanth Narayanan:** Writing – review & editing, Writing – original draft, Funding acquisition.

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.

Data availability

No data was used for the research described in the article.

Acknowledgments

The results reported herein correspond to the specific aims of Grant Nos. 1763134 and 2204942 from National Science Foundation. Research was also supported by the Army Research Office (ARO) and was accomplished under Cooperative Agreement Number W911NF-20-2-0053. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation or Army Research Office.

References

[1] G. Fink, Stress: concepts, definition and history, in: Reference Module in Neuroscience and Biobehavioral Psychology, Elsevier, 2017.
[2] M.-F. Marin, et al., Chronic stress, cognitive functioning and mental health, Neurobiol. Learn. Mem. 96 (4) (2011) 583–595, https://doi.org/10.1016/j.nlm.2011.02.016. Nov.
[3] D.C. Ganster, J. Schaubroeck, Work stress and employee health, J. Manag. 17 (2) (1991) 235–271, https://doi.org/10.1177/014920639101700202. Jun.
[4] B. Brunner, I. Igic, A.C. Keller, S. Wieser, Who gains the most from improving working conditions? Health-related absenteeism and presenteeism due to stress at work, Eur. J. Health Econ. 20 (8) (2019) 1165–1180, https://doi.org/10.1007/s10198-019-01084-9. Nov.
[5] J. Kallio, et al., Assessment of perceived indoor environmental quality, stress and productivity based on environmental sensor data and personality categorization, Build. Environ. 175 (2020), 106787, https://doi.org/10.1016/j.buildenv.2020.106787. May.
[6] T.Q. Thach, et al., Associations of perceived indoor environmental quality with stress in the workplace, Indoor Air 30 (6) (2020) 1166–1177.
[7] X. Zhang, Z. Lian, Y. Wu, Human physiological responses to wooden indoor environment, Physiol. Behav. 174 (2017) 27–34, https://doi.org/10.1016/J.PHYSBEH.2017.02.043.
[8] A. Hassan, et al., Do plants affect brainwaves? Effect of indoor plants in work environment on mental stress, Eur. J. Hortic. Sci. 85 (4) (2020) 279–283, https://doi.org/10.17660/eJHS.2020/85.4.9.
[9] U.S. Bureau of Labor Statistics, Occupational Employment and Wages, May, 2020, 2021, https://www.bls.gov/oes/current/oes430000.htm#nat.
[10] D.L. Smith, B. Bazalar, M. Wheeler, Public librarian job stressors and burnout predictors, J. Libr. Adm. (2020) 412–429.
[11] N. Hjortskov, D. Rissén, A.K. Blangsted, N. Fallentin, U. Lundberg, K. Søgaard, The effect of mental stress on heart rate variability and blood pressure during computer work, Eur. J. Appl. Physiol. 92 (1) (2004) 84–89.
[12] K.L. Cheras, A study of occupational stress and coping strategies among correctional officers in Kedah, Malaysia, J. Commun. Healthc. 16 (2010) 66–74.
[13] M. Rashid, C. Zimring, A review of the empirical literature on the relationships between indoor environment and stress in health care and office settings, Environ. Behav. 40 (2) (2008) 151–190, https://doi.org/10.1177/0013916507311550. Mar.
[14] S. Lamb, K.C.S. Kwok, A longitudinal investigation of work environment stressors on the performance and wellbeing of office workers, Appl. Ergon. 52 (2016) 104–111, https://doi.org/10.1016/j.apergo.2015.07.010. Jan.
[15] A. Singh, M. Syal, S. Korkmaz, S. Grady, Costs and benefits of IEQ improvements in LEED office buildings, J. Infrastruct. Syst. 17 (2) (2011) 86–94, https://doi.org/10.1061/(ASCE)IS.1943-555X.0000046. Jun.
[16] M. Awada, et al., Occupant health in buildings: impact of the COVID-19 pandemic on the opinions of building professionals and implications on research, Build. Environ. 207 (2022), 108440, https://doi.org/10.1016/j.buildenv.2021.108440. Jan.
[17] 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.
[18] H. Selye, The Stress of Life, 1956. New York.
[19] H. Selye, Stress and the General Adaptation Syndrome, *BMJ* 1 (4667) (Jun. 1950) 1383–1392, https://doi.org/10.1136/bmj.1.4667.1383.
[20] A.Y. Shalev, Acute stress reactions in adults, Biol. Psychiatr. (2002) 532–543.
[21] S. Elzeiny, M. Qaraqe, Blueprint to workplace stress detection approaches, in: 2018 International Conference on Computer and Applications (ICCA), 2018, pp. 407–412, https://doi.org/10.1109/COMAPP.2018.8460293. Aug.
[22] S.V. Madhu, A. Siddiqui, N.G. Desai, S.B. Sharma, A.K. Bansal, Chronic stress, sense of coherence and risk of type 2 diabetes mellitus, Diabetes Metab. Syndr. Clin. Res. Rev. 13 (1) (2019) 18–23.
[23] G. Fink, Stress science: neuroendocrinology, in: Stress: Definition and History, 2010, pp. 3–9.
[24] Cleveland Clinic, Stress, 2021. https://my.clevelandclinic.org/health/articles/11874-stress.
[25] F. Edition, Diagnostic and Statistical Manual of Mental Disorders, Am Psychiatric Assoc, 2013.
[26] T. Cox, Stress, Coping and Problem Solving, Work Stress, 1987, pp. 5–14.
[27] R.S. Lazarus, S. Folkman, Stress, Appraisal, and Coping, Springer publishing company, 1984.
[28] D.S. Goldstein, Stress-induced activation of the sympathetic nervous system, Baillieres. Clin. Endocrinol. Metab. 1 (2) (1987) 253–278, https://doi.org/10.1016/S0950-351X(87)80063-0. May.
