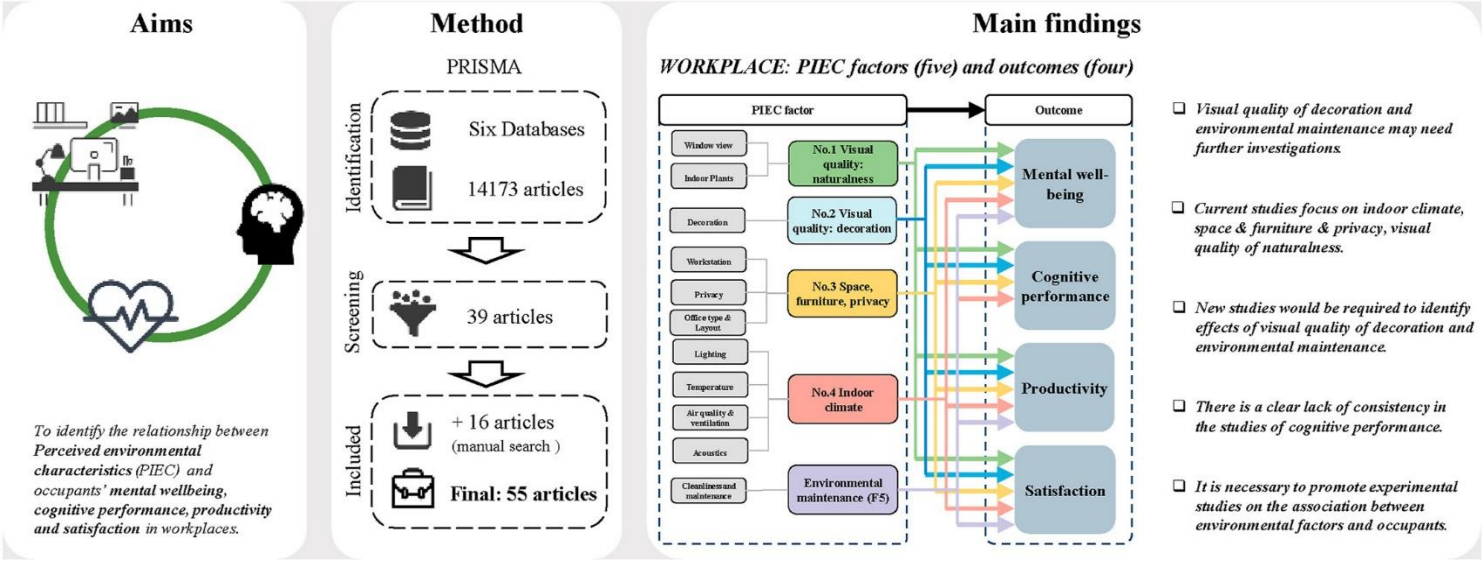
Xi Zhang, Jiangtao Du, David Chow, Association between perceived indoor environmental characteristics and occupants' mental well-being, cognitive performance, productivity, satisfaction in workplaces: A systematic review, Building and Environment, 2023, 110985,

https://doi.org/10.1016/j.buildenv.2023.110985.



Association between perceived indoor environmental characteristics and occupants' mental well-being, cognitive performance, productivity, satisfaction in workplaces: a systematic review

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Abstract:

As office workers spend a substantial amount of time on working indoors, the indoor environmental quality can significantly affect their mental and work performances. This systematic review provides a synthesis of current studies on the relationship between perceived indoor environmental characteristics (PIEC) and occupants' mental wellbeing, cognitive performance, productivity and satisfaction in offices. Eleven PIEC domains were summarised into five factors, including visual quality of naturalness, visual quality of decoration, space & furniture & privacy, indoor climate, and environmental maintenance. Key findings are listed as follows. First, effects of indoor climate, space & furniture & privacy, and visual quality of naturalness were broadly studied, while visual quality of decoration and environmental maintenance did not receive enough attention. Second, many studies supported significant effects of indoor climate, space & furniture & privacy, visual quality of naturalness on mental wellbeing, productivity and satisfaction. Third, new studies would be required to identify effects of visual quality of decoration and environmental maintenance on occupants. Fourth, there is a clear lack of consistency in the studies of cognitive performance. Finally, it would be necessary to promote experimental studies (randomized controlled and quasi) to test the association between these environmental factors and occupants' performances in offices.

