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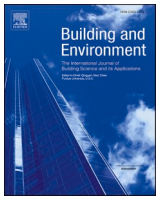

Perceived air quality (PAQ) assessment methods in office buildings: A systematic review towards an indoor smellscape approach

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ABSTRACT

Indoor air quality (IAQ) has significant impacts on office occupants' productivity, well-being and health. Addressing IAQ not only means ensuring that contaminants are below harmful concentration but also that people exposed are satisfied. However, current standards often lack clear metrics and thresholds dedicated to Perceived Air Quality (PAQ). Therefore, it is important to examine whether there is a prevalent method in the literature that could lead towards standardization. This review study constitutes the first comprehensive critical exploration of the subject. Adopting the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, the objective is to synthesize and compare diverse methods (subjective vs instrumental evaluations; object of judgment; component of perception; rating scales) for assessing PAQ in office buildings, based on insights from 93 field and laboratory studies. Results show that the assessment of PAQ predominantly relies on questionnaires (90 %), with a very smaller percentage using alternative methods such as olfactory indices, diaries, interviews, sensory testing, and text mining techniques. Workers' satisfaction is the most commonly evaluated aspect in PAQ questionnaires, often measured on a 7-point Likert scale. Odours are typically characterized in terms of intensity by utilizing a continuous 6-point unidirectional scale. Olfactory stimuli are usually considered with a negative connotation, being the absence of odour the target of IAQ design. The present study proposes a future research agenda that introduces the importance of a perceptual approach to evaluate the indoor olfactory environments (or smellscapes), aiming to create working spaces that are not only odour-neutral but also olfactorily pleasant.

List of abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AC	Acoustic comfort
Acc	Mean vote of air acceptability
A	Acceptability
B	Bidirectional
C	Comfort
CBE	Center of the Built Environment
CD	Continuous divided
CU	Continuous undivided
CEN	European Committee for Standardization
Ch	Character
CISBE	Chartered Institute of Building Services Engineers
D	Dichotomous
DTP	Double Translation Process
F/S	Freshness/Stuffiness

(*continued on next column*)

(*continued*)

GC-MS	Gas Chromatography – Mass Spectrometry
GC-O	Gas Chromatography – Olfactometry
I	Intensity
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
ISO	International Organization for Standardization
L	Likert
LEED	Leadership in Energy and Environmental Design
M	Monodirectional
MC	Multiple-choice
N/A	Not applicable
N/S	Not specified
P	Perception
PAQ	Perceived Air Quality
PD	Percentage of Dissatisfied
POE	Post Occupancy Evaluation
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses

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(*continued*)

O	Odour
Q	Quality
S	Satisfaction
SBS	Sick Building Syndrome
TC	Thermal comfort
TVOC	Total Volatile Organic Compounds
VC	Visual comfort
VOCs	Volatile Organic Compounds
WHO	World Health Organization

1. Introduction

Since the 1980s, there has been a growing interest in the impact of indoor air quality (IAQ) on well-being, productivity, and health [1]. This is particularly true today as buildings are constructed with increased airtightness for reasons of energy efficiency. Office buildings are a very sensitive building category as people spend a significant amount of time in them, but as end users, they often have limited control over ventilation and IAQ.

Organizations such as the World Health Organization (WHO) have proposed guidelines for pollutants and thresholds to ensure acceptable IAQ, considering their harmful effects on health [2]. Thus, achieving good IAQ goes beyond safeguarding health; it must also create feelings of comfort, pleasure, and enhance productivity.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines Acceptable IAQ the "Air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80 % or more) of the people exposed do not express dissatisfaction" [3]. On the other hand, Acceptable perceived air quality (PAQ) is defined as the "Air in an occupied space toward which a substantial majority of occupants express no dissatisfaction on the basis of odour and sensory irritation. Acceptable PAQ is necessary, but not sufficient, to meet acceptable IAQ" [4]. Furthermore, the concept of odour is introduced in standards as "A quality of gases, liquids, or particles that stimulates the olfactory organ" [3]. From these definitions, it is evident that PAQ is a sub-aspect of IAQ, which involves both objective requirements (concentration of contaminants) and subjective requirements (i.e., satisfaction in reference to PAQ). On the other hand, the perceptual evaluation of odours is a sub-aspect of PAQ, which is a broader evaluation compared to that of odour because it also covers other aspects, such as possible mucosal irritations (e.g., eyes, throat, nose).

People can assess PAQ based on a feeling of comfort, which can be more precise than instrumental devices [5]. This sense of comfort relies on information gathered through various sensory organs, including the nose, throat, eyes, skin, and hypothalamus. The combined response to temperature, humidity, and a wide range of contaminants allows us to perceive the air as either fresh and pleasant or stale, stuffy, and irritating [6].

Assessing IAQ based on human senses is challenging due to various factors. Firstly, there are many different chemicals involved, and some harmful air contaminants might not be sensed at all (for example, carbon monoxide or radon) [7]. Even for pollutants that can be detected by their odour or irritation effects, it is necessary to determine who is to judge what is acceptable. This could involve a random sample of occupants, a panel of individuals entering a building, those untrained (i.e., uncalibrated but representative, sometimes called "naïve"), or individuals trained to respond according to consistent criteria. Moreover, the challenge of adaptation should be considered. Indeed, it takes only 3 min for people to become less sensitive to odours present in a room [4]. Over longer periods (weeks or months), individuals may come to accept even a harmless odour as normal. Another challenge arises from the interaction of IAQ with other factors. Human responses may stem from IAQ problems, but they can also be influenced by factors independent from IAQ, such as temperature, humidity, draught, lighting, noise, or personal control over the environment [8,9].

To assess PAQ, Standards ISO 16000-30 [10] and ISO 16000-28 [11] introduced the predicted Percentage of Dissatisfied (PD) index, as a percentage ratio of dissatisfied individuals to the total number of the untrained panel of people. However, there is a lack of standardized methods to determine this dissatisfaction percentage. In the following, the PD calculation methods outlined in standards and protocols are introduced. These methods involve both approaches relying on human feedback and methods using proxies such as indices obtained through instrumental measurements. Additionally, chemical and cognitive investigation techniques are presented, which can offer complementary information to objective and subjective evaluations.

Standards such as CEN 1752 [12], ISO 16814 [4] and ISO 17772-1 [13] express the PD as a function of ventilation rates, Olf and Decipol index, and CO_2 concentration. Other standards, like ISO 28802 [14], suggest evaluating PAQ through questionnaires, introducing the intensity, acceptability and satisfaction scales. Subjective evaluation is also recommended by ASHRAE 62.1 and Chartered Institute of Building Services Engineers (CISBE), that defines acceptable PAQ if less than 50 % people perceive odours, less than 20 % feel discomfort, less than 10 % experience mucous irritation, and less than 5 % feel irritable for less than 2 % of the time in enclosed spaces [3,15]. Leading building classification and certification protocols like WELL and LEED adopt subjective survey methods, utilizing tools like the CBE (Center for the Built Environment) Occupant Survey [16]. Furthermore, there are also methods of chemical and cognitive investigation that can complement subjective measurements of PAQ by adding information on the chemical nature of odours or cognitive insights into the mechanisms underlying the perception of olfactory stimuli depending on the activated part of the brain. Electronic noses can detect and differentiate odours by mimicking the capabilities of a human nose. Conductance sensors can detect odours through changes in electrical conductivity caused by the presence of specific chemical substances in the odours. Brain imaging techniques are used to study brain activity associated with the perception of odours.

Since there are various methods for assessing PAQ, it is important to examine whether there is a prevalent method in the literature that could lead towards future standardization, thereby facilitating the harmonization of methodologies employed in IAQ research and enabling future meta-analyses. Adopting the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [17], this review aims to address the following research questions: (1) How is PAQ assessed in office buildings in the literature? (1.1) To what extent are the metrics used in the literature present in existing standards and protocols?

2. Methods

A literature review analysis was conducted to investigate the methods of evaluating PAQ as documented in scientific literature, with a focus on office buildings. The literature review adheres to the PRISMA guidelines [17] to ensure a systematic approach to the collection, analysis, and reporting of relevant literature.

2.1. Search strategy

A literature search was conducted on the 'Scopus' database in July 2023 to identify studies related to the perception of IAQ ('perceived air quality' OR 'odour*' OR 'smell*' OR 'odour*' OR 'scent*' OR 'indoor environmental quality') specifically in office environments ('office*'). The complete research query was formulated as follows: ((((('perceived air quality' OR 'odour*' OR 'smell*' OR 'odour*' OR 'scent*' OR 'indoor environmental quality') AND ('office*'))). The decision to use both "perceived air quality"/"indoor environmental quality" and "odour*"/"odour*"/"smell*"/"scent*" as search keywords aimed to capture a broad range of studies on both general indoor air quality perception (as a

subfield of indoor environmental quality research) and specific odour perception research. This approach addresses the lack of consistent terminology in the field, ensuring a comprehensive review by maximizing the inclusion of relevant articles and minimizing the risk of omitting important studies.

The search included papers that focused on PAQ assessments (I1). Articles written in English (I3) after the year 2000 (I4) were considered in their final version (I5), excluding books, book chapters, and conference papers (E1). Field studies conducted in office buildings or laboratory experiments simulating office environments through furnishings and participant activities were included (I2). Papers from distant research areas unrelated to indoor environments (e.g., business, dentistry) were excluded (E2). The inclusion and exclusion criteria are detailed in Table 1.

A total of 1244 documents were retrieved using the specified research query. Some articles were excluded through search filtering based on language (n = 79), year of publication (n = 132), publication stage (n = 9), document type (n = 368), and subject area (n = 117). Titles and abstracts of 483 articles were reviewed, leading to exclusion of articles not focused on offices (n = 157), and not addressing occupants' perception of indoor air quality (n = 207).

A total of 119 articles were assessed for eligibility, and their full text was reviewed. Subsequently, 24 articles were further excluded as not representing field studies or laboratory experiments (n = 10), not addressing occupants' perception of IAQ (n = 14) and as from distant research area (n = 2). Ultimately, the articles included in the review amounted to 93 papers.

Fig. 1 illustrates the selection procedure in accordance with the PRISMA guidelines.

2.2. Data extraction and analysis

The data information was manually extracted from the papers, encompassing general article information (e.g., keywords), details on the type of study (i.e., field study or laboratory experiment), the country and the altitude where it was performed, the type of buildings assessed (i.e., year of construction/renovation of the office building, office layout), the monitoring details (i.e., year, season, monitoring duration), and the human sample (i.e., total number of human samples, number of males, number of females, average age). Regarding the assessment methods of PAQ, details were recorded regarding the evaluation approach (e.g., questionnaire, text mining), and in the case of questionnaire evaluations, the type of questionnaire (i.e., one-off or right here-right now), the assessed categories (e.g., air acceptability, odour intensity), and the related scale (e.g., Likert, check-box) and number of points. Additionally, information was gathered to determine if the papers also evaluated the effects of PAQ on health and productivity.

For the completed review table, please refer to Supplementary Material.

Table 1
Eligibility criteria used in the selection process of the articles.

Inclusion criteria	Exclusion criteria
I1 - Studies which assess the PAQ.	E1 - Books, book chapters, conference papers.
I2 - Field studies in office buildings, or laboratory experiments recreating an office environment.	E2 - Subject area: Business, management and Accounting, Computer Science, Arts and Humanities, Dentistry, Agricultural and Biological Sciences, Pharmacology, Toxicology and Pharmaceutics, Mathematics, Physics and Astronomy, Earth and Planetary Sciences, Veterinary, Health Professions, Nursing, Economics, Econometrics and Finance, Decision Sciences.
I3 - Journal articles whose text is fully available in English.	
I4 - Recent studies published after 2000.	
I5 - Publication stage: final version.	

3. Results

3.1. Description of the included papers

Ninety-three studies addressing the perception of indoor air quality in offices, published from 2000 to July 2023, have been reviewed. A notable 40 % of these articles were published in the last five years (2019–2023), with a peak in 2020 and 2021, which may be related to the spread of the Covid-19 pandemic and a consequent interest in the subject (Fig. 2). Ninety-eight percent of the studies analyse at least one additional domain besides IAQ, with thermal comfort being the most common, given the established influence of parameters such as air temperature and relative humidity on PAQ [18]. However, in recent years, there has been a growing trend towards an approach that simultaneously considers all domains of IEQ (IAQ, thermal comfort, acoustic comfort, visual comfort) (Fig. 2). This could be the effect of milestones review works on multi-domain studies in 2018–2020, also following the activity of international working group (e.g., IEA EBC Annex 79) [19,20]. It should be noticed that no study has investigated the relationships of IAQ exclusively with visual comfort or exclusively with acoustic comfort.

Examining studies worldwide, it was found that 19 % were conducted in the United States (North America), 14 % in Denmark (Europe), and 8 % each in China and Singapore (Asia). This highlights a non-uniform distribution of studies across the globe that may lead to findings that are not universally applicable due to perception bias and environmental variability across different countries (Fig. 3).