[29] A. Kaklauskas, et al., Web-based biometric computer mouse advisory system to analyze a user's emotions and work productivity, Eng. Appl. Artif. Intell. 24 (6) (2011) 928–945, https://doi.org/10.1016/j.engappai.2011.04.006. Sep.
[30] J. Hernandez, P. Paredes, A. Roseway, M. Czerwinski, Under pressure: sensing stress of computer users, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2014, pp. 51–60.
[31] M. Bickford, Stress in the workplace: a general overview of the causes, the effects, and the solutions, Can. Ment. Heal. Assoc. Newfoundl. Labrador Div. 8 (1) (2005) 1–3.
[32] D.H. Hellhammer, S. Wüst, B.M. Kudielka, Salivary Cortisol as a Biomarker in Stress Research, Psychoneuroendocrinology, 2009, pp. 163–171.
[33] W. Liao, W. Zhang, Z. Zhu, Q. Ji, A real-time human stress monitoring system using dynamic Bayesian network, in: IEEE Computer Society Conference on Computer Vision and Pattern Recognition, 2005, p. 70.
[34] S. Koldijk, M.A. Neerincx, W. Kraaij, Detecting work stress in offices by combining unobtrusive sensors, IEEE Trans. Affect. Comput. 9 (2) (2018) 227–239, https://doi.org/10.1109/TAFFC.2016.2610975. Apr.
[35] Y.M. Lim, A. Ayesh, M. Stacey, Detecting cognitive stress from keyboard and mouse dynamics during mental arithmetic, in: 2014 Science and Information Conference, 2014, pp. 146–152, https://doi.org/10.1109/SAI.2014.6918183. Aug.
[36] A. Alberdi, A. Aztiria, A. Basarab, Towards an automatic early stress recognition system for office environments based on multimodal measurements: a review, J. Biomed. Inf. 59 (2016) 49–75.
[37] D. Moher, et al., Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement, Syst. Rev. 4 (1) (2015) 1, https://doi.org/10.1186/2046-4053-4-1. Dec.
[38] S. Begum, M.U. Ahmed, P. Funk, N. Xiong, B. Von Schéele, Using calibration and fuzzification of cases for improved diagnosis and treatment of stress, in: 8th European Workshop on Case-Based Reasoning in the Health Sciences, 2006, pp. 113–122.
[39] M. H. Díaz, F.M. Cid, J. Otárola, R. Rojas, O. Alarcón, L. Cañete, EEG Beta band frequency domain evaluation for assessing stress and anxiety in resting, eyes closed, basal conditions Procedia Comput. Sci. 162 (2019) 974–981, https://doi.org/10.1016/j.procs.2019.12.075.
[40] S.H. Seo, J.T. Lee, M. Crisan, Stress and EEG, in: Convergence and Hybrid Information Technologies, 2010, pp. 413–424.
[41] G.C. Blackhart, J.A. Minnix, J.P. Kline, Can EEG asymmetry patterns predict future development of anxiety and depression?: a preliminary study, Biol. Psychol. 72 (1) (2006) 46–50.
[42] R.S. Lewis, N.Y. Weekes, T.H. Wang, The effect of a naturalistic stressor on frontal EEG asymmetry, stress, and health, Biol. Psychol. 75 (3) (2007) 239–247.
[43] U. Lundberg, et al., Psychophysiological stress and EMG activity of the trapezius muscle, Int. J. Behav. Med. 1 (4) (1994) 354–370.
[44] G.M. Flodgren, A.G. Crenshaw, M. Gref, M. Fahlström, Changes in interstitial noradrenaline, trapezius muscle activity and oxygen saturation during low-load work and recovery, Eur. J. Appl. Physiol. 107 (1) (2009) 31–42.
[45] P. Ren, A. Barreto, J. Huang, Y. Gao, F.R. Ortega, M. Adjouadi, Off-line and on-line stress detection through processing of the pupil diameter signal, Ann. Biomed. Eng. 42 (1) (2014) 162–176.
[46] S. Baltaci, D. Gokcay, Stress detection in human–computer interaction: fusion of pupil dilation and facial temperature features, Int. J. Human–Computer Interact. 32 (12) (2016) 956–966.
[47] M.N.H. Mohd, M. Kashima, K. Sato, M. Watanabe, A Non-invasive Facial Visual-Infrared Stereo Vision Based Measurement as an Alternative for Physiological Measurement, 2015, pp. 684–697.
[48] M. Haak, S. Bos, S. Panic, L.J. Rothkrantz, Detecting stress using eye blinks and brain activity from EEG signals, in: Proceeding of the 1st Driver Car Interaction and Interface (DCII 2008), 2009, pp. 35–60.
[49] H. Jahncke, S. Hygge, N. Halin, A.M. Green, K. Dimberg, Open-plan office noise: cognitive performance and restoration, J. Environ. Psychol. 31 (4) (Dec. 2011) 373–382, https://doi.org/10.1016/j.jenvp.2011.07.002.
[50] 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 14 (60) (2012) 260.
[51] D.F. Dinges, et al., Optical computer recognition of facial expressions associated with stress induced by performance demands, Aviat Space Environ. Med. 76 (6) (2005) 172–182.
[52] M. Rodrigues, S. Gonçalves, D. Carneiro, P. Novais, F. Fdez-Riverola, Keystrokes and Clicks: Measuring Stress on E-Learning Students, 2013, pp. 119–126.
[53] H. Lu, et al., StressSense, in: Proceedings of the 2012 ACM Conference on Ubiquitous Computing - UbiComp '12, 2012, p. 351, https://doi.org/10.1145/2370216.2370270.
[54] J. Radun, H. Maula, V. Rajala, M. Scheinin, V. Hongisto, Speech is special: the stress effects of speech, noise, and silence during tasks requiring concentration, Indoor Air 31 (1) (2021), https://doi.org/10.1111/ina.12733.
[55] Y. Lee, E.C. Nelson, M.J. Flynn, J.S. Jackman, Exploring Soundscaping Options for the Cognitive Environment in an Open-Plan Office, Build. Acoust., 2020.