Keywords:

Perceived Indoor Environmental Characteristics, Mental Wellbeing, Cognitive Performance, Productivity, Satisfaction, PRISMA

1. Introduction

1.1 Environmental qualities in workplaces

A modern office can be defined as a place encompassing ‘spatial environment (where humans perform work), physical environment (physical objects and bodies in and around an organization), and built environment (architecture, urban locale)’ [1]. Over the decades, the office design has been implemented mainly based on indoor environmental performance, with an aim to produce the most efficient use of space, while considering health and safety requirements at work [2]. Previous studies in this field have focused on the quality of typical physical environment characteristics, including air temperature, air quality, lighting, acoustic, layout, ergonomics [3, 4]. As the benefit of indoor natural elements was identified, nature-related office environment characteristics, such as indoor plants and window view, have received an increasing attention [5, 6]. Recently, researchers have started to notice that an office environment is a complex psycho-physical system comprising not only the nature and arrangement of all the objects in the workplace but also occupants’ perceptions and evaluations for these objects [7, 8]. Therefore, a new research trend in assessing environmental quality of an indoor workplace has just occurred, i.e., an integrated approach taking into account physical factors (via objective measures), perceived environmental characteristics (via subjective measures), and human performance (via objective and subjective measures) [9, 10]. The perceived indoor environmental characteristics (PIEC) can be reflected as occupants’ perception of their indoor work environmental characteristics [8]. Such a perception of environment has been defined as ‘awareness of, or feelings about, the environment, and as the act of apprehending the environment by the senses’ [11] and its nature can be expressed as ‘not directly controlled by the stimulus; linked to and indistinguishable from other aspects of psychological

functioning; relevant and appropriate to specific environmental contexts' [12].

1.2 Occupants' mental health and performance in workplaces

As office workers spend a substantial amount of time on working indoors, their work performance, health and well-being can be significantly affected by the indoor environmental quality of workplaces [13]. A number of early studies have proved that poor physical environment quality can induce a series of work-related illnesses (e.g., dry eyes, back pain) [14-16] and can thus reduce productivity [17, 18]. In recent years, with the increasing complexity of working environment in modern workplaces, occupants' mental disorder has been recognized as one of major health & wellbeing issues concerned by mangers and authorities [19, 20]. For office workers, the mental disorder can cause significantly low productivity, which is responsible for an enormous loss in global economy at more than one trillion dollars each year [21]. Fortunately, professional organizations and governments have been aware of this risk and have started to promote healthy environmental interventions for occupants in office buildings [22-24]. It can be noticed that previous studies of environmental effects on mental health in an office focused on the conventional physical factors, such as thermal [25], lighting [26], noise [27], air quality [4]. Thus, there is still a significant lack of studies which have tested the association between perceived office environment and mental well-being among office workers. In addition, it has been scientifically proved that office workers' cognitive level is associated with their mental health and work performance [18, 28, 29]. However, the effect of perceived environmental qualities on cognitive performance and relevant productivity has not been fully investigated in office buildings [30].

1.3 Research gaps and the present study

As listed in Table 1, since 2005, nine literature reviews have studied the relationship

between indoor environment characteristics in various offices and occupant's mental health, satisfaction and work performance [9, 10, 30-36]. It can be found that five of the nine reviews selected only one environmental characteristic as the key intervention, such as natural-base element [30, 33] or office type & layout [31, 32, 34]. On the other hand, a variety of environmental characteristics (interventions) were explored in other four reviews, including indoor climate [9, 10, 35, 36], office type/layout & natural element [9, 10, 35, 36], interior design [9, 10, 36, furniture [35], acoustic privacy [10], and individual control [35, 36]. As regards the latter four reviews, there might still be some limitations found from the methods/results. First, conventional physical factors, such as indoor climate (air quality, thermal, lighting and acoustics) and office type/layout, were still the focus of environmental qualities in offices, while the perceived indoor environmental characteristic (PIEC) has not attracted considerable attention. In a recent review [10], some PIECs were preliminarily discussed, including perception of naturalness (greenery and window view) and interior (colour and texture). This review has started to emphasize the importance of PIECs in offices and the necessity to further investigate their effects on human performance, especially in relation to natural elements, interior design, workstation and privacy. Second, some critical indoor environmental characteristics identified in previous studies were not fully considered in these reviews, such as visual privacy [37, 38], decoration [39], workstation functional feature [40], cleanliness and maintenance [41, 42]. Third, these reviews were implemented through searching two databases (Scopus and Web of Science). It could be still required to expand the searching range to include relevant sources as more as possible, particularly for the databases used in medical/health research (e.g., MEDLINE, CINAHL Plus, PsycINFO) and built environment research (Art & Architecture Complete). Finally, for these reviews, there was a lack of

professional protocol/method applied in the assessment of the research quality of papers included for detailed analysis. A valid objective method to evaluate academic qualities of papers would be required for conducting a literature review in the field of health/medical research [43, 44].