Two-thirds of the reviewed studies were conducted as field studies, while one-third took place in laboratories simulating office environments. Table 2 illustrates the relative frequencies of information reported in the reviewed papers.

The monitoring duration was less than one week in 57 % of lab studies, whereas it spanned several months in the case of field studies, allowing for a relatively even coverage of all seasons. Studies have been conducted in open-space building types (no partitions, low partitions, high partitions) and enclosed office types (shared, private) with similar relative frequencies in the case of field studies. However, there is a higher frequency of simulation for the enclosed type in lab studies.

Field studies involved more than 100 participants in 65 % of cases, while laboratory studies typically included a range of 11–50 participants in 70 % of cases. Information on the average age of the human sample, when available, indicates a preference for the age range of 18–28 years, especially in lab studies where this occurs in 70 % of cases due to the recruitment of predominantly student participants.

Studies were either gender-balanced or skewed towards either female or male participants, especially when investigating phenomena specific to a particular gender (e.g., Ref. [21]). In this analysis, gender balance is considered achieved if there is a ratio of 50 ± 5 % of men/-women. It can be noticed that gender balance was more easily attainable in lab studies where participants were pre-selected.

Thirty-one percent of the total studies investigated how IAQ enhances or interferes with office productivity, while 36 % of the studies focused on its impact on health. Productivity is assessed through questionnaires [22–37], simulated office tasks [22–24,38–43], or standardized cognitive tests related to psychomotor performance, attention, and memory [31]. The health effects are evaluated in terms of SBS, typically employing a self-reported pathological approach, where participants declare the frequency of psychophysical problems during their office stay through questionnaires [18,23,24,29,31,39–61].

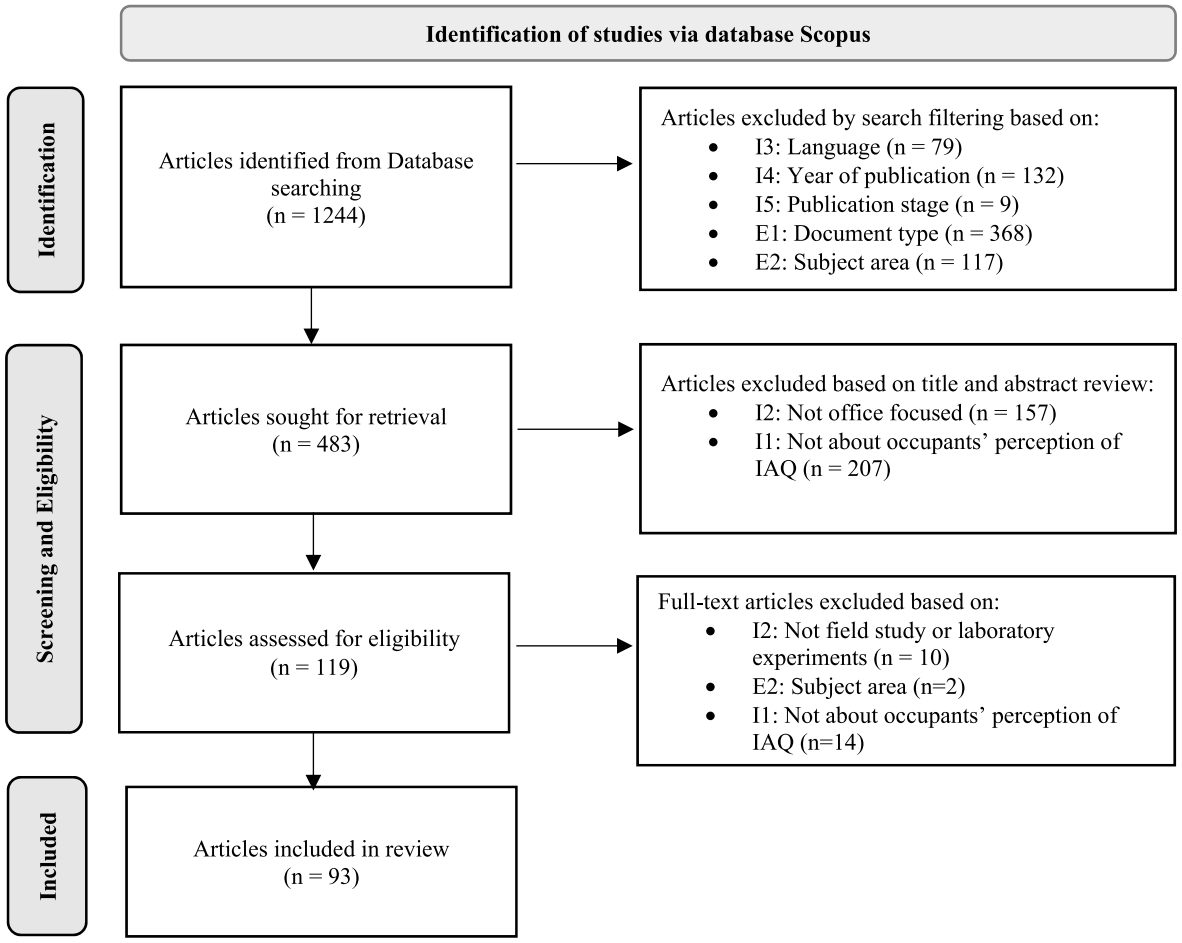

Fig. 1. PRISMA flow diagram for the identification of the studies via database.

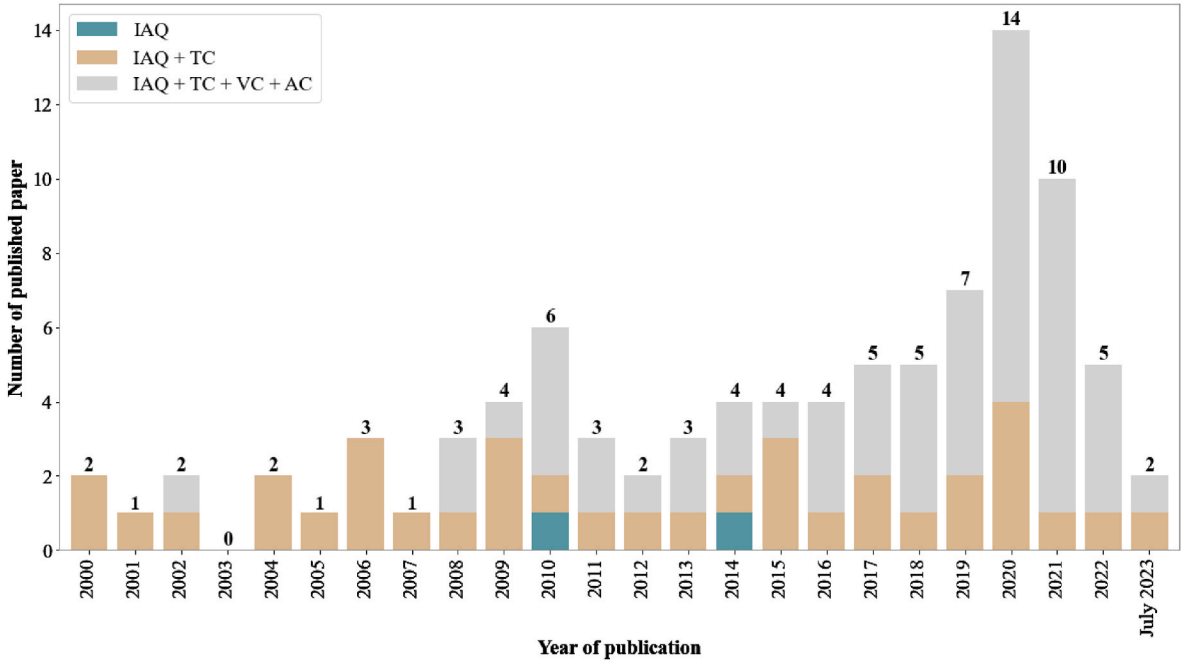

Fig. 2. Number of PAQ in office articles published per year of publication with respect to the combination of indicated domains. IAQ = Indoor Air Quality; TC = Thermal Comfort; AC = Acoustic Comfort; VC = Visual Comfort.

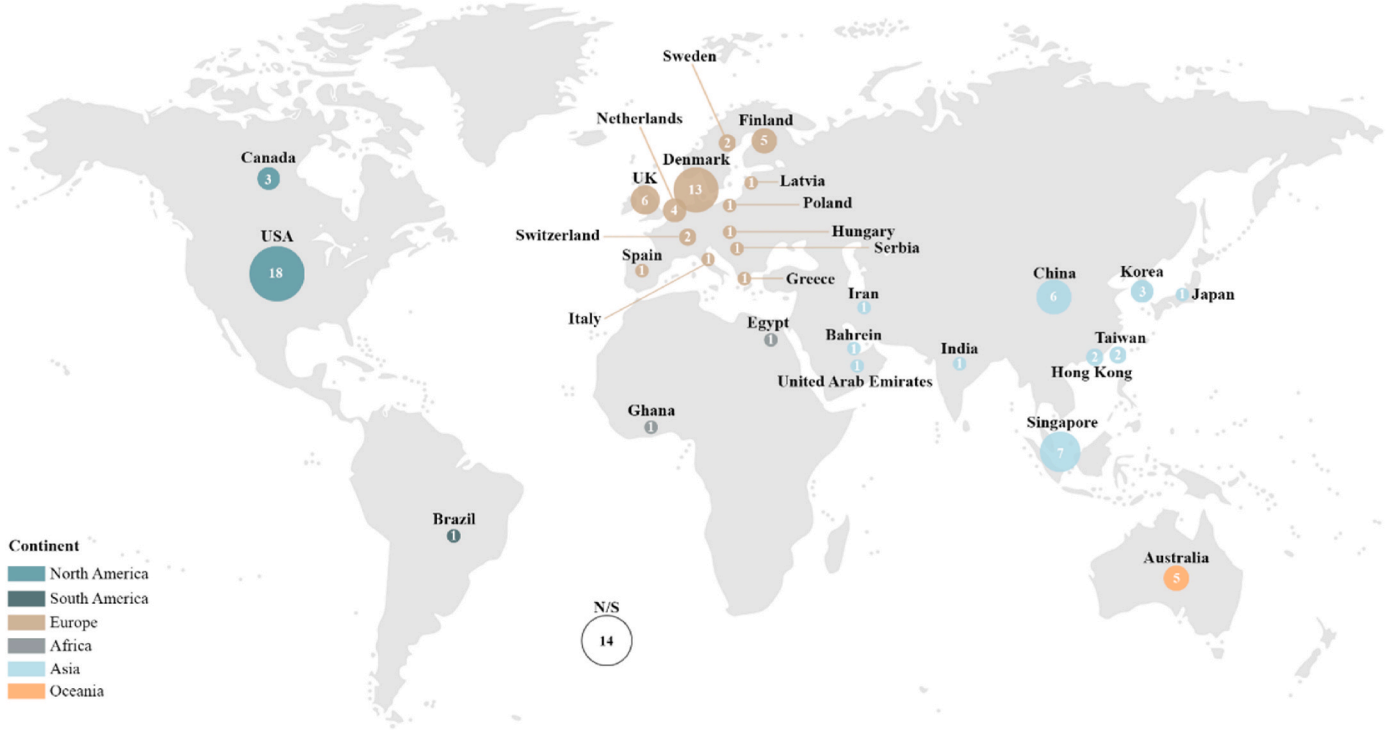

Fig. 3. Geographical distribution of PAQ studies conducted in offices from 2000 to July 2023. N/S = not specified.

3.2. Assessment methods of PAQ in office buildings

The assessment of PAQ in the 93 reviewed papers involves both methods relying on human feedback and methods using proxies such as indices obtained through instrumental measurements. Among the former, we find diaries [62,63], interviews [63], sensory testing [23,64], and text mining techniques [65], as well as questionnaires, which are employed in the vast majority of cases [21–23,23,25–36,38–43,45–50,52–63,63–112]. In the second case, indices such as Olf and Decipol [23,66], or the Indoor Air Quality Component Index [68] are utilised. Fig. 4 illustrates the distribution of the assessment methods of PAQ in office buildings while the following paragraphs focus on each method.

3.2.1. Olf and Decipol

Only 2 % of the analysed papers, which were conducted in Denmark in the early 2000s, attempt to investigate IAQ using the Olf and Decipol indices [23,66].