[56] P.C. Wong, J.X. Jin, G.M. Gunasekera, R. Abel, E.R. Lee, S. Dhar, Aging and Cortical Mechanisms of Speech Perception in Noise, Neuropsychologia, 2009.
[57] M. Awada, B. Becerik-Gerber, G. Lucas, S. Roll, Cognitive performance, creativity and stress levels of neurotypical young adults under different white noise levels, Sci. Rep. 12 (1) (Aug. 2022) 14566, https://doi.org/10.1038/s41598-022-18862-w.
[58] L. Lan, Z. Lian, Use of neurobehavioral tests to evaluate the effects of indoor environment quality on productivity, Build. Environ. 44 (11) (2009) 2208–2217, https://doi.org/10.1016/J.BUILDENV.2009.02.001.
[59] S. Sepehri, M. Aliabadi, R. Golmohammadi, M. Babamiri, Human cognitive functions and psycho-physiological responses under low thermal conditions in a simulated office environment, Work 69 (1) (2021) 197–207, https://doi.org/10.3233/WOR-213469.
[60] L. Smith, H.J. Jeppesen, H. Bøggild, Internal locus of control and choice in health service shift workers, Ergonomics 50 (9) (2007) 1485–1502.
[61] R. Mork, H.K. Falkenberg, K.I. Fostervold, H.M.S. Thorud, Discomfort glare and psychological stress during computer work: subjective responses and associations between neck pain and trapezius muscle blood flow, Int. Arch. Occup. Environ. Health (2020) 29–42.
[62] J. Ju, C. D, Y. Lin, Effects of correlated color temperature on spatial brightness perception, Color Res. Appl. 37 (6) (2012) 450–454.
[63] B. Manav, An experimental study on the appraisal of the visual environment at offices in relation to colour temperature and illuminance, Build. Environ. 42 (2) (2007) 979–983, https://doi.org/10.1016/J.BUILDENV.2005.10.022.
[64] S. Ergan, A. Radwan, Z. Zou, H. Tseng, X. Han, Quantifying human experience in architectural spaces with integrated virtual reality and body sensor networks, J. Comput. Civ. Eng. 33 (2) (2019), https://doi.org/10.1061/(ASCE)CP.1943-5487.0000812.
[65] Y. Choi, M. Kim, C. Chun, Measurement of occupants' stress based on electroencephalograms (EEG) in twelve combined environments, Build. Environ. 88 (2015) 65–72, https://doi.org/10.1016/J.BUILDENV.2014.10.003.
[66] Z. Tu, Y. Li, S. Geng, K. Zhou, R. Wang, X. Dong, Human responses to high levels of carbon dioxide and air temperature, Indoor Air 31 (3) (2021), https://doi.org/10.1111/ina.12769.
[67] S.N. Kamaruzzaman, N.A. Sabrani, The effect of indoor air quality (IAQ) towards occupants' psychological performance in office buildings, J. Des. Built 4 (1) (2011) 49–61.
[68] M. Awada, B. Becerik-Gerber, G. Lucas, S.C. Roll, Associations among home indoor environmental quality factors and worker health while working from home during COVID-19 pandemic, ASME J. Eng. Sustain. Build. Cities 2 (4) (2021), https://doi.org/10.1115/1.4052822. Nov.
[69] A.G.M. Bergefurt, M. Weijs-Perrée, R. Appel-Meulenbroek, T.A. Arentze, The influence of employees' workspace satisfaction on mental health while working from home during the COVID-19 pandemic, in: Healthy Buildings 2021-Europe, 2021, pp. 1–9.
[70] C. Sun, Z. Lian, L. Lan, Work performance in relation to lighting environment in office buildings, Indoor Built Environ. 28 (8) (2019), https://doi.org/10.1177/1420326X18820089.
[71] L. Rossi, A. Prato, L. Lesina, A. Schiavi, Effects of low-frequency noise on human cognitive performances in laboratory, Build. Acoust. 25 (1) (2018), https://doi.org/10.1177/1351010X18756800.
[72] J. Kim, M. Kong, T. Hong, K. Jeong, M. Lee, Physiological response of building occupants based on their activity and the indoor environmental quality condition changes, Build. Environ. 145 (2018) 96–103, https://doi.org/10.1016/J.BUILDENV.2018.09.018.
[73] T. Vehviläinen, et al., High indoor CO_2 concentrations in an office environment increases the transcutaneous CO_2 level and sleepiness during cognitive work, J. Occup. Environ. Hyg. 13 (1) (2016), https://doi.org/10.1080/15459624.2015.1076160.
[74] R. Zhang, et al., Impacts of Dynamic LED Lighting on the Well-Being and Experience of Office Occupants, Int. J. Environ. Res. Public Health 17 (19) (Oct. 2020) 7217, https://doi.org/10.3390/ijerph17197217.
[75] K. Chamilothori, G. Chinazzo, J. Rodrigues, E.S. Dan-Glauser, J. Wienold, M. Andersen, Subjective and physiological responses to façade and sunlight pattern geometry in virtual reality, Build. Environ. 150 (2019) 144–155, https://doi.org/10.1016/J.BUILDENV.2019.01.009.
[76] 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. 37 (2) (2009) 129–147.
[77] P. Leather, D. Beale, L. Sullivan, Noise, psychosocial stress and their interaction in the workplace, J. Environ. Psychol. 23 (2) (2003) 213–222.
[78] 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. 44 (2015) 34–44.
[79] S. Klitzman, J.M. Stellman, The impact of the physical environment on the psychological well-being of office workers, Soc. Sci. Med. 29 (6) (1989) 733–742.
[80] K. Azuma, et al., Effects of inhalation of emissions from Cedar timber on psychological and physiological factors in an indoor environment, Environments 3 (4) (2016) 37.
[81] A.M. Abbasi, M. Motamedzade, M. Aliabadi, R. Golmohammadi, L. Tapak, Combined effects of noise and air temperature on human neurophysiological responses in a simulated indoor environment, Appl. Ergon. 88 (2020), 103189, https://doi.org/10.1016/J.APERGO.2020.103189.
[82] C. Dai, Z. Lian, The effects of sound loudness on subjective feeling, sympathovagal balance and brain activity, Indoor Built Environ. 27 (9) (2018) 1287–1300, https://doi.org/10.1177/1420326X17719490.