Given Table1, occupants' mental health and satisfaction in offices were the main outcome discussed in most reviews [10, 30-36]. Four reviews have clearly identified effects of environmental factors on the productivity of office workers [9, 10, 31, 34]. For the productivity, the influence of physical factors (indoor climate and office type/layout) was mainly investigated while there was still a lack of studies of PIEC effect. In addition, only one review [30] summarized the association between indoor plant and cognitive performance in offices. As highlighted in a study [28], the general cognitive ability of office workers can well predict their work performances (productivity) in all jobs. Thus, there is a critical need to carry on collecting more proofs to define the relationship between PIECs and occupants' cognitive performance and productivity in offices.

Based on the discussions above, the present study indicates a systematic review of the effects of perceived indoor environmental qualities on occupants' mental well-being, cognitive performance, productivity, satisfaction in workplaces. The aims of this systematic review are given as follows:

- Providing a synthesis of studies covering a full range of indoor environmental characteristics in workplaces.
- Summarising and analysing the relationship between PIEC and occupants' mental well-being, cognitive performance, productivity, and satisfaction.
- Using multiple databases to collect relevant studies.

Findings of this new review could help researchers to understand effects of the

perceived indoor environment on occupants' mental and work performances in workplaces, while it will also produce useful design guidelines and strategies to support the development of healthy office buildings in terms of occupants' mental well-being, cognitive performance, productivity and satisfaction.

Table 1. Summary of previous reviews of office environmental factors and occupants' mental and work performances.

Author (year)	Database	Environmental factors (interventions)																Occupants' mental well-being and performance (outcomes)			
		Indoor climate				Office type and layout	Natural element		Interior design			Workstation and furniture		Privacy		Others		Mental health	Cognitive performance	Productivity	Satisfaction
		Indoor air quality	Thermal	Lighting	Noise and acoustics		Indoor plants	Natural window view	Texture	Colour	Decoration	Workstation functional features	Furniture in workstation	Acoustic privacy	Visual privacy	Individual control	Cleanliness and maintenance				
Al Horr et al. (2016) [9]	Over 80 journals and magazines.	※	※	※	※	※	※	※	※	※										■	
Bergefurt et al. (2022) [10]	Scopus.	※	※	※	※	※	※	※	※	※				※				■		■	■
Colenberg & Jylhä. (2022) [36]	Scopus, Web of Science.			※	※	※	※	※			※					※		■			
Colenberg et al. (2021) [35]	Scopus, Web of Science.			※	※	※	※	※					※			※		■			
James et al. (2021) [34]	Scopus, Web of Science, Emerald Insight.					※												■		■	■
De Croon et al. (2005) [31]	Picarta, OSHROM, PsycINFO, Biological abstracts, Sociological abstracts, Embase, Ergonomic Abstracts.					※												■		■	■
Gritzka et al. (2020) [30]	PubMed, Embase, CENTRAL, CINHAL, and PsycINFO.						※											■	■		■
Sadick & Kamardeen. (2020) [33]	Scopus.						※	※										■			
Richardson et al. (2017) [32]	Medline, Embase, PsychInfo, Sociological Abstracts, Web of Science, Scopus, Education Source, EBSCO, Google. Scholar.					※												■			■

Note: ※- Intervention item. ■- Outcome item.

2. Method

This review was implemented following the method of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [43].

2.1 Search strategy and information sources

From March to April 2023, a systematic literature search by authors was conducted using six frequently accessed databases, including MEDLINE, CINAHL Plus, Web of Science, APA PsycINFO, Scopus, and Art & Architecture Complete. Appendix A shows the search syntax and the number of results for MEDLINE. Other five databases adopted the same search syntax. The terms applied in the search syntax were identified from the literature reviews that have previously examined the relationship between indoor environmental characteristics and mental health, cognitive performance, productivity, and satisfaction [9, 10, 30-36]. In addition, with an aim to identify additional articles, the systematic search adopted the manual screening to further assess the references from eligible articles included and published systematic reviews and meta-analyses. Articles written in non-English were excluded in this review, whilst only the studies published after 1980 were considered because the modern office has been initially developed since 1980 [45, 46].

2.2 Inclusion and exclusion criteria

As shown in Table 2, the inclusion and exclusion criteria for this systematic review were fundamentally developed based on the Population, Intervention/exposure, Comparator, Outcome criteria (PICO) [47]. In addition, type of space, type of study, and type of publication were added. In this review, any studies were eligible if they can meet the following criteria:

- *Population*: the participants should be adults (age ≥18 years) who work in regular offices, regardless of sex, ethnicity or nationality. Studies with participants

working in non-regular offices (e.g., home, flexible offices, outdoors or other non-office environment) were not eligible.