Introduced in 1988 by Fanger [113], the Olf index is used to quantify pollution sources, while the Decipol is employed to measure the concentration of air pollution perceived by humans. An Olf is defined as the emission rate of air pollutants from a standard person (bioeffluents). Any other pollutant source intensity is expressed as an equal source intensity, defined as the number of standard persons (Olf) causing the same dissatisfaction for the actual pollution source. If we dilute a pollutant source with 10 L/s of pure air, the perceived pollutant intensity is defined as 1 Decipol, or 1 Decipol equals 0.1 Olf/(L/s). The Decipol, in particular, is used in literature to quantify the percentage of dissatisfaction related to IAQ, exploiting the relationship between dissatisfaction percentage (PD, %) and perceived air pollution (Decipol, C), using Equations (1) and (2) [23,66]. When pollution intensity exceeds 31.3 Decipols, the IAQ dissatisfaction percentage is deemed absolute dissatisfaction.

$$C \leq 31.3\ decipols, C = 112(In(PD) - 5.98)^{-4} \quad (1)$$

$$C > 31.3\ decipols, PD = 100\% \quad (2)$$

3.2.2. Indoor air quality component index I_{IAQ}

Mujan et al. [68] (1 % of the reviewed papers) tried to correlate occupants' satisfaction with the concentrations of indoor air pollutants such as Total Volatile Organic Compounds (TVOC), $PM_{2.5}$, and CO_2, using the Indoor Air Quality Index (I_{IAQ}). This index represents the minimum value among satisfaction indices I_{CO2}, I_{TVOC}, $I_{PM2.5}$, respectively calculated by measuring logarithmic concentrations of CO_2, TVOC, and $PM_{2.5}$ according to Equations (3)–(6) [68]. Part of a comprehensive index covering all aspects of Indoor Environmental Quality (I_{IEQ}), the I_{IAQ} demonstrated good agreement with occupants' perception, with a mean absolute error of less than 3 %.

$$I_{IAQ} = \min\left(I_{CO2}, I_{TVOC}, I_{PM2.5}\right) \quad (3)$$

$$I_{CO2} = 100 - 70 \bullet log\frac{C_{CO2}}{415} \quad (4)$$

$$I_{TVOC} = 100 - 100 \bullet log\frac{C_{TVOC}}{30} \quad (5)$$

$$I_{PM2.5} = 100 - 85 \bullet log\frac{C_{PM2.5}}{10} \quad (6)$$

3.2.3. Questionnaire

The vast majority of reviewed papers (90 %) investigate PAQ through the use of questionnaires.

The questionnaire method involves quantifying human responses to an environment using subjective scales on surveys relevant to the psychological or physiological phenomenon of interest [14].

Questionnaires are administered in paper form [46,68,103] or digitally, either as web-based surveys sent via email [50,83,98,102,104,105] or through dedicated smartphone or computer applications [34,52,106], or via an intranet [80]. A novel method for collecting feedback is through occupant voting systems (OVS), which allow occupants to express their discomfort using a button with a corresponding colour, positioned at each workstation [114,115].

Questionnaires, typically developed in English, are administered in

Table 2
Relative frequencies of information reported in the reviewed papers. N/S = Not specified. IAQ = Indoor Air Quality; TC = Thermal Comfort; AC = Acoustic Comfort; VC = Visual Comfort.

	Field (N = 70)	Lab (N = 23)	Total (N = 93)	
IAQ + TC	27 %	73 %	38 %	**IEQ domains**
IAQ + TC + VC + AC	70 %	27 %	60 %	
IAQ	3 %	0 %	2 %	
Winter	20 %	18 %	20 %	**Season of monitoring**
Spring	14 %	7 %	13 %	
Summer	14 %	30 %	18 %	
Autumn	15 %	12 %	13 %	
N/S	37 %	33 %	36 %	
Less than 1 week	6 %	57 %	18 %	**Duration of monitoring**
1 week–4 weeks	10 %	17 %	12 %	
5 weeks - 1 year	27 %	17 %	25 %	
More than 1 year	1 %	0 %	1 %	
N/S	56 %	9 %	44 %	
Open – no partitions	18 %	0 %	10 %	**Office type**
Open – low partitions	11 %	14 %	12 %	
Open – high partitions	11 %	5 %	10 %	
Enclosed - private	12 %	18 %	18 %	
Enclosed - shared	18 %	32 %	20 %	
N/S	30 %	31 %	30 %	
Less than 10	1 %	13 %	4 %	**Human sample size**
11 - 50	14 %	70 %	28 %	
51- 100	7 %	17 %	10 %	
101 - 1000	39 %	0 %	29 %	
More than 1000	26 %	0 %	19 %	
N/S	12 %	0 %	10 %	
18–28	10 %	70 %	25 %	**Human sample age (avg)**
29–39	6 %	4 %	5 %	
40 - 50	9 %	9 %	9 %	
N/S	75 %	17 %	61 %	
Gender balanced	17 %	61 %	28 %	**Sex**
More male	20 %	4 %	16 %	
More female	20 %	26 %	22 %	
N/S	43 %	9 %	34 %	
Productivity	32 %	30 %	31 %	**Effects of PAQ**
SBS	32 %	48 %	36 %	

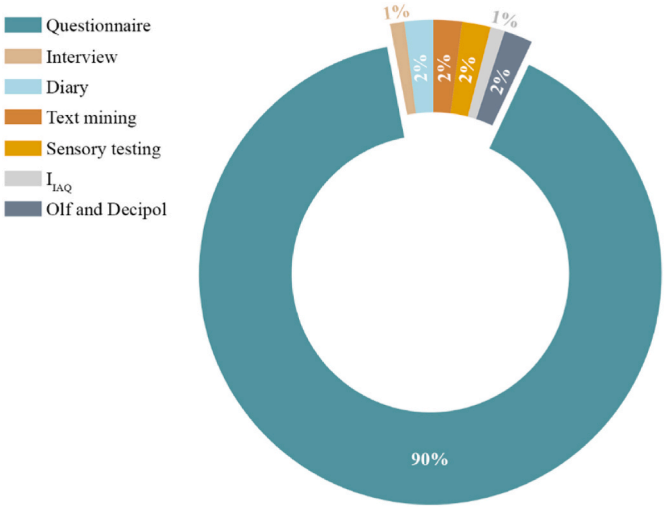

Fig. 4. Assessment methods of PAQ in office buildings in the reviewed papers.

the same language [27,43,81] or translated into respondents' native languages [57,60,105]. In the latter case, the semantic, conceptual, and normative equivalence of survey questions should be ensured by back translating the survey questions into English and verifying their accuracy before finalizing the translated versions, as outlined in the Double Translation Process (DTP) [116].

39 % of studies assessing PAQ through questionnaires employ 'point-in-time' (or 'right here-right now') questions [21–23,31,34,38–43,45,50,56,61,66,68,70,72,74,75,79,82,86,90,92,93,97,106–108,112,114,115,117]. These questions are utilised to evaluate PAQ at a single moment and can be repeated, allowing for correlation with environmental factors. On the other hand, 48 % of studies use 'one-off questions' to assess PAQ over a specific timeframe, which can be indefinite [25,26,28,29,32,33,35]– [37,46]– [49,51,54,55,57,60,61,67,71,73,76]–[78,80,81,83]–[85,87–89,93]– [99,102,104,108,111,118] or relative to a specific period, such as 1 month [57] or 3 months [61]. 13 % of papers don't specify the timeframe of the questions. The underlying premise of the one-off approach is that occupants can recall instances or periods of comfort/discomfort, identify patterns in building operation, and provide 'overall' or 'average' comfort ratings for their environment. The 'one-off' questionnaire approach is more commonly employed in post occupancy evaluations (POE) of real buildings where the goal is to understand occupants' overall satisfaction over repeated conditions. In contrast, the 'right here-right now' questionnaire is primarily used in lab studies, seeking correlations between perceptual parameters and specific environmental conditions.

The investigated studies assess PAQ by examining two different objects of judgment, i.e. general feedback regarding IAQ, and/or specific feedback regarding odours. The second category of questions allows for more detailed responses regarding odours compared to the broader category of questions, of which it is a subgroup. Evaluations encompass different components of experience, which can be categorized into six groups, namely freshness/stuffiness, quality, comfort, acceptability, satisfaction, intensity, and character. The IAQ is most often evaluated in terms of satisfaction, acceptability and freshness/stuffiness. Odours are mainly evaluated in terms of intensity. Fig. 5 illustrates the clustering of reviewed papers involving the questionnaire method according to the object of judgment and the assessed component of perception.

Various types of scales are utilised, including Likert, continuous divided, continuous undivided, multiple-choice question, and dichotomous scales. These scales can be unidirectional (e.g., 0 never, 1 sometimes, 2 often [47]) or bidirectional (e.g., +3 very satisfied, +2 satisfied, +1 slightly satisfied, 0 neither satisfied nor dissatisfied, −1 slightly dissatisfied, −2 dissatisfied, −3 very dissatisfied [25]), with preferable values found towards the 'right-hand' or 'left-hand' of the scale (e.g., 0 air stuffy, 100 air fresh [82]) or towards the centre of the scale (e.g., very dry, very humid [70]), featuring a point of neutrality (e.g., 1 very dissatisfied, 2 dissatisfied, 3 neither satisfied nor dissatisfied, 4 satisfied, 5 very satisfied [119]), or without a neutral point (e.g., +1 clearly acceptable, +0.1 just acceptable, −0.1 just unacceptable, −1 clearly unacceptable [21]). Table 3 illustrates the different objects of judgment, component of perception and scale type employed in the reviewed papers. Graphical examples of the different scale types can be found in the Supplementary Material.

The choice of the type of scale and the number of points influences the calculation of PD. PD towards IAQ is mostly assessed using a bidirectional Likert satisfaction scale with 7 points, including a neutral point (from "very dissatisfied" to "very satisfied") [25,27,28,30,32,35,36,55,56,61,69,76,77,83,85,91,93–97,106,108] or a bidirectional continuous acceptability scale divided into 4 points without a neutral point (from "clearly acceptable" to "clearly unacceptable") [21–23,38–41,45,59,66,72,80,82,90,107,120]. PD towards odours is mostly evaluated on a continuous unidirectional intensity scale with 6 points (from "no odour" to "overpowering odour") [22,23,39,40,59,66,72,80]. Odour satisfaction scales are typically unidirectional, ranging from olfactory neutrality to olfactory dissatisfaction [29,46,61,103,108,111]. Only 5 % of the reviewed articles investigate satisfaction in the comparison of odours, assuming the existence of positive odours [33,81,101,105].

In the case of satisfaction regarding IAQ, PD can be calculated as the percentage ratio of people who gave a score equal to or lower than −1 to

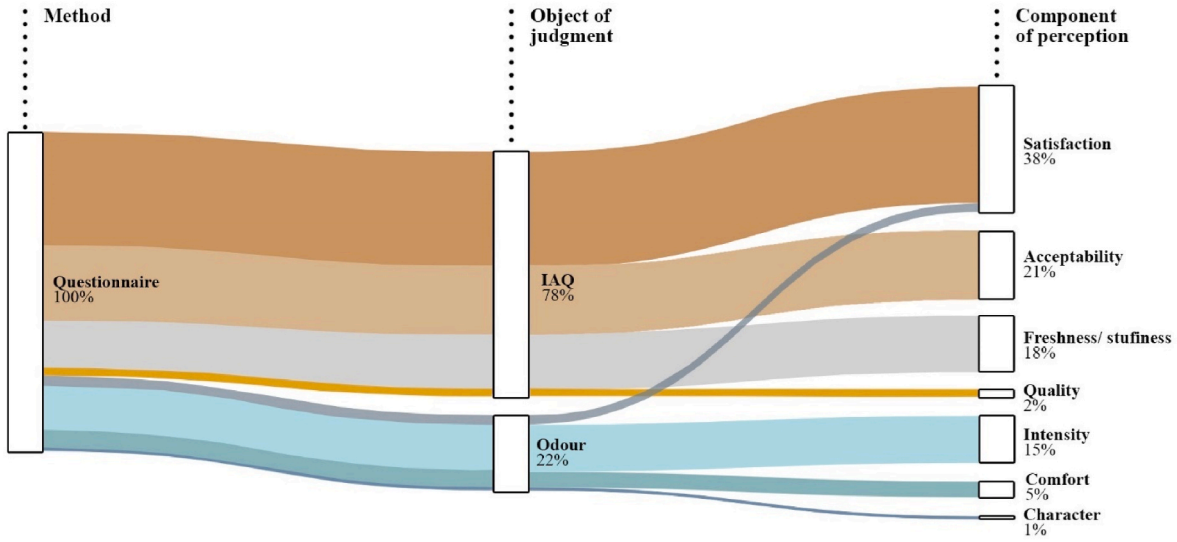

Fig. 5. Clustering of reviewed papers involving the questionnaire method.

the total number of participants [85], or the average score can be calculated, and participants are considered dissatisfied if this average score is equal to or lower than −2 [91].

In the case of acceptability of PAQ, the mean acceptability ratings can be converted to PD according to the equation by Gunnarsen and Fanger [121]:

$$PD_{IAQ} = \frac{\exp(-0.18 - 5.28\,Acc)}{1 + \exp(-0.18 - 5.28Acc)} x100 \quad (7)$$

Where PD = Percentage of dissatisfied with the air quality (%) and Acc = Mean vote of air acceptability.

PD can also be calculated as the percentage ratio of people who responded with values between clearly unacceptable and just unacceptable to the total number of respondents [80,82]. In some instances, only individuals who stated that PAQ is clearly unacceptable are considered dissatisfied [66,72]. The mean acceptability ratings can also be transformed to PD and subsequently into Decipol units, which are used to quantify the PD related to PAQ [23,66].