[83] J. Kristiansen, et al., Stress reactions to cognitively demanding tasks and open-plan office noise, Int. Arch. Occup. Environ. Health 82 (5) (2009), https://doi.org/10.1007/s00420-008-0367-4.
[84] E.D. Walker, A. Brammer, M.G. Cherniack, F. Laden, J.M. Cavallari, Cardiovascular and stress responses to short-term noise exposures—a panel study in healthy males, Environ. Res. 150 (2016) 391–397, https://doi.org/10.1016/J.ENVRES.2016.06.016.
[85] 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. 40 (3) (2008) 175–200.
[86] T. Derksen, F. Franchimon, J.E.M.H. van Bronswijk, Impact of management attitudes on perceived thermal comfort, Scand. J. Work. Heal. Suppl. 2008 (4) (2008) 43–45.
[87] A. Hedge, W.R. Sims, F.D. Becker, Effects of lensed-indirect and parabolic lighting on the satisfaction, visual health, and productivity of office workers, Ergonomics 38 (2) (1995) 260–290, https://doi.org/10.1080/00140139508925103.
[88] E.L.J. Sander, C. Marques, J. Birt, M. Stead, O. Baumann, Open-plan office noise is stressful: multimodal stress detection in a simulated work environment, J. Manag. Organ. (2021) 1–17.
[89] S. Sakuragawa, Y. Miyazaki, T. Kaneko, T. Makita, Influence of wood wall panels on physiological and psychological responses, J. Wood Sci. 51 (2) (2005), https://doi.org/10.1007/s10086-004-0643-1.
[90] M.D. Burnard, A. Kutnar, Human stress responses in office-like environments with wood furniture, Build. Res. Inf. 48 (3) (2020) 316–330.
[91] B. Schwartz, J.M. Kapellusch, A. Baca, B. Wessner, Medium-term effects of a two-desk sit/stand workstation on cognitive performance and workload for healthy people performing sedentary work: a secondary analysis of a randomised controlled trial, Ergonomics 62 (6) (2019) 794–810, https://doi.org/10.1080/00140139.2019.1577497. Jun.
[92] J.M. Frost, M. Douglas, D.J. Terbizan, Pattern of attention, stress, anxiety, and musculoskeletal discomfort levels when using a sit-stand desk in a college class, J. Phys. Educ. Sport 20 (2020) 2118–2125.
[93] S.A. Samani, S.Z.A. Rasid, S. bt Sofian, Perceived level of personal control over the work environment and employee satisfaction and work performance, Perform. Improv. 54 (9) (2015) 28–35, https://doi.org/10.1002/pfi.21499. Oct.
[94] M.T. Paciuk, The Role of Personal Control of the Environment in Thermal Comfort and Satisfaction at the Workplace, 1989.
[95] Y.-H. Huang, M.M. Robertson, K.-I. Chang, The role of environmental control on environmental satisfaction, communication, and psychological stress, Environ. Behav. 36 (5) (2004) 617–637, https://doi.org/10.1177/0013916503262543. Sep.
[96] M.M. Robertson, M. O'Neill, Effects of environmental control on stress, performance and group effectiveness, Proc. Hum. Factors Ergon. Soc. Annu. Meet. 43 (8) (1999) 552–556, https://doi.org/10.1177/154193129904300801. Sep.
[97] M. Rizzo, Synesthesia: a union of the senses, 1413–1413, Neurology 39 (10) (1989), https://doi.org/10.1212/WNL.39.10.1413. Oct.
[98] S.L. Schatz, C.A. Bowers, 10 questions on room color: answers for workplace designers, Ergon. Des. Q. Hum. Factors Appl. 13 (4) (2005) 21–27, https://doi.org/10.1177/106480460501300406. Oct.
[99] N. Kwallek, C.M. Lewis, A.S. Robbins, Effects of office interior color on workers' mood and productivity, Percept. Mot. Skills 66 (1) (1988), https://doi.org/10.2466/pms.1988.66.1.123.
[100] J. Kim, R. De Dear, Workspace satisfaction: the privacy-communication trade-off in open-plan offices, J. Environ. Psychol. 36 (2013) 18–26.
[101] M. Rashid, J. Wineman, C. Zimring, Space, behavior, and environmental perception in open-plan offices: a prospective study, Environ. Plann. Plann. Des. 36 (3) (2009) 432–449, https://doi.org/10.1068/b33034.
[102] A. Haapakangas, V. Hongisto, J. Varjo, M. Lahtinen, Benefits of quiet workspaces in open-plan offices – evidence from two office relocations, J. Environ. Psychol. 56 (2018) 63–75, https://doi.org/10.1016/j.jenvp.2018.03.003. Apr.
[103] T. Galanti, G. Guidetti, E. Mazzei, S. Zappalà, F. Toscano, Work from home during the COVID-19 outbreak, Publish Ah, J. Occup. Environ. Med. (2021), https://doi.org/10.1097/JOM.0000000000002236. Apr.
[104] R.S. Ulrich, R.F. Simons, B.D. Losito, E. Fiorito, M.A. Miles, M. Zelson, Stress recovery during exposure to natural and urban environments, J. Environ. Psychol. 11 (3) (1991) 201–230.
[105] F. Abd-Alhamid, M. Kent, J. Calautit, Y. Wu, Evaluating the impact of viewing location on view perception using a virtual environment, Build. Environ. 180 (2020), 106932, https://doi.org/10.1016/J.BUILDENV.2020.106932.
[106] W.H. Ko, et al., The impact of a view from a window on thermal comfort, emotion, and cognitive performance, Build. Environ. 175 (2020).
[107] M. Elsadek, B. Liu, J. Xie, Window View and Relaxation: Viewing Green Space from a High-Rise Estate Improves Urban Dwellers' Wellbeing, vol. 55, Urban For. Urban Green., 2020, 126846, https://doi.org/10.1016/J.UFUG.2020.126846.
[108] C.-Y. Chang, P.-K. Chen, Human response to window views and indoor plants in the workplace, Hortscience 40 (5) (2005), https://doi.org/10.21273/HORTSCI.40.5.1354.
[109] T. Bringslimark, T. Hartig, G.G. Patil, Psychological benefits of indoor plants in workplaces: putting experimental results into context, Hortscience 42 (3) (2007) 581–587.
[110] J.F. Thayer, et al., Effects of the physical work environment on physiological measures of stress, Eur. J. Prev. Cardiol. 17 (4) (2010) 431–439.
[111] W.S. Shin, The influence of forest view through a window on job satisfaction and job stress, Scand. J. For. Res. 22 (3) (2007) 248–253, https://doi.org/10.1080/02827580701262733.