- *Type of space*: The office should be a normal workplace (e.g., private office and open-planned office) or a full-scale mock-up workplace for conducting experiments. Studies which were carried out in non-office workplaces (e.g., factory, care house, hospital wards, and shops), environmental chambers or virtual office were excluded.
- *Intervention*: At least one perceived indoor environmental characteristic (PIEC) should be investigated, including visual aspects (view, decoration, colour), spatial features, naturalness, lighting, thermal environment, acoustics, air quality, furniture and facilities, privacy, cleanliness and maintenance. Studies focusing on unclear environmental characteristics (e.g., just overall indoor environment quality was mentioned) or special devices/equipment and settings (e.g., a novel air conditioning system, the electrochromic glazing) were not eligible.
- *Outcome*: At least one of four outcomes, such as mental well-being, cognitive performance, productivity, satisfaction, should be achieved. However, the following studies were not eligible, including 1) outcomes measured by only self-developed instruments without any validations, 2) outcomes with only physiological health studies (e.g., cancer, cervical spondylosis, musculoskeletal disorders), 3) outcomes focusing on only sick building syndrome symptoms or sick leave.
- *Type of study*: The types should be randomized controlled trials, non-randomized controlled trials, cross-sectional, longitudinal, quasi-experimental studies, prospective or retrospective cohort studies. Study protocols, systematic reviews, qualitative studies, and studies that did not test associations were excluded.

- *Type of publication*: Only peer reviewed journals were eligible for inclusion. Non-peer reviewed journals, abstract, books or book chapters, conference proceedings and presentations, dissertations, commentaries and editorials were excluded.

Table 2. Inclusion and exclusion criteria

	Inclusion	Exclusion
Participants	• Adults with all genders, ethnicity, and nationality • People who work in offices, can be defined as "occupant", "office worker", "employee", etc.	• Individuals who work from home or flexible offices. • People who work outdoors or non-office environment.
Type of space	• Normal offices (including private office and open-planned office). • Full scale mock-up office for experiments.	• Non-office workplaces including factory, care house, hospital wards, shops, etc. • Environmental chambers (not specifically designed as workspaces). • Virtual office.
Intervention / Exposure (and Comparator)	• Articles which should test at least one of perceived indoor environmental characteristics, including visual aspects (view, decoration, colour), spatial features, naturalness, lighting, thermal environment, acoustics, air quality, furniture and facilities, privacy, cleanliness and maintenance, etc.	• Unclear environmental characteristics (e.g., just the overall indoor environment quality was mentioned). • Special devices/equipment and settings (e.g., a novel air conditioning system, the electrochromic glazing).
Outcome	• Articles which should include at least one of outcomes such as mental well-being, cognitive performance, satisfaction, productivity.	• Outcomes measured by self-developed instruments without any validations. • Studies which include only physiological health studies (e.g., cancer, cervical spondylosis, musculoskeletal disorders, etc.). • Outcomes that include only sick building syndrome symptoms or sick leave.
Type of Study	• Randomized controlled trials, non-randomized controlled trials, cross-sectional, longitudinal, quasi-experimental studies, prospective or retrospective cohort studies.	• Study protocols, systematic reviews, qualitative studies. • Studies which did not test associations.
Type of publication	• Peer reviewed journal	• Non-peer reviewed journal, abstract, books or book chapters, conference proceedings and presentations, dissertations, commentaries, editorials.

2.3 Screening strategy and selection process

Figure 1 displays the searching process and literature selection of this systematic review according to the protocol of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [43]. First, in the identification stage, the search in six databases was conducted based on the search strategy. The retrieved articles (n = 14173) were processed in terms of data deduplication using the software Zotero (www.zotero.org). Second, in the screening stage, titles and abstracts were screened and assessed to select eligible articles (n = 339) by two reviewers individually. In addition, full texts of these eligible articles were further assessed by the two reviewers to achieve articles included (n = 39). Any disagreements were resolved through comprehensive discussions among reviewers. The whole screening procedure was conducted based on the inclusion and exclusion criteria (Table 1). Last, in the included stage, some new studies (n = 16) were also added, which were achieved from the references of retrieved articles (n = 39) and previously published reviews. Therefore, a total of 55 articles were finally included in this systematic review.