Regarding odour intensity, a vote of odour intensity in the range from 0 (no odour) to 1 (slightly odorous) is considered satisfied, and beyond this range is considered dissatisfied [22,29,31,34,38–40,46,61,70,72,80,103,107,108,111,122]. The focus is normally on odours that negatively impact perception, and there is no exploration of potential satisfaction associated with pleasant olfactory stimuli.

When assessing PAQ through questionnaires, most studies (59 %) also evaluate other aspects of IEQ like thermal comfort, acoustic comfort, and visual comfort. Additionally, PAQ assessment is often linked with productivity evaluation in 34 % of studies, and with the evaluation of SBS in 36 % of cases. Other questionnaire modules can be used to collect data on office usage (e.g., working hours, occupancy density) and/or respondent characteristics (e.g., demographic information, personal habits).

3.2.4. Diary

2 % of reviewed papers investigate PAQ using diaries. The Diary method entails participants documenting their observations, emotions, or encounters related to PAQ at irregular intervals throughout the day [123]. Diaries may be either unstructured or structured, the latter involving predefined questions or scales to gauge perceptions of odours, stuffiness, or other sensory experiences [62]. Diaries can also take the form of video recordings over a specific period; every time workers encounter an episode they wish to note, they can document it through these recordings [63].

3.2.5. Interview

1 % of reviewed papers investigate PAQ using interviews. Interviews involve direct conversation between the researcher and participants, offering a platform for in-depth exploration of individual experiences with PAQ. These can be structured (i.e., using predetermined questions with fixed response formats), semi-structured (i.e., using predefined questions with flexibility for follow-up inquiries), or unstructured (i.e., using free-flowing conversation), allowing flexibility in how information is gathered. Gathering direct feedback through interviews has the advantage of further exploring responses, getting in-depth information on participants' experience. Interviews can be combined with sensory tests, such as employing video-taped smell-oriented interviews using paper strips impregnated with "office smells" like coffee, sweat, and office furniture [63].

3.2.6. Text mining

2 % of reviewed papers investigate PAQ using text mining techniques. Text mining involves analysing large volumes of text data to extract relevant information about PAQ. This can include online reviews [65] or responses in POE surveys [69]. Using algorithms and natural language processing, researchers can identify patterns, trends, and themes related to air quality perceptions without direct interaction with participants.

3.2.7. Sensory testing

2 % of reviewed papers investigate PAQ using sensory testing. Unlike other subjective techniques such as questionnaires, diaries, interviews or text mining, sensory tests are specifically targeted to find the cause(s) of unpleasant or objectionable odours. Sensory testing is a structured approach where participants (either trained or untrained) assess specific sensory aspects of air quality on site [23,64] or in controlled environments. In the latter case, air is collected from the site and transported to the laboratory in sampling containers where it is presented to human participants using odour presentation instruments, such as olfactometers. The evaluation is point in time, and the duration of odour exposure should not exceed 90 s, to avoid adaptive phenomena [10].

Sensory testing is used to classify odours according to.

- Rating of acceptability by untrained panel (yes/no question; continuous scale from "clearly acceptable" to "clearly unacceptable");

Table 3
Different question types clustered according to object of judgment (IAQ = indoor air quality; O = odour), component of experience (F/S = freshness/stuffiness; Q = quality; S = satisfaction; A = acceptability; C = comfort; I = intensity; Ch = character), scale type (CD = continous divided; CU = continous undivided; L = Likert; D = dichotomous; MC = multiple-choice), scale direction (B = bidirectional; M = monodirectional), number of scale points. N/S = not specified; N/A = not applicable.

Ref	Question	Object of judgment	Component of experience	Scale Type	Scale direction	Number of scale points
[38] [39,59,66]	***"The air is"***	IAQ	F/S	CD (fresh, neutral, stuffy)	B	3
[22,23,40,52,90,107]	***"Right now my environment can be described as follows:"***	IAQ	F/S	CU (air stuffy – air fresh)	B	2
[70]	***"Perception of the environment in the climatic chamber, what do you think about the air quality?"***	IAQ	Q	CU (very good – very bad)	B	2
[29,31,103]	***"Estimate the air quality"***	IAQ	F/S	L (stuffy-fresh)	B	7
[47]	***"Stuffy air"***	IAQ	F/S	L (no, never, yes sometimes, yes often)	M	4
[21–23,38–41,45,59,66, 72,80,82,90,107,120]	***"How do you assess the air quality?"***	IAQ	A	CD (clearly acceptable – clearly unacceptable)	B	4
[50,73]	***"Is the indoor quality being perceived in the office environment acceptable to you?"***	IAQ	A	D (yes, no)	N/A	2
[68]	***"How do you perceive the current quality of the air in the room?"***	IAQ	S	CD (total dissatisfaction – total satisfaction)	B	100
[87,88,102]	***"Please rate your level of satisfaction or dissatisfaction with the air quality of your work environment"***	IAQ	S	L (very unsatisfied – very satisfied)	B	7
[99]	***"Are you satisfied with the indoor air quality?"***	IAQ	S	D (yes/no)	N/A	2
[61]	***"Unpleasant odour"***	O	C	L (yes, often – no, never)	M	3
[108]	***"Are you currently bothered by the smells, scents, or perfumes around your workspace?"***	O	C	L (yes, definitely- no)	M	3
[105]	***"In your opinion, how do the odours of the work environment you spend most of your time affect your well-being and contentment?"***	O	C	L (strongly negatively – strongly positively)	B	5
[46]	***"How often do you feel annoyed (uncomfortable) by the stuffy air/bad smell?"***	O	C	L (often – never)	M	4
[99]	***"Are there unpleasant odours in the room?"***	O	C	D (yes/no)	N/A	2
[38,107]	***"Rate the intensity of odour"***	O	I	CD (overwhelming – no odour)	M	6
[22,23,39,40,59,66,72, 80]	***"Assess odour intensity"***	O	I	CD (no odour – overpowering odour)	M	5
[70]	***"Perception of the environment in the climatic chamber, what do you think about the odour strength?"***	O	I	CU (no odour – very strong)	M	2
[31]	***"Estimate the intensity of odour"***	O	I	L (no odour – unbearably strongly odour)	M	6
[34]	***"How would you estimate the odour intensity at the moment?"***	O	I	L (very good – very bad)	B	5
[82]	***N/S***	IAQ	F/S	CU (air stuffy – air fresh)	B	100
[34,58]	***N/S***	IAQ	Q	L (very good – very bad)	B	5
[54]	***N/S***	IAQ	Q	L (very good – poor)	M	4
[57,81,111]	***N/S***	IAQ	F/S	CD (stuffy – fresh)	B	7
[92]	***N/S***	IAQ	A	CD (clearly unacceptable – clearly acceptable)	B	9
[50]	***N/S***	IAQ	A	L (just barely acceptable – completely acceptable)	M	7
[50]	***N/S***	IAQ	A	L (just barely unacceptable – completely unacceptable)	M	7
[25,27,28,30,32,35,36, 55,56,61,69,76,77,83, 85,91,93–97,106,108]	***N/S***	IAQ	S	L (very satisfied – very dissatisfied)	B	7
[101,104,119]	***N/S***	IAQ	S	L (very dissatisfied – very satisfied)	B	5
[33,37,74,102]	***N/S***	IAQ	S	L (dissatisfied – satisfied)	B	7
[98,118]	***N/S***	IAQ	S	CU (most unsatisfied – most satisfied)	B	200
[111]	***N/S***	O	I	CD (smelly – odourless)	M	7
[81]	***N/S***	O	S	CD (unsatisfactory – satisfactory)	B	7
[33]	***N/S***	O	S	L (dissatisfied – satisfied)	B	7
[101]	***N/S***	O	S	L (very dissatisfied – very satisfied)	B	7
[29,103]	***N/S***	O	I	L (smelly – odourless)	M	7
[67]	***N/S***	O	Ch	MC (no odour, metal, wood, fruit, car exhaust, other)	N/A	N/A

- Rating of intensity with a comparative scale by a trained panel (sensory comparison between the sample and a series of concentrations of a calibrated reference substance (e.g. acetone));
- Rating of intensity with a category scale by a trained or untrained panel;
- Rating of hedonic tone by a trained or untrained panel (scale from −4 (extremely unpleasant) to +4 (extremely pleasant) with a neutral point);
- Evaluation of odour quality through descriptive verbal classifications [64].

Panel members undergo an olfactory test [23,64] to assess their ability to identify odours, their intensity and discriminate between different odours.

4. Discussion

The 93 reviewed papers on PAQ in offices present diverse evaluation methodologies, often not standardized by any specific standard. In almost all cases, they share the approach of considering the condition of olfactory neutrality as the most satisfactory for individuals. The following paragraphs discuss the various assessment methods for PAQ in office buildings towards the introduction of a smellscape approach for the indoor built environment.

4.1. Assessment methods of PAQ in office buildings

International standards such as CEN 1752 [12], ISO 16814 [4], and ISO 17772-1 [13] define categories of PAQ to be evaluated using proxies obtained through instrumental measurements, such as CO_2 concentrations, ventilation rates, or Decipol index. These evaluations necessitate the presence of qualified personnel and specific instrumentation. Probably due to this limitation, researchers often rely on human feedback using questionnaires, which are more cost-effective in distribution. The collection of subjective feedback is also adopted by practitioners, as recommended by leading building certification protocols such as WELL and LEED.

When evaluating PAQ, questions commonly target two objects of evaluation, i.e. a general assessment on IAQ (e.g., “How do you perceive the current quality of the air in the room?” [68]) or odours (e.g., “Are there unpleasant odours in the room?” [99]). In the former case, a 7-point Likert satisfaction scale is used in most cases, ranging from “very dissatisfied” to “very satisfied” [25,27,28,30,32,35,36,55,56,61,69,76,77,83,85,91,93–97,106,108]. This scale resembles the 7-point satisfaction scale which is standardized in the case of thermal comfort [124] but is not standardized in the case of PAQ. In the latter case, odours are normally evaluated using a continuous intensity scale (from “no odour” to “overpowering odour”) [22,23,39,40,59,72,80]. This scale can be found in sensory testing standards such as ISO 16000-30 [10] and ISO 16000-28 [11]. Choosing to evaluate IAQ in general or specifically odours shifts the focus from a broader, complex concept to a more specific, sensory one. The first object of evaluation has the power to encompass a wider range of aspects that are part of PAQ, such as irritations or visibility issues (in terms of smog or chemical fog) caused by certain pollutants.

In order to assess the two different evaluation objects, a total of 37 different evaluation scales are used in literature (Table 3). Choosing one evaluation scale over another can potentially influence the results, as each scale involves different methods and thresholds for calculating PD. This can compromise the meta-analysis of the data and thus the formation of substantial scientific evidence on the subject.

In conclusion, there exists a gap in the standardization of PAQ assessment methods. Standards often recommend indices that are not practically utilised. In literature, the evaluation scales that are employed often differ from study to study, making comparisons between the different papers challenging due to the lack of consistency.

4.2. Beyond odour neutrality towards an indoor smellscape approach

The assessment of PAQ in offices revolves around the percentage of people perceiving the air as unacceptable. The focus of the reviewed papers is primarily on evaluating factors that negatively impact human experience, with no consideration for those positively influencing the perception of office air quality. One of the most commonly perceived aspects of IAQ by individuals is odours, which is normally characterized using intensity scales (from “no odour” to “overpowering odour”).

According to the reviewed papers, an indoor office environment is deemed as satisfactory if it reflects a condition of olfactory neutrality, meaning people do not perceive any odour [59,99,111]. If an odour is detected, individuals are considered dissatisfied, and the environmental quality is deemed unacceptable.

This approach is also shared by international standards and regulations. ISO 28802 states that "it can be reasonably assumed that if a person rates an environment as ’smelly,’ then they would prefer no smell at all." [14]. In this sense, the term “smell” itself is assumed just with a negative connotation.

However, this is a research gap as neutralizing odours might not always be the ideal solution. The presence of pleasant olfactory stimuli can be perceived as more comfortable than the complete absence of detectable odours [125], positively affecting people’s mood, well-being, health, satisfaction (also in other domains), and behaviour across various everyday situations, such as spending patterns or increasing productivity [126,127].

In the practices of assessing and designing IAQ, there could thus be a shift from perceiving odour as a "waste" to seeing it as a potential "resource". This involves shifting the focus from odours that cause discomfort to those that can potentially be pleasant. This paradigm shift in the target of building design from a neutral to a potentially pleasant condition for humans has already been made in other IEQ domains (Fig. 6). In the thermal domain, research has progressed beyond the conventional approach based exclusively on the steady-state heat balance equation, which posits ‘neutrality’ as the optimal state for occupant comfort. This has evolved towards the concept of thermal alliesthesia, which acknowledges that people can find pleasure in a broader range of thermal conditions, depending on the context and the human physiological conditions [128]. In the acoustic field, there has been a transition from focusing on noise issues to valuing sound as potentially a design resource through the introduction of the indoor soundscape approach, where soundscape is defined as the “acoustic environment as perceived or experienced and/or understood by a person or people, in context” [129]. Similarly, in the visual domain, environmental satisfaction is no longer solely determined by illuminance levels (lux). Instead, researchers have been exploring the effects of the context (e.g., window view quality) and non-visual effects (e.g., circadian lights) on perception [130,131].