[112] M. Elsadek, B. Liu, Effects of viewing flowering plants on employees' wellbeing in an office-like environment, Indoor Built Environ. 30 (9) (2020) 1429–1440, https://doi.org/10.1177/1420326X20942572.

[113] J. Yin, J. Yuan, N. Arfaei, P.J. Catalano, J.G. Allen, J.D. Spengler, Effects of biophilic indoor environment on stress and anxiety recovery: a between-subjects experiment in virtual reality, Environ. Int. 136 (2020), 105427, https://doi.org/10.1016/J.ENVINT.2019.105427.

[114] J. Yin, S. Zhu, P. MacNaughton, J.G. Allen, J.D. Spengler, Physiological and cognitive performance of exposure to biophilic indoor environment, Build. Environ. 132 (2018) 255–262, https://doi.org/10.1016/J.BUILDENV.2018.01.006.

[115] M. Toyoda, Y. Yokota, M. Barnes, M. Kaneko, Potential of a small indoor plant on the desk for reducing office workers' stress, HortTechnology 30 (1) (2020) 55–63, https://doi.org/10.21273/HORTTECH04427-19.

[116] M. Lee, J. Lee, B.-J. Park, Y. Miyazaki, Interaction with indoor plants may reduce psychological and physiological stress by suppressing autonomic nervous system activity in young adults: a randomized crossover study, J. Physiol. Anthropol. 34 (1) (2015) 21, https://doi.org/10.1186/s40101-015-0060-8.

[117] C.M. Lindberg, et al., Effects of office workstation type on physical activity and stress, Occup. Environ. Med. 75 (10) (2018) 689–695.

[118] J. Yin, N. Arfaei, P. MacNaughton, P.J. Catalano, J.G. Allen, J.D. Spengler, Effects of biophilic interventions in office on stress reaction and cognitive function: a randomized crossover study in virtual reality, Indoor Air 29 (6) (2019) 1028–1039, https://doi.org/10.1111/ina.12593. Nov.

[119] 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 53 (1) (2016) 9–20.