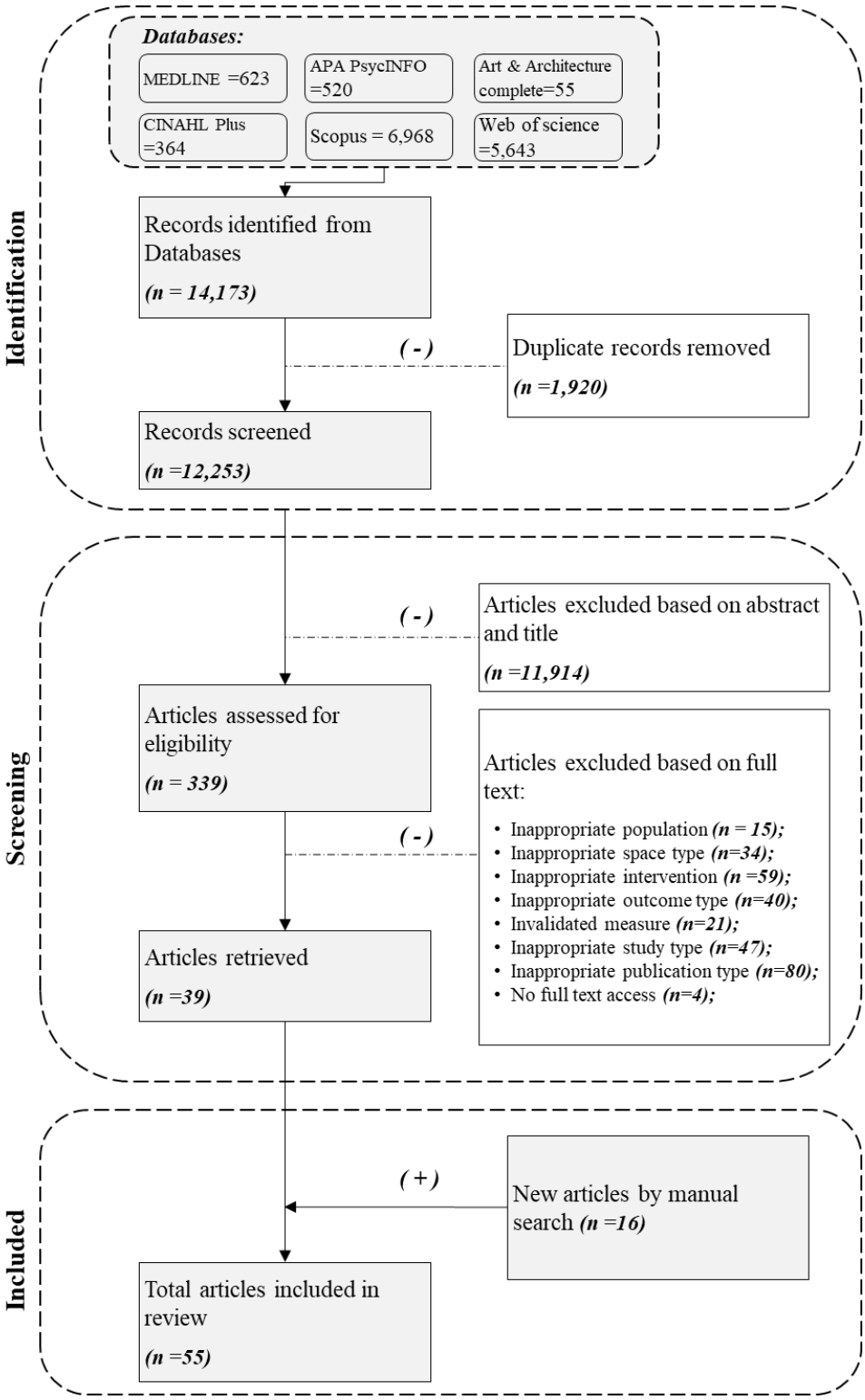

Figure 1. Flowchart of searching process and literature selection. Note: '(-)' represents 'removing articles'; '(+)' represents 'adding new articles.' (PRISMA)

2.4 Analyses

2.4.1 Data extraction

One reviewer extracted all key information from eligible studies (n = 55) and another reviewer cross-checked the information. The agreement was achieved through the discussion. If a disagreement occurs, a third reviewer will be consulted. Based on systematic review guidance [48, 49], the information extracted was collated as follows: 1) first author and year of publication, 2) study location, 3) type of study, 4) population characteristics: sample size, age, and percentage of female participants, 5) intervention: type of PIECs, measures (objective and subjective) and instrument / equipment used (if applicable), 6) outcome: measures and the effect of PIEC on outcomes. Section 3.1 presents a summary of these studies, whilst more detailed results are discussed in sections of 3.2, 3.3 & 3.4.

2.4.2 Assessment of methodological quality

In this systematic review, the methodological quality of eligible articles (n = 55) was assessed by two reviewers using the U.S. National Institutes of Health quality assessment tool [44] independently. These articles included cross-sectional study, longitudinal study (cohort study), quasi-experiment (before-after study with no control group) and controlled intervention study (randomized experimental trails). Thus, according to this tool [44], the cross-sectional study, cohort study and controlled intervention study were assessed using 14-item criteria, while the before-after study with no control group adopted 12-item criteria. Each item in all criteria can be marked as “Yes (Y)”, “No (N)”, “Cannot determine (CD)”, “Not Applicable (NA)”, and “Not Reported (NR)”. The overall study quality can be therefore assessed as “good”, “fair” or “poor”. The results of study qualities can be found in section 3.5.