Unsurprisingly, in recent years, there has been a growing interest in the concept of smellscape in the built environment [132]. In 1985, Porteous introduced the smellscape concept [133], described as the smell environment perceived and understood by a person in a place. Distinguishing between "smell" (i.e., a sensation detected by inhaling airborne molecules of a substance) and "odour" (i.e., the combined substances in the air causing olfactory sensations), the former emphasizes the human experience as a perceptual construct, making it a user-centred approach within the built environment community. This definition originated and is used in outdoor settings [134], but it could be adapted to indoor environments. Drawing on the definition of indoor soundscape, the indoor smellscape could be defined as the smell environment perceived and understood by a person in an indoor context. The term "context," as opposed to the original term "place" used in Porteous’s definition [133], also accounts for social, cultural, and historical aspects [135]. The indoor smellscape approach will be seen as an expansion of the "traditional" odour control approach. The traditional approach focuses only on "odours", which are "combined substances in the air

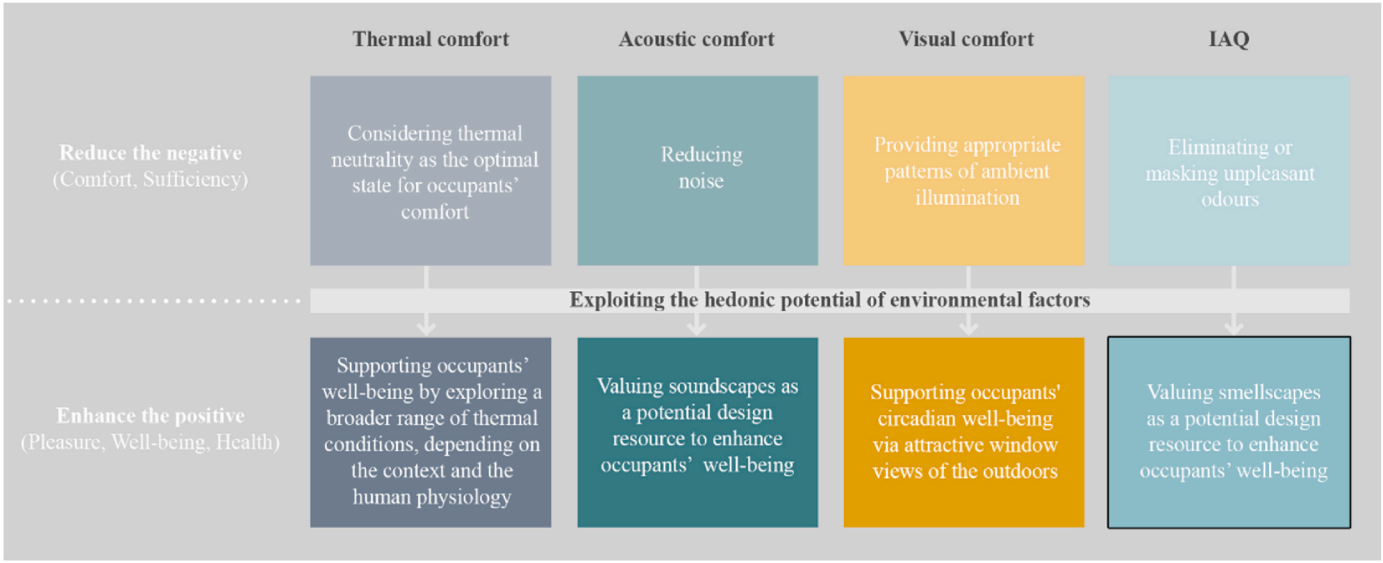

Fig. 6. Approaches exploiting the hedonic potential of environmental factors in IEQ domains.

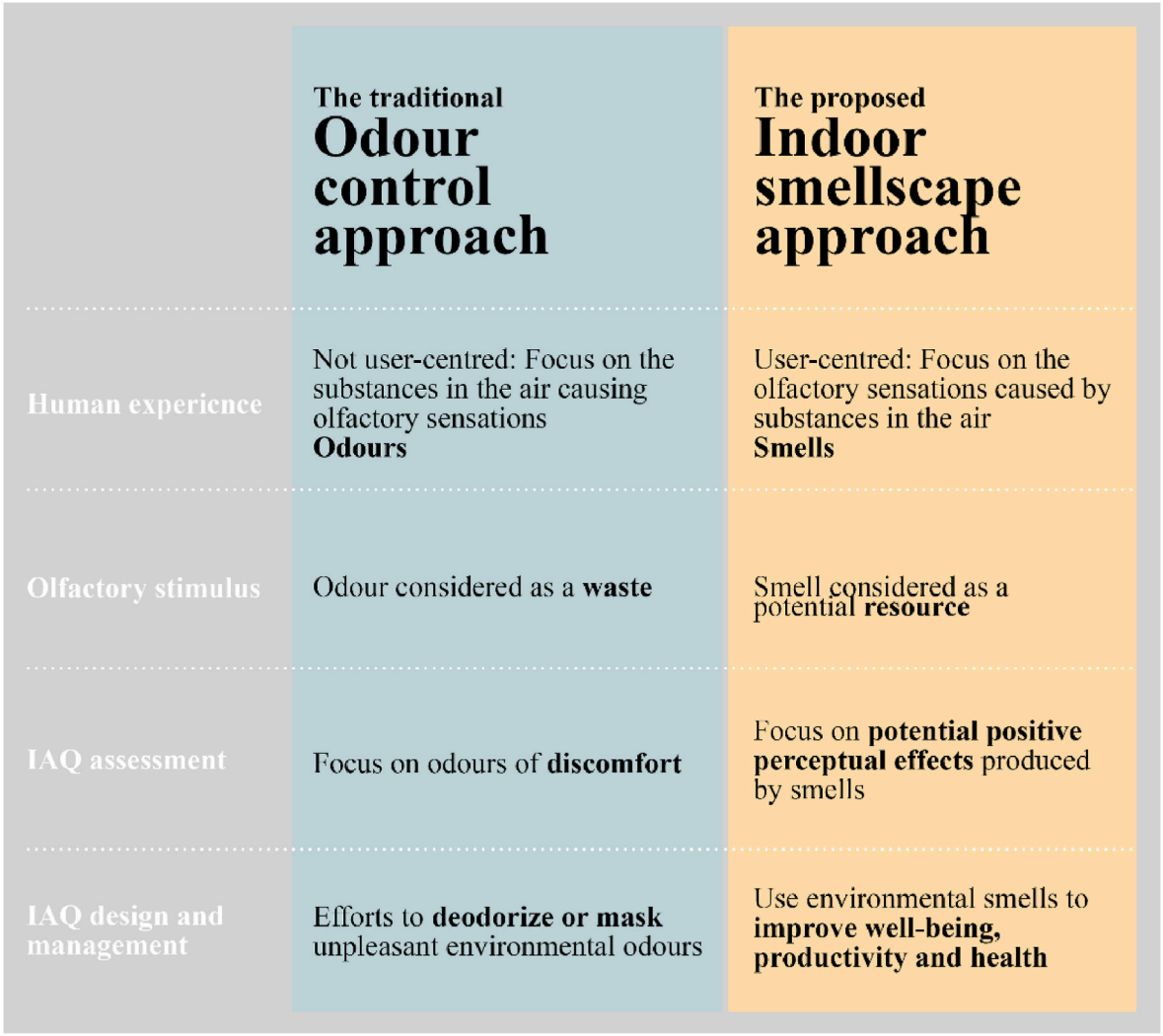

Fig. 7. Manifesto of the proposed indoor smellscape approach, developed in analogy to Kang et al. [136].

causing olfactory sensations," and which carry a negative connotation. On the other hand, the "smellscape" approach will talk more generally about "smells" meaning the "sensations detected by inhaling airborne molecules of a substance" ", with possible negative or positive connotations. Fig. 7 shows a graphical synthesis of the proposed paradigm shift towards the definition of a framework of an indoor smellscape approach.

To move towards an approach that accounts for human experience in the olfactory stimuli of indoor environments, it is essential to understand the main dimensions underlying olfactory perception, along which assess people's perception of the olfactory environment (e.g., in POEs). However, to date, indicators contributing to the emotional dimensions of smell perceptions are not yet fully understood, and a model of indoor smellscape perception is still lacking. This gap is partly due to the fact that smellscape studies have primarily focused on the outdoor environment [134]. Additionally, there is a lack of studies attempting to link the chemical characterization of olfactory stimuli that could potentially elicit positive perceptual responses in occupants. Indeed, existing studies have investigated pollutants such as carbonyl chemicals and volatile organic compounds (VOCs) with the aim of correlating high levels of these substances with people's discomfort in relation to odours (and generally to a poor PAQ) [64,67,101].

4.3. Future research directions

This review has painted a complex picture of the methods for assessing PAQ in office buildings. A possible definition of the indoor smellscape approach has been introduced, proposing a paradigm shift towards an assessment method and design that focuses on the human experience related to non-neutral olfactory stimuli in indoor environments, leveraging on the hedonic potential of olfactory stimuli. Future work will need to.

- Validate the accuracy of existing evaluation scales towards a standardization.
- Study the main dimensions underlying human perception of indoor smellscapes (e.g., arousal, comfort), as already done for other domains [129,135].
- Construct a consistent measurement system based on principal component dimension underlying people's perception of indoor smellscapes. This model would be highly valuable in POE studies, as it would indicate the perceptual constructs to be measured and the attribute scales to be employed. Furthermore, understanding human perceptual response to the olfactory environment will be fundamental for filling the gap between predicted and experienced olfactory performance of built environments. Fig. 8 highlights the importance of having a principal component model of olfactory perception to, for instance, measure the effectiveness of an improvement intervention.
- Complement the study of the perceptual aspects of indoor smellscapes with instrumental approaches for the chemical characterization of indoor smellscapes. The goal is to model perception based on measurable parameters, moving towards the development of indices that allow for predicting perception based on objective measurements. This would be very useful as it would enable the design of smellscape interventions by predicting the perceptual effect they will generate.
- In addition, research will also need to explore the possible effects (positive or negative) on health of a non-neutral olfactory environment.

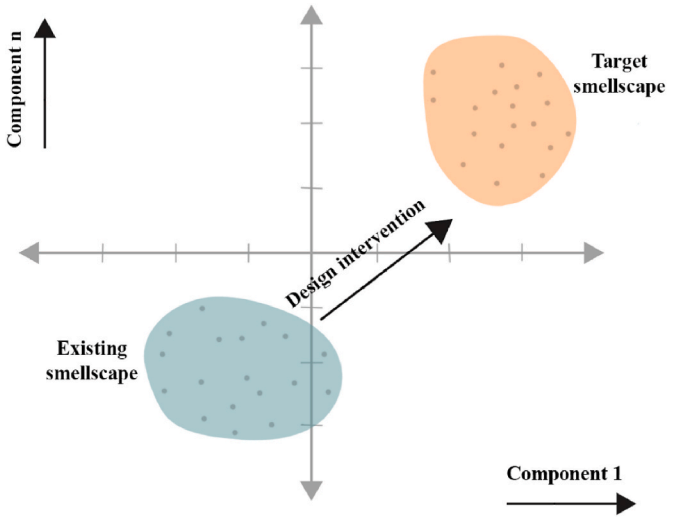

Fig. 8. Using a n-dimensions space for target-setting for smellscape design, example of a two-dimensions space developed in analogy to Cain et al. [137]. Each point represents a person's perception of the evaluated smellscape.

5. Conclusions

The current study systematically examined 93 research papers focusing on PAQ in office buildings with the following objectives: (1) to understand the various assessment methods for PAQ adopted in literature studies, and (1.1) to assess whether these methods align with existing standards and protocols.

In a context where there is a lack of shared standardized methods for determining the PD towards PAQ and inconsistencies across literature studies, this paper represents the first comprehensive examination of the topic with a critical perspective.

Regarding the first research question, the main conclusions are.

- In literature, the assessment of PAQ relies predominantly on questionnaires (90 %), with a smaller percentage using alternative methods like Olf and Decipol (2 %), I_{IAQ} (1 %), diaries (2 %), interviews (1 %), sensory testing (2 %), and text mining techniques (2 %) (paragraph 3.2).
- Questionnaires evaluate two objects of judgment (IAQ in general and odour) on various components of experience (freshness/stuffiness, quality, comfort, acceptability, satisfaction, perceived odour intensity, and perceived odour character) using different scales (Likert, continuous divided, continuous undivided, open question, checkbox question, multi-choice question, and dichotomous scales) with different number of points. The different scales impact the calculation of the PD, thereby potentially influencing the results and hindering the comparison between studies (paragraph 3.2.3).
- The most commonly assessed aspect of PAQ is satisfaction, often measured on a 7-point Likert scale, ranging from "very dissatisfied" to "very satisfied" (paragraph 4.1).
- Odours are typically assessed in terms of intensity using a continuous unidirectional categorical scale, ranging from no odour to overpowering odour, with variations in the number of points (e.g., 5 or 6 points) (paragraph 4.1).
- In literature, an indoor office environment is considered satisfactory if no odour is present (paragraph 4.2).