[120] K. Gillis, B. Gatersleben, A review of psychological literature on the health and wellbeing benefits of biophilic design, Buildings 5 (3) (2015) 948–963, https://doi.org/10.3390/buildings5030948. Aug.

[121] N.E. Klepeis, et al., The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants, J. Expo. Sci. Environ. Epidemiol. 11 (3) (2001) 231–252, https://doi.org/10.1038/sj.jea.7500165. Jul.

[122] E. Largo-Wight, W.W. Chen, V. Dodd, R. Weiler, Healthy workplaces: the effects of nature contact at work on employee stress and health, Publ. Health Rep. 126 (1) (2011) 124–130, https://doi.org/10.1177/00333549111260S116.

[123] M. Roskams, B. Haynes, A randomised field experiment to test the restorative properties of purpose-built biophilic 'regeneration pods, J. Corp. Real Estate 22 (4) (2020) 297–312, https://doi.org/10.1108/JCRE-05-2020-0018. Sep.

[124] B.-S. Kweon, R.S. Ulrich, V.D. Walker, L.G. Tassinary, Anger and stress, Environ. Behav. 40 (3) (2008) 355–381, https://doi.org/10.1177/0013916506298797. May.

[125] J.J. Alvarsson, S. Wiens, M.E. Nilsson, Stress recovery during exposure to nature sound and environmental noise, Int. J. Environ. Res. Publ. Health 7 (3) (2010) 1036–1046, https://doi.org/10.3390/ijerph7031036. Mar.

[126] E. Ratcliffe, B. Gatersleben, P.T. Sowden, Bird sounds and their contributions to perceived attention restoration and stress recovery, J. Environ. Psychol. 36 (2013) 221–228, https://doi.org/10.1016/j.jenvp.2013.08.004. Dec.

[127] B. Ali, N.A. Al-Wabel, S. Shams, A. Ahamad, S.A. Khan, F. Anwar, Essential oils used in aromatherapy: a systemic review, Asian Pac. J. Trop. Biomed. 5 (8) (2015) 601–611, https://doi.org/10.1016/j.apjtb.2015.05.007. Aug.

[128] N. Motomura, A. Sakurai, Y. Yotsuya, Reduction of mental stress with lavender odorant, Percept. Mot. Skills 93 (3) (2001) 713–718, https://doi.org/10.2466/pms.2001.93.3.713. Dec.

[129] A.M. Pálsdóttir, S. Spendrup, L. Mårtensson, K. Wendin, Garden smellscape–experiences of plant scents in a nature-based intervention, Front. Psychol. 12 (2021), https://doi.org/10.3389/fpsyg.2021.667957. Jun.

[130] A. Steinemann, Ten questions concerning fragrance-free policies and indoor environments, Build. Environ. 159 (2019), 106054, https://doi.org/10.1016/j.buildenv.2019.03.052. Jul.

[131] R. Liu, M. Awada, B. Becerik-Gerber, G. Lucas, S.C. Roll, Gender moderates the edicts of ambient bergamot scent on stress restoration in offices, J. Environ. Psychol. (2022).

[132] B. Jiang, C.-Y. Chang, W.C. Sullivan, A dose of nature: tree cover, stress reduction, and gender differences, Landsc. Urban Plann. 132 (2014) 26–36, https://doi.org/10.1016/j.landurbplan.2014.08.005. Dec.

[133] M. Hedblom, et al., Reduction of physiological stress by urban green space in a multisensory virtual experiment, Sci. Rep. 9 (1) (2019), 10113, https://doi.org/10.1038/s41598-019-46099-7. Dec.

[134] E. Heyman, B. Gunnarsson, L. Dovydavicius, Management of urban nature and its impact on bird ecosystem services, in: Ecology and Conservation of Birds in Urban Environments, Springer International Publishing, Cham, 2017, pp. 465–488.

[135] Y. Xiao, B. Becerik-Gerber, G. Lucas, S.C. Roll, Impacts of working from home during COVID-19 pandemic on physical and mental well-being of office workstation users, J. Occup. Environ. Med. 63 (3) (2021).

[136] D. Giusino, N. Bowman, F. Toscano, Work from home (WFH) during COVID-19: is virtual reality (VR) a new solution to new problems? J. Occup. Environ. Med. 63 (10) (2021) e755–e756, https://doi.org/10.1097/JOM.0000000000002339. Oct.

[137] H.-Y. Choi, Working in the metaverse: does telework in a metaverse office have the potential to reduce population pressure in megacities? Evidence from young adults in seoul, South Korea, Sustainability 14 (6) (2022) 3629, https://doi.org/10.3390/su14063629. Mar.

[138] Zhang Gao, Gao Zhu, Qiu, Exploring psychophysiological restoration and individual preference in the different environments based on virtual reality, Int. J. Environ. Res. Publ. Health 16 (17) (2019) 3102, https://doi.org/10.3390/ijerph16173102. Aug.

[139] S. Yeom, H. Kim, T. Hong, Psychological and physiological effects of a green wall on occupants: a cross-over study in virtual reality, Build. Environ. 204 (2021), 108134, https://doi.org/10.1016/j.buildenv.2021.108134. Oct.

[140] S. Ergan, A. Radwan, Z. Zou, H. Tseng, X. Han, Quantifying human experience in architectural spaces with integrated virtual reality and body sensor networks, J. Comput. Civ. Eng. 33 (2) (2019), https://doi.org/10.1061/(ASCE)CP.1943-5487.0000812. Mar.