3. Result

3.1 Summary of included studies

According to Table 3, these studies (n = 55) were conducted in 22 countries. Most studies were implemented in USA (n = 20), followed by Canada (n = 7). Six studies were conducted in multiple countries. Studies (n = 55) included thirty cross-sectional surveys, thirteen randomized experimental trails, eight longitudinal studies, and four quasi-experiments with longitudinal (before-after) designs. Over half studies (n = 36) have the sample size of less than 300. In addition, around 60% studies were conducted during the recent period from 2010 to 2022. Six studies were implemented during the Covid-19 pandemic (2020-2022).

Table 3. Summary of final studies included (n=55).

Characteristics	Number (n)	Characteristics	Number (n)
Country and Region		**Study design**	
USA	20	Randomized experimental	13
Canada	7	Quasi-experimental	4
Sweden	5	Cross-sectional	30
Finland	3	Longitudinal	8
Australia	3		
Japan	2	**Sample size**	
Norway	2	≤ 100	21
China	1	101 - 299	15
Denmark	1	300 - 499	6
France	1	501 - 999	6
Greece	1	1001 - 2499	2
Italy	1	≥ 2500	5
India	1		
Netherlands	1	**Publication period**	
New Zealand	1	2020 - 2022	6
Portugal	1	2010 - 2019	27
Slovenia	1	2000 - 2009	13
South Africa	1	1990 - 1999	7
South Europe	1	1980 - 1989	2
South Korea	1		
Turkey	1		
UK	1		
Unknown	12		

3.2 Achieved PIEC domains and measures

Perceived indoor environmental characteristics in these studies (n = 55) can be categorized into eleven key domains (Table 4). The number of studies on indoor climate was the largest, including lighting (n = 20), temperature (n = 9), air quality and ventilation (n = 9), and acoustics (n = 16). Office type & layout (n = 18) and furniture & workstation (n = 16) were also broadly studied. Other PIEC domains included indoor plants (n = 12), windows view (n = 11), indoor plants (n = 12), office decoration (n = 9) and privacy (n = 8). The number of studies on office cleanliness & maintenance (n = 4) was small. Twenty-three studies only assessed subjective measures, while objective measures were examined in four studies. Eight studies used both subjective and objective measures (only for indoor climate and window). In addition, twenty studies did not apply any measures.

In addition, appendices of B, C, D, and E list the detailed measures of PIEC. Objective measures, i.e., various physical environmental indicators, included circadian stimulus [50], illuminance [51-55], colour temperature [54], sound pressure level [51, 56], temperature [51, 57], CO_2 concentration [51, 57], relative humidity [57], the number of occupants in the workspace [58, 59], the distance to windows [58], and the distance to shared service spaces [60]. The objective environmental indictors were assessed by various equipment, such as lux meter, air quality meter, acoustic meter, etc.

Subjective measures used for assessing the perceived quality of environmental characteristics (n = 23) can be found as follows:

- Amount of environmental characteristics - amount of sunlight exposure [53], amount of indoor plants [59, 61-63], amount of natural elements from windows [53, 61, 64].

- Presence of environmental characteristics - presence of windows with nature view or plant [65], presence of forest window view [66].
- Type of environmental characteristics - type of window view [59].

Various self-reported questionnaires were adopted to assess subjective measures (n = 31), such as Nature Contact Questionnaire [61, 63], CBE occupant satisfaction questionnaire [42, 67, 68].

Table 4. PIEC domains achieved (55 studies).

Author (year)	Perceived environmental characteristics										
	Office type & layout	**Windows & window view**	**Indoor plants**	**Decoration**	**Furniture & workstation**	**Cleanliness & maintenance**	**Privacy**	**Lighting**	**Temperature**	**Air quality & ventilation**	**Acoustics**
An et al. (2016) [69]			●					●			
Aries et al. (2010) [58]	□	□ & ●									
Aristizabal et al. (2021) [70]			×	×							×
Bergström et al. (2015) [71]	×										
Bjørnstad et al. (2015) [61]		●	●								
Block & Stokes. (1989) [72]	×										
Brennan et al. (2002) [73]	●										
Bringslimark et al. (2007) [62]			●								
Burnard & Kutnar. (2020) [74]					×						
Carlopio & Gardner (1992) [75]	×				×						
Danielsson & Theorell. (2019) [76]	×										
Danielsson & Bodin. (2008) [77]	×										
Dravigne et al. (2008) [65]		●	●								
Dreyer et al. (2018) [78]		●					●	●	●	●	●
Figueiro et al. (2017) [50]								□			
Frontczak et al. (2012) [67]	●			●	●	●		●	●	●	●
Genjo et al. (2019) [79]			×								
Hongisto et al. (2016) [51]				●	●		●	□ & ●	□ & ●	□ & ●	□ & ●
Hua & Yang. (2014) [60]	□										
Humphreys & Nicol. (2007) [57]								□ & ●	□ & ●	□ & ●	□ & ●

Note: □ – objective measure**;** ●- subjective measure; × - no measures.