Regarding the second research question, the main conclusions are.

- The methods for evaluating PD towards PAQ are not universally standardized by existing standards and protocols (paragraph 4.1).
- The evaluation using instrumental indices, which are suggested by standards, are not commonly used by researchers and practitioners (paragraph 4.1).
- The satisfaction scale for PAQ, which is mainly used in literature, is not standardized but is adapted from the reference standard for thermal comfort (paragraph 4.1).

- Both in literature and in standards, the condition of olfactory neutrality is considered the preferable state (paragraph 4.2).

In conclusion, the paper advocates for a paradigm shift, moving beyond the approach of perceiving odour as a "nuisance" to recognizing it as a potential "resource," and for standardization to facilitate comparison across future studies. The paper introduces a possible definition of indoor smellscape as the smell environment perceived and understood by a person in an indoor context.

CRediT authorship contribution statement

Giulia Torriani: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Simone Torresin:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Irene Lara-Ibeas:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Rossano Albatici:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Francesco Babich:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

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

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.buildenv.2024.111645.

References

[1] K.W. Tham, Indoor air quality and its effects on humans—a review of challenges and developments in the last 30 years, Energy Build. 130 (2016) 637–650, https://doi.org/10.1016/j.enbuild.2016.08.071.
[2] World Health Organization, WHO Guidelines for Indoor Air Quality: Selected Pollutants, 2010.
[3] R. and A.-C.E.E. American Society of Heating, Ventilation for Acceptable Indoor Air Quality. ASHRAE Standard, 62, 2022, 1.
[4] International Organization for Standardization, ISO 16814:2019 - Indoor Environmental Quality – Methods of Evaluation of Thermal and Air Quality Conditions, 2019.
[5] G.M. Shepherd, The human sense of smell: are we better than we think? PLoS Biol. 2 (2004) e146, https://doi.org/10.1371/journal.pbio.0020146.
[6] N. Jones, D. Rog, Olfaction: a review, J. Laryngol. Otol. 112 (1998) 11–24, https://doi.org/10.1017/S0022215100139829.
[7] W. Song, M.-P. Kwan, Air pollution perception bias: mismatch between air pollution exposure and perception of air quality in real-time contexts, Health Place 84 (2023) 103129, https://doi.org/10.1016/j.healthplace.2023.103129.
[8] M. Schweiker, E. Ampatzi, M.S. Andargie, R.K. Andersen, E. Azar, V. M. Barthelmes, C. Berger, L. Bourikas, S. Carlucci, G. Chinazzo, L.P. Edappilly, M. Favero, S. Gauthier, A. Jamrozik, M. Kane, A. Mahdavi, C. Piselli, A.L. Pisello, A. Roetzel, A. Rysanek, K. Sharma, S. Zhang, Review of multi-domain approaches to indoor environmental perception and behaviour, Build. Environ. 176 (2020) 106804, https://doi.org/10.1016/j.buildenv.2020.106804.
[9] G. Torriani, G. Lamberti, F. Fantozzi, F. Babich, Exploring the impact of perceived control on thermal comfort and indoor air quality perception in schools, J. Build. Eng. (2022) 105419, https://doi.org/10.1016/J.JOBE.2022.105419.
[10] International Organization for Standardization, ISO 16000-30 - Sensory Testing of Indoor Air, 2014.
[11] International Organization for Standardization, ISO 16000-28 - Determination of Odour Emissions from Building Products Using Test Chambers, 2020.
[12] European Committee for Standardization, CEN CR 1752 - Ventilation for Buildings. Design Criteria for the Indoor Environment, 1999.
[13] International Organization for Standardization, ISO 17772-1 - Energy Performance of Buildings – Indoor Environmental Quality – Part 1: Indoor Environmental Input Parameters for the Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics, 2017.
[14] ISO 28802, Ergonomics of the Physical Environment - Assessment of Environments by Means of an Environment Survey Involving Physical Measurmenets of the Environement and Subjective Responses of People, 2012.
[15] J. Pei, M. Qu, L. Sun, X. Wang, Y. Yin, The relationship between indoor air quality (IAQ) and perceived air quality (PAQ) – a review and case analysis of Chinese residential environment, Energy and Built Environment (2022), https://doi.org/10.1016/j.enbenv.2022.09.005.
[16] L.t. Graham, T. parkinson, S. schiavon, Lessons learned from 20 years of CBE's occupant surveys, Buildings and Cities 2 (2021) 166–184, https://doi.org/10.5334/bc.76.
[17] M.J. Page, J.E. McKenzie, P.M. Bossuyt, I. Boutron, T.C. Hoffmann, C.D. Mulrow, L. Shamseer, J.M. Tetzlaff, E.A. Akl, S.E. Brennan, R. Chou, J. Glanville, J. M. Grimshaw, A. Hróbjartsson, M.M. Lalu, T. Li, E.W. Loder, E. Mayo-Wilson, S. McDonald, L.A. McGuinness, L.A. Stewart, J. Thomas, A.C. Tricco, V.A. Welch, P. Whiting, D. Moher, The PRISMA 2020 statement: an updated guideline for reporting systematic reviews, BMJ (2021) n71, https://doi.org/10.1136/bmj.n71.
[18] L. Fang, G. Clausen, P.O. Fanger, Impact of temperature and humidity on the perception of indoor air quality, Indoor Air 8 (1998) 80–90, https://doi.org/10.1111/j.1600-0668.1998.t01-2-00003.x.
[19] S. Torresin, G. Pernigotto, F. Cappelletti, A. Gasparella, Combined effects of environmental factors on human perception and objective performance: a review of experimental laboratory works, Indoor Air 28 (2018) 525–538, https://doi.org/10.1111/ina.12457.
[20] W. O'Brien, A. Wagner, M. Schweiker, A. Mahdavi, J. Day, M.B. Kjærgaard, S. Carlucci, B. Dong, F. Tahmasebi, D. Yan, T. Hong, H.B. Gunay, Z. Nagy, C. Miller, C. Berger, Introducing IEA EBC annex 79: key challenges and opportunities in the field of occupant-centric building design and operation, Build. Environ. 178 (2020) 106738, https://doi.org/10.1016/j.buildenv.2020.106738.
[21] S. Schiavon, D. Rim, W. Pasut, W.W. Nazaroff, Sensation of draft at uncovered ankles for women exposed to displacement ventilation and underfloor air distribution systems, Build. Environ. 96 (2016) 228–236, https://doi.org/10.1016/j.buildenv.2015.11.009.
[22] L. Fang, D.P. Wyon, G. Clausen, P.O. Fanger, Impact of indoor air temperature and humidity in an office on perceived air quality, SBS symptoms and performance, Indoor Air, Supplement 14 (2004) 74–81, https://doi.org/10.1111/j.1600-0668.2004.00276.x.
[23] Z. Bako-Biro, P. Wargocki, C.J. Weschler, P.O. Fanger, Effects of pollution from personal computers on perceived air quality, SBS symptoms and productivity in offices, Indoor Air 14 (2004) 178–187, https://doi.org/10.1111/j.1600-0668.2004.00218.x.
[24] L. Šeduikyté, R. Bliüdžius, Pollutants emission from building materials and their influence on indoor air quality and people performance in offices, J. Civ. Eng. Manag. 11 (2005) 137–144, https://doi.org/10.1080/13923730.2005.9636343.
[25] Y.S. Lee, S.-K. Kim, Indoor environmental quality in LEED-certified buildings in the U.S, J. Asian Architect. Build Eng. 7 (2008) 293–300, https://doi.org/10.3130/jaabe.7.293.
[26] C.F. Chen, S. Yilmaz, A.L. Pisello, M. De Simone, A. Kim, T. Hong, K. Bandurski, M.V. Bavaresco, P.L. Liu, Y. Zhu, The impacts of building characteristics, social psychological and cultural factors on indoor environment quality productivity belief, Build. Environ. 185 (2020) 107189, https://doi.org/10.1016/J.BUILDENV.2020.107189.
[27] Y.S. Lee, D.A. Guerin, Indoor environmental quality differences between office types in LEED-certified buildings in the US, Build. Environ. 45 (2010) 1104–1112, https://doi.org/10.1016/J.BUILDENV.2009.10.019.
[28] G. Brager, L. Baker, Occupant satisfaction in mixed-mode buildings, Build. Res. Inf. 37 (2009) 369–380, https://doi.org/10.1080/09613210902899785.
[29] Z. Gou, D. Prasad, S.S.-Y. Lau, Impacts of green certifications, ventilation and office types on occupant satisfaction with indoor environmental quality, Architect. Sci. Rev. 57 (2014) 196–206, https://doi.org/10.1080/00038628.2014.908113.
[30] B.G. Sediso, M.S. Lee, Indoor environmental quality in Korean green building certification criteria—certified office buildings—occupant satisfaction and performance, Sci Technol Built Environ 22 (2016) 606–618, https://doi.org/10.1080/23744731.2016.1176849.
[31] H. Maula, V. Hongisto, V. Naatula, A. Haapakangas, H. Koskela, The effect of low ventilation rate with elevated bioeffluent concentration on work performance, perceived indoor air quality, and health symptoms, Indoor Air 27 (2017) 1141–1153, https://doi.org/10.1111/ina.12387.
[32] H. Lou, D. Ou, A comparative field study of indoor environmental quality in two types of open-plan offices: open-plan administrative offices and open-plan research offices, Build. Environ. 148 (2019) 394–404, https://doi.org/10.1016/j.buildenv.2018.11.022.