[141] Y. Zhang, B. Xiao, M. Al-Hussein, X. Li, Prediction of human restorative experience for human-centered residential architecture design: a non-immersive VR–DOE-based machine learning method, Autom. ConStruct. 136 (2022), 104189, https://doi.org/10.1016/j.autcon.2022.104189. Apr.

[142] T. Hartig, K. Korpela, G.W. Evans, T. Gärling, A measure of restorative quality in environments, Scand. Hous. Plann. Res. 14 (4) (1997) 175–194, https://doi.org/10.1080/02815739708730435. Jan.

[143] J. Yin, S. Zhu, P. MacNaughton, J.G. Allen, J.D. Spengler, Physiological and cognitive performance of exposure to biophilic indoor environment, Build. Environ. 132 (2018) 255–262, https://doi.org/10.1016/j.buildenv.2018.01.006. Mar.

[144] 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. 42 (1) (2010) 29–36, https://doi.org/10.1016/j.apergo.2010.04.003. Dec.

[145] Y.-H. Lin, C.-Y. Chen, S.-Y. Lu, Physical discomfort and psychosocial job stress among male and female operators at telecommunication call centers in Taiwan, Appl. Ergon. 40 (4) (2009) 561–568, https://doi.org/10.1016/j.apergo.2008.02.024. Jul.

[146] J. Kim, R. de Dear, C. Cândido, H. Zhang, E. Arens, Gender differences in office occupant perception of indoor environmental quality (IEQ), Build. Environ. 70 (2013) 245–256, https://doi.org/10.1016/j.buildenv.2013.08.022. Dec.

[147] G. Havenith, H. van Middendorp, The relative influence of physical fitness, acclimatization state, anthropometric measures and gender on individual reactions to heat stress, Eur. J. Appl. Physiol. Occup. Physiol. 61 (5–6) (1990) 419–427, https://doi.org/10.1007/BF00236062. Dec.

[148] T. Chaudhuri, D. Zhai, Y.C. Soh, H. Li, L. Xie, Random forest based thermal comfort prediction from gender-specific physiological parameters using wearable sensing technology, Energy Build. 166 (2018) 391–406, https://doi.org/10.1016/j.enbuild.2018.02.035. May.

[149] A.M. Abbasi, E. Darvishi, M.A. Rodrigues, K. Sayehmiri, Gender differences in cognitive performance and psychophysiological responses during noise exposure and different workloads, Appl. Acoust. 189 (2022), 108602, https://doi.org/10.1016/j.apacoust.2021.108602. Feb.

[150] A. Kuijsters, J. Redi, B. de Ruyter, I. Heynderickx, Lighting to make you feel better: improving the mood of elderly people with affective ambiences, PLoS One 10 (7) (2015), e0132732, https://doi.org/10.1371/journal.pone.0132732. Jul.

[151] J. Van Hoof, J.L.M. Hensen, Thermal comfort and older adults, Gerontechnology 4 (4) (2006), https://doi.org/10.4017/gt.2006.04.04.006.00. Oct.

[152] A.E. Carrillo, et al., Heart rate variability during high heat stress: a comparison between young and older adults with and without Type 2 diabetes, Am. J. Physiol. Integr. Comp. Physiol. 311 (4) (2016) R669–R675, https://doi.org/10.1152/ajpregu.00176.2016. Oct.

[153] C. Chou, L.-C. Chen, Effects on different age levels of distinct lighting environment design, J. Ind. Prod. Eng. 30 (8) (Dec. 2013) 488–494, https://doi.org/10.1080/21681015.2013.863228.

[154] M. Luo, W. Ji, B. Cao, Q. Ouyang, Y. Zhu, Indoor climate and thermal physiological adaptation: evidences from migrants with different cold indoor exposures, Build. Environ. 98 (2016) 30–38, https://doi.org/10.1016/j.buildenv.2015.12.015. Mar.

[155] H. Enomoto, K. Ikeda, K. Azuma, Y. Tochihara, Observation of the thermal conditions of the workers in the 'cool biz' implemented office, J. Occup. Saf. Health 2 (1) (2009) 5–10, https://doi.org/10.2486/josh.2.5.

[156] L. Hartog, M. Weijs-Perrée, R. Appel-Meulenbroek, The influence of personality on user satisfaction: multi-tenant offices, Build. Res. Inf. 46 (4) (2018) 402–416, https://doi.org/10.1080/09613218.2017.1307015. May.

[157] J.A. McCusker, Individuals and Open Space Office Design: the Relationship between Personality and Satisfaction in an Open Space Work Environment, Alliant International University, Los Angeles, 2002.

[158] M.H. Beheshti, et al., The influence of personality traits and gender on noise annoyance in laboratory studies, Pers. Indiv. Differ. 148 (2019) 95–100, https://doi.org/10.1016/j.paid.2019.05.027. Oct.

[159] K.M. Walbam, The relevance of sensory processing disorder to social work practice: an interdisciplinary approach, Child Adolesc. Soc. Work. J. 31 (1) (2014) 61–70, https://doi.org/10.1007/s10560-013-0308-2. Feb.

[160] A. Ben-Sasson, L. Hen, R. Fluss, S.A. Cermak, B. Engel-Yeger, E. Gal, A meta-analysis of sensory modulation symptoms in individuals with autism spectrum disorders, J. Autism Dev. Disord. 39 (1) (2009) 1–11, https://doi.org/10.1007/s10803-008-0593-3. Jan.