Table 4. PIEC domains achieved (55 studies) (continued).

Author (year)	Perceived environmental characteristics										
	Office type & layout	**Windows & window view**	**Indoor plants**	**Decoration**	**Furniture & workstation**	**Cleanliness & maintenance**	**Privacy**	**Lighting**	**Temperature**	**Air quality & ventilation**	**Acoustics**
Joines et al. (2015) [52]								□			
Kim & De Dear. (2012) [42]	●			●	●	●		●	●	●	●
Kim & De Dear. (2013) [68]	●			●	●	●		●	●	●	●
Klitzman & Stellman. (1989) [80]					●		●	●		●	●
Ko et al. (2020) [81]		×									
Kweon et al. (2008) [39]				×							
Lamb & Kwok. (2016) [82]								●	●		●
Largo-Wight et al. (2011) [63]			●								
Larsen et al. (1998) [83]			×								
Laurence et al. (2013) [84]	×						●				
Leather et al. (1998) [53]		●						□ & ●			
Leder et al. (2016) [85]	●	●			●			□ & ●	□ & ●	□ & ●	
Lottrup, L., et al. (2015) [59]	●	●	●								
Lusa et al. (2019) [86]				●	●			●			●
Mills et al. (2007) [54]								□			
Newsham et al. (2009) [37]							●	□ & ●		□ & ●	□ & ●
O'Neill. (1994) [40]					●						
Raanaas et al. (2011) [87]			×								
Roberts et al. (2019) [88]					×						
Rolo et al. (2010) [41]	●					●		●	●		●

Note: □ – objective measure**;** ●- subjective measure; × - no measures.

Table 4. PIEC domains achieved (55 studies). (Continued).

Author (year)	Perceived environmental characteristics										
	Office type & layout	**Windows & window view**	**Indoor plants**	**Decoration**	**Furniture & workstation**	**Cleanliness & maintenance**	**Privacy**	**Lighting**	**Temperature**	**Air quality & ventilation**	**Acoustics**
Seddigh et al. (2014) [89]	×										
Seddigh et al. (2015) [56]											□ & ●
Shen et al. (2020) [90]				×							
Smith-Jackson & Klein (2009) [91]											×
Shin (2007) [66]		●									
Spreckelmeyer (1993) [92]					●		●	●			●
Stone & English. (1998) [93]				×	×						
Stone & Irvine. (1994) [6]		×									
Thatcher et al. (2020) [94]			●								
Toyoda et al. (2020) [95]			×								
van Esch et al. (2019) [64]		●									
Veitch et al. (2007) [38]					●		●	●			●
Veitch et al. (2008) [55]								□ & ●			
Yildirim et al. (2007) [96]	×				×						
Zerella et al. (2017) [97]	●				●		●				
Sum of studies with this domain	**18**	**11**	**12**	**9**	**16**	**4**	**8**	**20**	**9**	**9**	**16**

Note: □ – objective measure**;** ●- subjective measure; × - no measures.

3.3 Measures of four outcomes

3.3.1 Mental well-being

According to Appendix B, a total of 31 studies investigated the effect of PIEC on mental well-being. The number of studies on occupants' stress and mental workload was the largest (n = 16). Other studies included various indicators of mental well-being, such as general well-being (n = 9), mood and emotion (n = 7), anxiety (n = 4), burnout and emotional exhaustion (n = 3), motivation and vitality (n = 3), motivation and vitality (n = 3), depression (n = 2), quality of life (n = 1), fatigue (n = 1), and work engagement (n = 1). The self-reported questionnaire was applied as the most common instrument to measure mental well-being (n = 32), such as Perceived Stress Questionnaire [98], SF-36 [99], Warwick Edinburgh Mental Well-being Scale [100], Positive and Negative Affect Schedule [101]. In addition, physiological instruments (e.g., salivary cortisol concentration, heart rate, skin conductance level and response) were used to measure occupants' stress levels [70, 74, 79, 95].