[33] T. Thach, D. Mahirah, C. Sauter, A.C. Roberts, G. Dunleavy, N. Nazeha, Y. Rykov, Y. Zhang, G.I. Christopoulos, C. Soh, J. Car, Associations of perceived indoor environmental quality with stress in the workplace, Indoor Air 30 (2020) 1166–1177, https://doi.org/10.1111/ina.12696.
[34] J. Kallio, E. Vildjiounaite, J. Koivusaari, P. Räsänen, H. Similä, V. Kyllönen, S. Muuraiskangas, J. Ronkainen, J. Rehu, K. Vehmas, 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.
[35] G. Motalebi, A. Sal Moslehian, E. Hasanzadeh, The most effective indoor environmental quality factors related to worker satisfaction and performance: a case of the administrative office building at Ferdowsi University of Mashhad, Int. J. Occup. Saf. Ergon. 27 (2021) 358–370, https://doi.org/10.1080/10803548.2019.1582886.
[36] S. Bae, C.S. Martin, A.O. Asojo, Indoor environmental quality factors that matter to workplace occupants: an 11-year-benchmark study, Build. Res. Inf. 49 (2021) 445–459, https://doi.org/10.1080/09613218.2020.1794777.
[37] Ö. Göçer, C. Candido, L. Thomas, K. Göçer, Differences in occupants' satisfaction and perceived productivity in high- and low-performance offices, Buildings 9 (2019) 199, https://doi.org/10.3390/buildings9090199.
[38] S. Schiavon, B. Yang, Y. Donner, V.W.-C. Chang, W.W. Nazaroff, Thermal comfort, perceived air quality, and cognitive performance when personally controlled air movement is used by tropically acclimatized persons, Indoor Air 27 (2017) 690–702, https://doi.org/10.1111/ina.12352.
[39] P. Wargocki, L. Lagercrantz, T. Witterseh, J. Sundell, D.P. Wyon, P.O. Fanger, Subjective perceptions, symptom intensity and performance: a comparison of two independent studies, both changing similarly the pollution load in an office, Indoor Air 12 (2002) 74–80, https://doi.org/10.1034/j.1600-0668.2002.01101.x.
[40] P. Wargocki, D.P. Wyon, J. Sundell, G. Clausen, P.O. Fanger, The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity, Indoor Air 10 (2000) 222–236, https://doi.org/10.1034/j.1600-0668.2000.010004222.x.
[41] L. Lan, P. Wargocki, D.P. Wyon, Z. Lian, Effects of thermal discomfort in an office on perceived air quality, SBS symptoms, physiological responses, and human performance, Indoor Air 21 (2011) 376–390, https://doi.org/10.1111/j.1600-0668.2011.00714.x.
[42] J.S. Park, C.H. Yoon, The effects of outdoor air supply rate on work performance during 8-h work period, Indoor Air 21 (2011) 284–290, https://doi.org/10.1111/j.1600-0668.2010.00700.x.
[43] U. Satish, M.J. Mendell, K. Shekhar, T. Hotchi, D. Sullivan, S. Streufert, W.J. Fisk, Is CO_2 an indoor pollutant? direct effects of low-to-moderate CO_2 concentrations on human decision-making performance, Environ. Health Perspect. 120 (2012) 1671–1677, https://doi.org/10.1289/ehp.1104789.
[44] L. Mølhave, Effects on eyes and nose in humans after experimental exposure to airborne office dust, Indoor Air 10 (2000) 237–245, https://doi.org/10.1034/j.1600-0668.2000.010004237.x.
[45] J. Niu, N. Gao, M. Phoebe, Z. Huigang, Experimental study on a chair-based personalized ventilation system, Build. Environ. 42 (2007) 913–925, https://doi.org/10.1016/J.BUILDENV.2005.10.011.
[46] Y.K. Kim, Y. Abdou, A. Abdou, H. Altan, Indoor environmental quality assessment and occupant satisfaction: a post-occupancy evaluation of a uae university office building, Buildings 12 (2022), https://doi.org/10.3390/buildings12070986.
[47] T. Lindgren, A case of indoor air pollution of ammonia emitted from concrete in a newly built office in Beijing, Build. Environ. 45 (2010) 596–600, https://doi.org/10.1016/J.BUILDENV.2009.07.014.
[48] A. Singh, M. Syal, S. Korkmaz, S. Grady, Costs and benefits of IEQ improvements in leed office buildings, J. Infrastruct. Syst. 17 (2011) 86–94, https://doi.org/10.1061/(ASCE)IS.1943-555X.0000046.
[49] K. Azuma, K. Ikeda, N. Kagi, U. Yanagi, H. Osawa, Prevalence and risk factors associated with nonspecific building-related symptoms in office employees in Japan: relationships between work environment, Indoor Air Quality, and occupational stress, Indoor Air 25 (2015) 499–511, https://doi.org/10.1111/ina.12158.
[50] R. Maddalena, M.J. Mendell, K. Eliseeva, W.R. Chan, D.P. Sullivan, M. Russell, U. Satish, W.J. Fisk, Effects of ventilation rate per person and per floor area on perceived air quality, sick building syndrome symptoms, and decision-making, Indoor Air 25 (2015) 362–370, https://doi.org/10.1111/ina.12149.
[51] S. Lee, M.H. Park, B.Y. Jeong, Gender differences in public office workers' satisfaction, subjective symptoms and musculoskeletal complaints in workplace and office environments, Int. J. Occup. Saf. Ergon. 24 (2018) 165–170, https://doi.org/10.1080/10803548.2016.1272959.
[52] J. Verhaart, R. Li, W. Zeiler, User interaction patterns of a personal cooling system: a measurement study, Sci Technol Built Environ 24 (2018) 57–72, https://doi.org/10.1080/23744731.2017.1333365.
[53] J.-Y. Lee, P. Wargocki, Y.-H. Chan, L. Chen, K.-W. Tham, Indoor environmental quality, occupant satisfaction, and acute building-related health symptoms in Green Mark-certified compared with non-certified office buildings, Indoor Air 29 (2019) 112–129, https://doi.org/10.1111/ina.12515.
[54] V. Sahu, B.R. Gurjar, Spatial and seasonal variation of air quality in different microenvironments of a technical university in India, Build. Environ. 185 (2020) 107310, https://doi.org/10.1016/J.BUILDENV.2020.107310.
[55] C. Candido, S. Marzban, S. Haddad, M. Mackey, A. Loder, Designing healthy workspaces: results from Australian certified open-plan offices, Facilities 39 (2020) 411–433, https://doi.org/10.1108/F-02-2020-0018.
[56] D. Licina, S. Yildirim, Occupant satisfaction with indoor environmental quality, sick building syndrome (SBS) symptoms and self-reported productivity before and after relocation into WELL-certified office buildings, Build. Environ. 204 (2021) 108183, https://doi.org/10.1016/J.BUILDENV.2021.108183.
[57] M.A. Ortiz, P.M. Bluyssen, Profiling office workers based on their self-reported preferences of indoor environmental quality and psychosocial comfort at their workplace during COVID-19, Build. Environ. 211 (2022), https://doi.org/10.1016/j.buildenv.2021.108742.
[58] H. Orru, H. Olstrup, A. Hagenbjörk, S. Nordin, K. Orru, Exposures, symptoms and risk perception among office workers in relation to nanoparticles in the work environment, Int. J. Environ. Res. Publ. Health 19 (2022) 5789, https://doi.org/10.3390/ijerph19105789.
[59] K.W.D. Cheong, W.J. Yu, K.W. Tham, S.C. Sekhar, R. Kosonen, A study of perceived air quality and sick building syndrome in a field environment chamber served by displacement ventilation system in the tropics, Build. Environ. 41 (2006) 1530–1539, https://doi.org/10.1016/j.buildenv.2005.06.003.
[60] P.M. Bluyssen, C. Roda, C. Mandin, S. Fossati, P. Carrer, Y. de Kluizenaar, V. G. Mihucz, E. de Oliveira Fernandes, J. Bartzis, Self-reported health and comfort in "modern" office buildings: first results from the European OFFICAIR study, Indoor Air 26 (2016) 298–317, https://doi.org/10.1111/ina.12196.
[61] T. Kostiainen, M. Lahtinen, K. Salmi, E. Kähkönen, J. Lampinen, Modeling of subjective responses to indoor air quality and thermal conditions in office buildings, HVAC R Res. 14 (2008) 905–923, https://doi.org/10.1080/10789669.2008.10391046.
[62] L.M. Reinikainen, J.J.K. Jaakkola, Significance of humidity and temperature on skin and upper airway symptoms, Indoor Air 13 (2003) 344–352, https://doi.org/10.1111/j.1600-0668.2003.00155.x.
[63] K. Riach, S. Warren, Smell organization: bodies and corporeal porosity in office work, Hum. Relat. 68 (2015) 789–809, https://doi.org/10.1177/0018726714545387.
[64] C.Y. Peng, C.H. Lan, T.J. Wu, Investigation of indoor chemical pollutants and perceived odor in an area with complaints of unpleasant odors, Build. Environ. 44 (2009) 2106–2113, https://doi.org/10.1016/J.BUILDENV.2009.03.001.
[65] G. Chinazzo, Investigating the indoor environmental quality of different workplaces through web-scraping and text-mining of Glassdoor reviews, Build. Res. Inf. 49 (2021) 695–713, https://doi.org/10.1080/09613218.2021.1908879.
[66] W. Sakr, C.J. Weschler, P.O. Fanger, The impact of sorption on perceived indoor air quality, Indoor Air 16 (2006) 98–110, https://doi.org/10.1111/j.1600-0668.2005.00406.x.
[67] G. Tamás, C.J. Weschler, J. Toftum, P.O. Fanger, Influence of ozone-limonene reactions on perceived air quality, Indoor Air 16 (2006) 168–178, https://doi.org/10.1111/j.1600-0668.2005.00413.x.
[68] I. Mujan, D. Licina, M. Kljajić, A. Čulić, A.S. Anđelković, Development of indoor environmental quality index using a low-cost monitoring platform, J. Clean. Prod. 312 (2021), https://doi.org/10.1016/j.jclepro.2021.127846.
[69] M. Moezzi, J. Goins, Text mining for occupant perspectives on the physical workplace, Build. Res. Inf. 39 (2011) 169–182, https://doi.org/10.1080/09613218.2011.556008.
[70] Z. Pan, L. Mølhave, S.K. Kjaergaard, Effects on eyes and nose in humans after experimental exposure to airborne office dust, Indoor Air 10 (2000) 237–245, https://doi.org/10.1034/j.1600-0668.2000.010004237.x.
[71] C.-A. Roulet, S.C. Sekhar, K.W. Tham, K.W. Cheong, Ventilation, indoor environment quality and climate—comparison of European and Singapore office buildings, Int. J. Ambient Energy 23 (2002) 108–112, https://doi.org/10.1080/01430750.2002.9674877.
[72] L. Šeduikyte, R. Bliūdžius, Pollutants emission from building materials and their influence on indoor air quality and people performance in offices, J. Civ. Eng. Manag. 11 (2005) 137–144, https://doi.org/10.3846/13923730.2005.9636343.
[73] L.T. Wong, K.W. Mui, P.S. Hui, A multivariate-logistic model for acceptance of indoor environmental quality (IEQ) in offices, Build. Environ. 43 (2008) 1–6, https://doi.org/10.1016/J.BUILDENV.2007.01.001.
[74] J. Kim, T. Hong, M. Kong, K. Jeong, Building occupants' psycho-physiological response to indoor climate and CO2 concentration changes in office buildings, Build. Environ. 169 (2020) 106596, https://doi.org/10.1016/J.BUILDENV.2019.106596.
[75] H. Tang, Y. Ding, B. Singer, Interactions and comprehensive effect of indoor environmental quality factors on occupant satisfaction, Build. Environ. 167 (2020) 106462, https://doi.org/10.1016/J.BUILDENV.2019.106462.
[76] A.K. Aboulfotouh, O. Tolba, S. Ezzeldin, The impact of workspace location and indoor environmental quality on employees' satisfaction within office buildings: a case study in Cairo, Indoor Built Environ. 31 (2022) 2094–2114, https://doi.org/10.1177/1420326X20944561.
[77] T. Parkinson, S. Schiavon, J. Kim, G. Betti, Common sources of occupant dissatisfaction with workspace environments in 600 office buildings, Buildings and Cities 4 (2023) 17–35, https://doi.org/10.5334/bc.274.
[78] A.K. Kaushik, M. Arif, M.M.G. Syal, M.Q. Rana, O.T. Oladinrin, A.A. Sharif, A. S. Alshdiefat, Effect of indoor environment on occupant air comfort and productivity in office buildings: a response surface analysis approach, Sustainability 14 (2022), https://doi.org/10.3390/su142315719.
[79] B. Yang, Y. Liu, P. Liu, F. Wang, X. Cheng, Z. Lv, A novel occupant-centric stratum ventilation system using computer vision: occupant detection, thermal comfort, air quality, and energy savings, Build. Environ. 237 (2023), https://doi.org/10.1016/j.buildenv.2023.110332.
[80] J. Kolarik, J. Toftum, B.W. Olesen, A. Shitzer, Occupant responses and office work performance in environments with moderately drifting operative temperatures