[161] L. Nota, S. Santilli, M.C. Ginevra, S. Soresi, Employer attitudes towards the work inclusion of people with disability, J. Appl. Res. Intellect. Disabil. 27 (6) (2014) 511–520, https://doi.org/10.1111/jar.12081. Nov.

[162] M.T. Tomczak, Employees with autism spectrum disorders in the digitized work environment: perspectives for the future, J. Disabil. Pol. Stud. 31 (4) (2021) 195–205, https://doi.org/10.1177/1044207320919945. Mar.

[163] N. Magnavita, Work-related symptoms in indoor environments: a puzzling problem for the occupational physician, Int. Arch. Occup. Environ. Health 88 (2) (2015) 185–196, https://doi.org/10.1007/s00420-014-0952-7. Feb.

[164] B. Noble, N. Isaacs, S. Lamb, The impact of IEQ factors on people on the autism spectrum, in: International Conference of the Architectural Science Association, 2018, pp. 27–33.

[165] C.U. Greven, et al., Sensory Processing Sensitivity in the context of Environmental Sensitivity: a critical review and development of research agenda, Neurosci. Biobehav. Rev. 98 (2019) 287–305, https://doi.org/10.1016/j.neubiorev.2019.01.009. Mar.

[166] D. Clements-Croome, B. Turner, K. Pallaris, Flourishing workplaces: a multisensory approach to design and POE, Intell. Build. Int. 11 (3–4) (2019) 131–144, https://doi.org/10.1080/17508975.2019.1569491. Oct.

[167] M. Caniato, L. Zaniboni, A. Marzi, A. Gasparella, Evaluation of the main sensitivity drivers in relation to indoor comfort for individuals with autism spectrum disorder. Part 1: investigation methodology and general results, Energy Rep. 8 (2022) 1907–1920.

[168] W. Yang, H.J. Moon, Combined effects of acoustic, thermal, and illumination conditions on the comfort of discrete senses and overall indoor environment, Build. Environ. 148 (2019) 623–633, https://doi.org/10.1016/j.buildenv.2018.11.040. Jan.

[169] B. Sona, E. Dietl, A. Steidle, Recovery in sensory-enriched break environments: integrating vision, sound and scent into simulated indoor and outdoor environments, Ergonomics 62 (4) (2019) 521–536, https://doi.org/10.1080/00140139.2018.1491643. Apr.

[170] A. Steinemann, Ten questions concerning air fresheners and indoor built environments, Build. Environ. 111 (2017) 279–284, https://doi.org/10.1016/j.buildenv.2016.11.009. Jan.

[171] M. Roskams, B. Haynes, P.-J. Lee, S.-H. Park, Acoustic comfort in open-plan offices: the role of employee characteristics, J. Corp. Real Estate 21 (3) (2019) 254–270, https://doi.org/10.1108/JCRE-02-2019-0011. Sep.

[172] N. Baum, J. Chaddha, The impact of auditory white noise on cognitive performance, J. Sci. Med. (2021) 1–15, https://doi.org/10.37714/josam.vi0.82. Jun.

[173] D. Djenouri, R. Laidi, Y. Djenouri, I. Balasingham, Machine learning for smart building applications, ACM Comput. Surv. 52 (2) (2020) 1–36, https://doi.org/10.1145/3311950. Mar.

[174] A. Aryal, B. Becerik-Gerber, G.M. Lucas, S.C. Roll, Intelligent agents to improve thermal satisfaction by controlling personal comfort systems under different levels of automation, IEEE Internet Things J. 8 (8) (2021) 7089–7100, https://doi.org/10.1109/JIOT.2020.3038378. Apr.

[175] N. Stojanovic, D. Milenovic, Y. Xu, L. Stojanovic, D. Anicic, R. Studer, An intelligent event-driven approach for efficient energy consumption in commercial buildings, in: Proceedings of the 5th ACM International Conference on Distributed Event-Based System - DEBS '11, 2011, p. 303, https://doi.org/10.1145/2002259.2002299.

[176] G. Giannakakis, D. Grigoriadis, K. Giannakaki, O. Simantiraki, A. Roniotis, M. Tsiknakis, Review on psychological stress detection using biosignals, IEEE Trans. Affect. Comput. 13 (1) (2022) 440–460, https://doi.org/10.1109/TAFFC.2019.2927337. Jan.

[177] M.H.E.M. Browning, K.J. Mimnaugh, C.J. van Riper, H.K. Laurent, S.M. LaValle, Can simulated nature support mental health? Comparing short, single-doses of 360-degree nature videos in virtual reality with the outdoors, Front. Psychol. 10 (2020), https://doi.org/10.3389/fpsyg.2019.02667. Jan.

[178] N. Zhao, S. Seitinger, R. Richer, J.A. Paradiso, Real-time work environment optimization using multimodal media and body sensor network, Smart Heal 19 (2021), 100164, https://doi.org/10.1016/j.smhl.2020.100164. Mar.

[179] WELL, "WELL health-safety rating." https://www.wellcertified.com/.

[180] A.J. Hoisington, et al., Ten questions concerning the built environment and mental health, Build. Environ. 155 (2019) 58–69, https://doi.org/10.1016/j.buildenv.2019.03.036. May.