(RP-1269), HVAC R Res. 15 (2009) 931–960, https://doi.org/10.1080/10789669.2009.10390873.
[81] L.E. Thomas, Evaluating design strategies, performance and occupant satisfaction: a low carbon office refurbishment, Build. Res. Inf. 38 (2010) 610–624, https://doi.org/10.1080/09613218.2010.501654.
[82] B. Yang, S.C. Sekhar, A.K. Melikov, Ceiling-mounted personalized ventilation system integrated with a secondary air distribution system - a human response study in hot and humid climate, Indoor Air 20 (2010) 309–319, https://doi.org/10.1111/j.1600-0668.2010.00655.x.
[83] M. Frontczak, S. Schiavon, J. Goins, E. Arens, H. Zhang, P. Wargocki, Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design, Indoor Air 22 (2012) 119–131, https://doi.org/10.1111/j.1600-0668.2011.00745.x.
[84] S.H. Kwon, C. Chun, R.Y. Kwak, Relationship between quality of building maintenance management services for indoor environmental quality and occupant satisfaction, Build. Environ. 46 (2011) 2179–2185, https://doi.org/10.1016/J.BUILDENV.2011.04.028.
[85] 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.
[86] Y. Zhai, H. Zhang, Y. Zhang, W. Pasut, E. Arens, Q. Meng, Comfort under personally controlled air movement in warm and humid environments, Build. Environ. 65 (2013) 109–117, https://doi.org/10.1016/j.buildenv.2013.03.022.
[87] S. Schiavon, S. Altomonte, Influence of factors unrelated to environmental quality on occupant satisfaction in LEED and non-LEED certified buildings, Build. Environ. 77 (2014) 148–159, https://doi.org/10.1016/j.buildenv.2014.03.028.
[88] S. Altomonte, S. Schiavon, Occupant satisfaction in LEED and non-LEED certified buildings, Build. Environ. 68 (2013) 66–76, https://doi.org/10.1016/j.buildenv.2013.06.008.
[89] K.W. Tham, P. Wargocki, Y.F. Tan, Indoor environmental quality, occupant perception, prevalence of sick building syndrome symptoms, and sick leave in a Green Mark Platinum-rated versus a non-Green Mark-rated building: a case study, Sci Technol Built Environ 21 (2015) 35–44, https://doi.org/10.1080/10789669.2014.967164.
[90] W. Pasut, H. Zhang, E. Arens, Y. Zhai, Energy-efficient comfort with a heated/cooled chair: results from human subject tests, Build. Environ. 84 (2015) 10–21, https://doi.org/10.1016/j.buildenv.2014.10.026.
[91] J.H. Choi, J. Moon, Impacts of human and spatial factors on user satisfaction in office environments, Build. Environ. 114 (2017) 23–35, https://doi.org/10.1016/J.BUILDENV.2016.12.003.
[92] Y. Zhai, E. Arens, K. Elsworth, H. Zhang, Selecting air speeds for cooling at sedentary and non-sedentary office activity levels, Build. Environ. 122 (2017) 247–257, https://doi.org/10.1016/J.BUILDENV.2017.06.027.
[93] S. Altomonte, S. Saadouni, M.G. Kent, S. Schiavon, Satisfaction with indoor environmental quality in BREEAM and non-BREEAM certified office buildings, Architect. Sci. Rev. 60 (2017) 343–355, https://doi.org/10.1080/00038628.2017.1336983.
[94] Y. Liu, Z. Wang, B. Lin, J. Hong, Y. Zhu, Occupant satisfaction in Three-Star-certified office buildings based on comparative study using LEED and BREEAM, Build. Environ. 132 (2018) 1–10, https://doi.org/10.1016/J.BUILDENV.2018.01.011.
[95] M. Awada, I. Srour, A genetic algorithm based framework to model the relationship between building renovation decisions and occupants' satisfaction with indoor environmental quality, Build. Environ. 146 (2018) 247–257, https://doi.org/10.1016/j.buildenv.2018.10.001.
[96] S. Altomonte, S. Schiavon, M.G. Kent, G. Brager, Indoor environmental quality and occupant satisfaction in green-certified buildings, Build. Res. Inf. 47 (2019) 255–274, https://doi.org/10.1080/09613218.2018.1383715.
[97] L. Pastore, M. Andersen, Building energy certification versus user satisfaction with the indoor environment: findings from a multi-site post-occupancy evaluation (POE) in Switzerland, Build. Environ. 150 (2019) 60–74, https://doi.org/10.1016/j.buildenv.2019.01.001.
[98] J.-Y. Lee, P. Wargocki, Y.-H. Chan, L. Chen, K.-W. Tham, How does indoor environmental quality in green refurbished office buildings compare with the one in new certified buildings? Build. Environ. 171 (2020) 106677 https://doi.org/10.1016/j.buildenv.2020.106677.
[99] A. Prozuments, A. Borodinecs, J. Zemitis, Survey based evaluation of indoor environment in an administrative military facility, J. Sustain. Architect. Civ. Eng. 27 (2020) 96–107, https://doi.org/10.5755/j01.sace.27.2.26079.
[100] Ö. Göçer, C. Candido, L. Thomas, K. Göçer, Differences in occupants' satisfaction and perceived productivity in high- and low-performance offices, Buildings 9 (2019), https://doi.org/10.3390/buildings9090199.
[101] J. Park, V. Loftness, A. Aziz, T.-H. Wang, Critical factors and thresholds for user satisfaction on air quality in office environments, Build. Environ. 164 (2019) 106310, https://doi.org/10.1016/j.buildenv.2019.106310.
[102] A.M. Sadick, Z.E. Kpamma, S. Agyefi-Mensah, Impact of indoor environmental quality on job satisfaction and self-reported productivity of university employees in a tropical African climate, Build. Environ. 181 (2020) 107102, https://doi.org/10.1016/J.BUILDENV.2020.107102.
[103] J. Woo, P. Rajagopalan, M. Francis, P. Garnawat, An Indoor Environmental Quality Assessment of Office Spaces at an Urban Australian University, 49, Building Research & Information, 2021, pp. 842–858, https://doi.org/10.1080/09613218.2021.1944037.
[104] N. Albuainain, G. Sweis, W. AlBalkhy, R. Sweis, Z. Lafhaj, Factors affecting occupants' satisfaction in governmental buildings: the case of the kingdom of Bahrain, Buildings 11 (2021) 231, https://doi.org/10.3390/buildings11060231.
[105] Á. Borsos, E. Zoltán, É. Pozsgai, B. Cakó, G. Medvegy, J. Girán, The comfort map—a possible tool for increasing personal comfort in office workplaces, Buildings 11 (2021) 233, https://doi.org/10.3390/buildings11060233.
[106] M.J. Roskams, B.P. Haynes, Testing the relationship between objective indoor environment quality and subjective experiences of comfort, Build. Res. Inf. 49 (2021) 387–398, https://doi.org/10.1080/09613218.2020.1775065.
[107] W. Zhao, S. Kilpeläinen, R. Kosonen, J. Jokisalo, S. Lestinen, Y. Wu, P. Mustakallio, Human response to thermal environment and perceived air quality in an office with individually controlled convective and radiant cooling systems, Build. Environ. 195 (2021) 107736, https://doi.org/10.1016/J.BUILDENV.2021.107736.
[108] S. Crosby, A. Rysanek, Predicting thermal satisfaction as a function of indoor CO2 levels: bayesian modelling of new field data, Build. Environ. 209 (2022) 108569, https://doi.org/10.1016/J.BUILDENV.2021.108569.
[109] Z. Li, Q. Zhang, O.B. Kazanci, F. Fan, B.W. Olesen, Investigation of group differences in human perceptions of indoor environment in open-plan offices in a severe cold region, Build. Environ. 213 (2022) 108855, https://doi.org/10.1016/j.buildenv.2022.108855.
[110] J.A. Orosa, A. Baaliña, Improving PAQ and comfort conditions in Spanish office buildings with passive climate control, Build. Environ. 44 (2009) 502–508, https://doi.org/10.1016/j.buildenv.2008.04.013.
[111] I.A. Sakellaris, D.E. Saraga, C. Mandin, C. Roda, S. Fossati, Y. De Kluizenaar, P. Carrer, S. Dimitroulopoulou, V.G. Mihucz, T. Szigeti, J.G. Bartzis, P. M. Bluyssen, Perceived indoor environment and occupants' comfort in European "Modern" office buildings: the OFFICAIR Study, Int. J. Environ. Res. Publ. Health 13 (2016), https://doi.org/10.3390/ijerph13050444.
[112] M.O. Fadeyi, K.W. Tham, W.Y. Wu, Impact of asthma, exposure period, and filters on human responses during exposures to ozone and its initiated chemistry products, Indoor Air 25 (2015) 512–522, https://doi.org/10.1111/ina.12161.
[113] P.O. Fanger, Olf and decipol: new units for perceived air quality, Build. Serv. Eng. Res. Tecnol. 9 (1988) 155–157, https://doi.org/10.1177/014362448800900402.
[114] D. Sheikh Khan, J. Kolarik, P. Weitzmann, Occupants' interaction with an occupant voting system for thermal and indoor air quality feedback – case studies in office spaces, Front Built Environ 7 (2021), https://doi.org/10.3389/fbuil.2021.643630.
[115] A. Luna-Navarro, P. Fidler, A. Law, S. Torres, M. Overend, Building Impulse Toolkit (BIT): a novel IoT system for capturing the influence of façades on occupant perception and occupant-façade interaction, Build. Environ. 193 (2021) 107656, https://doi.org/10.1016/J.BUILDENV.2021.107656.
[116] C. Xu, S. Li, Influence of perceived control on thermal comfort in winter, A case study in hot summer and cold winter zone in China, J. Build. Eng. 40 (2021) 102389, https://doi.org/10.1016/J.JOBE.2021.102389.
[117] D. Sheikh Khan, J. Kolarik, P. Weitzmann, Application of an occupant voting system for continuous occupant feedback on thermal and indoor air quality – case studies in office spaces, Energy Build. 251 (2021) 111363, https://doi.org/10.1016/j.enbuild.2021.111363.
[118] J. Lee, P. Wargocki, Y. Chan, L. Chen, K. Tham, Indoor environmental quality, occupant satisfaction, and acute building-related health symptoms in Green Mark-certified compared with non-certified office buildings, Indoor Air 29 (2019) 112–129, https://doi.org/10.1111/ina.12515.
[119] A. Jamrozik, C. Ramos, J. Zhao, J. Bernau, N. Clements, T. Vetting Wolf, B. Bauer, A novel methodology to realistically monitor office occupant reactions and environmental conditions using a living lab, Build. Environ. 130 (2018) 190–199, https://doi.org/10.1016/j.buildenv.2017.12.024.
[120] G. Tamas, C.J. Weschler, J. Toftum, P.O. Fanger, Influence of ozone-limonene reactions on perceived air quality, Indoor Air 16 (2006) 168–178, https://doi.org/10.1111/j.1600-0668.2005.00413.x.
[121] L. Gunnarsen, P. Ole Fanger, Adaptation to indoor air pollution, Environ. Int. 18 (1992) 43–54, https://doi.org/10.1016/0160-4120(92)90209-M.
[122] K.W.D. Cheong, W.J. Yu, K.W. Tham, S.C. Sekhar, R. Kosonen, A study of perceived air quality and sick building syndrome in a field environment chamber served by displacement ventilation system in the tropics, Build. Environ. 41 (2006) 1530–1539, https://doi.org/10.1016/J.BUILDENV.2005.06.003.
[123] R. Larson, M. Csikszentmihalyi, The experience sampling method, in: Flow and the Foundations of Positive Psychology, Springer Netherlands, Dordrecht, 2014, pp. 21–34, https://doi.org/10.1007/978-94-017-9088-8_2.
[124] ASHRAE, Standard 55 - Thermal Environmental Conditions for Human Occupancy, 2020.
[125] C. Spence, Using ambient scent to enhance well-being in the multisensory built environment, Front. Psychol. 11 (2020), https://doi.org/10.3389/fpsyg.2020.598859.
[126] J.H.B. de Groot, Smells in sustainable environments: the scented silk road to spending, Front. Psychol. 12 (2021), https://doi.org/10.3389/fpsyg.2021.718279.
[127] J. Xiao, F. Aletta, A. Radicchi, Editorial: smells, well-being, and the built environment, Front. Psychol. 13 (2022), https://doi.org/10.3389/fpsyg.2022.880701.
[128] T. Parkinson, R. de Dear, Thermal pleasure in built environments: physiology of alliesthesia, Build. Res. Inf. 43 (2015) 288–301, https://doi.org/10.1080/09613218.2015.989662.
[129] S. Torresin, R. Albatici, F. Aletta, F. Babich, T. Oberman, S. Siboni, J. Kang, Indoor soundscape assessment: a principal components model of acoustic perception in residential buildings, Build. Environ. 182 (2020) 107152, https://doi.org/10.1016/j.buildenv.2020.107152.

[130] S.M. Pauley, Lighting for the human circadian clock: recent research indicates that lighting has become a public health issue, Med. Hypotheses 63 (2004) 588–596, https://doi.org/10.1016/j.mehy.2004.03.020.
[131] W.H. Ko, S. Schiavon, S. Altomonte, M. Andersen, A. Batool, W. Browning, G. Burrell, K. Chamilothori, Y.-C. Chan, G. Chinazzo, J. Christoffersen, N. Clanton, C. Connock, T. Dogan, B. Faircloth, L. Fernandes, L. Heschong, K.W. Houser, M. Inanici, A. Jakubiec, A. Joseph, C. Karmann, M. Kent, K. Konis, I. Konstantzos, K. Lagios, L. Lam, F. Lam, E. Lee, B. Levitt, W. Li, P. MacNaughton, A.M. Ardakan, J. Mardaljevic, B. Matusiak, W. Osterhaus, S. Petersen, M. Piccone, C. Pierson, B. Protzman, T. Rakha, C. Reinhart, S. Rockcastle, H. Samuelson, L. Santos, A. Sawyer, S. Selkowitz, E. Sok, J. Strømann-Andersen, W.C. Sullivan, I. Turan, G. Unnikrishnan, W. Vicent, D. Weissman, J. Wienold, Window view quality: why it matters and what we should do, Leukos 18 (2022) 259–267, https://doi.org/10.1080/15502724.2022.2055428.
[132] J. Xiao, F. Aletta, A. Radicchi, K. McLean, L.E. Shiner, C. Verbeek, Recent advances in smellscape research for the built environment, Front. Psychol. 12 (2021), https://doi.org/10.3389/fpsyg.2021.700514.
[133] J.D. Porteous, Smellscape, Prog. Phys. Geogr. Earth Environ. 9 (1985) 356–378, https://doi.org/10.1177/030913338500900303.
[134] J. Xiao, M. Tait, J. Kang, A perceptual model of smellscape pleasantness, Cities 76 (2018) 105–115, https://doi.org/10.1016/j.cities.2018.01.013.
[135] Ö. Axelsson, M.E. Nilsson, B. Berglund, A principal components model of soundscape perception, J. Acoust. Soc. Am. 128 (2010) 2836–2846, https://doi.org/10.1121/1.3493436.
[136] J. Kang, F. Aletta, T.T. Gjestland, L.A. Brown, D. Botteldooren, B. Schulte-Fortkamp, P. Lercher, I. van Kamp, K. Genuit, A. Fiebig, J.L. Bento Coelho, L. Maffei, L. Lavia, Ten questions on the soundscapes of the built environment, Build. Environ. 108 (2016) 284–294, https://doi.org/10.1016/j.buildenv.2016.08.011.
[137] R. Cain, P. Jennings, J. Poxon, The development and application of the emotional dimensions of a soundscape, Appl. Acoust. 74 (2013) 232–239, https://doi.org/10.1016/j.apacoust.2011.11.006.