3.3.2 Cognitive performance

Fourteen studies explored the effect of PIEC on cognitive performance (Appendix C). The cognitive performance was assessed according to various measures: attention (n = 9), response inhibition (n = 4), working memory (n = 3), general cognitive performance (n = 3), planning (n = 1), and perseverance (n = 1). Thirteen studies adopted cognitive tasks to measure occupants' cognitive performance, such as Stroop test [102], Digit Span task [103], and Card-sorting task [104]. One study applied both cognitive tasks and self-reported questionnaires (Expanded Tellegen Absorption Scale) to examine attention [91, 105], while another study only adopted the self-reported questionnaire [41].

3.3.3 Productivity

Occupants' productivity was tested in thirteen studies (see Appendix D). Self-report questionnaires were applied in twelve studies, while only one study used actual daily tasks (the number of answering phones and typing errors) to objectively measure productivity [79].

3.3.4 Satisfaction

Appendix E lists 26 studies on the effect of PIEC on occupants' job and environmental satisfaction. The main data on satisfaction were achieved from self-report questionnaires, such as the CBE occupants' satisfaction questionnaire [42, 67, 68].

3.4 Effects of perceived indoor environmental characteristics

According to appendices B, C, D and E, effects of PIEC on four outcomes (mental well-being, cognitive performance, productivity, and satisfaction) are given as follows.

3.4.1 Office type and layout

Compared with open-plan offices, employees who work in private offices had better health status [71, 77], and less cognitive stress [89] and mental wellbeing [41]. The effect of the private office on occupants' emotional exhaustion was mediated by privacy level [84]. Furthermore, a private office environment can improve occupants' productivity [71, 73] and satisfaction [72, 75-77, 85]. In addition, increasing social density (the number of occupants in the room) can lead to occupants' psychological discomfort [58] and dissatisfaction [51]. For office layout, the effect of perceived physical proximity on job satisfaction can be medicated by organizational culture [97]. Small distances between personal workstations and shared service & amenity spaces can produce high satisfaction [60]. Researchers revealed that employees whose workstation was close to windows had high satisfaction [96]. Three studies proved that the perceived quality of office layout significantly affected occupants' satisfaction [42,

67, 68].

However, for some mental health indicators, there were no significant differences found between staff in the private office and those in the open-plan office, such as burnout [89] and motivation [77]. In addition, one study did not find significant effects of proximity to windows on occupants' psychological discomfort [58]. Moreover, three studies indicated that office workers' cognitive performance or satisfaction cannot be significantly affected by the office type and layout [41, 59, 72].

3.4.2 Windows and window view

For mental well-being, compared with occupants in the office without windows, those working in the office with windows had higher positive emotions and lower negative emotions [81]. Studies found that employees working in offices with natural window views can achieve lower stress levels [66], lower depression and anxiety [69], less psychological discomfort [58], and higher life quality [65]. Increasing amounts of natural elements in the window view can significantly reduce emotional exhaustion, anxiety [61, 64], stress levels [61] and uptight & tense (marginally significant effect, $p = 0.09$) [53]. Researchers further found that the effect of the window view with natural elements on occupants' emotional exhaustion and anxiety can be mediated by several view features' qualities (e.g., view coherence, complexity, legibility, prospect, refuge) [64]. In addition, window view qualities had significant effect on human psychological discomfort [58]. For cognitive performance, Researchers revealed that occupants' working memory and response inhibition were significantly affected by the window view [58, 70]. Furthermore, occupants' satisfaction was significantly affected by natural window view [65, 66, 69], the amount of natural element in window view [64] and view quality [59]. The effect of the natural window view on satisfaction was mediated by visual properties, such as coherence and prospect [64].

However, some studies showed that there were no significant effects of the window view on hedonic/emotional wellbeing and negative feelings [78] and stress levels [63, 81]. Other studies also pointed out that some cognitive aspects were not associated with window view, such as short-term memory and planning [81] and general performance [6]. In addition, effects of window and natural window view on occupants' satisfaction were not found as significant in two studies [53, 85].

3.4.3 Indoor plants

Studies demonstrated that indoor plants can significantly affect various mental well-being indicators, including depression [69], anxiety [69], stress [70, 95], quality of life [65], general well-being [79]. Researchers further concluded that increasing the amount of indoor plants significantly reduced stress levels and anxiety [61]. For cognitive performance, compared with occupants in the office without plants, those working in the office with plants can achieve better performance in terms of working memory, response inhibition [70] and attention [94]. Interestingly, occupants' attention levels reduced when the number of indoor plants increased from low to high levels [83]. In addition, employees' productivity was significantly affected by indoor plants in view [62]. Occupants' overall satisfaction can receive significant effects from indoor plants [59, 65, 69, 70].

However, there were still some studies which cannot support the significant effects of indoor plant on mental and human performances, including anxiety [70], stress [5, 63, 79], well-being and work engagement [94]. Furthermore, Researchers found indoor plants cannot significantly predict occupants' attention capability [87]. In addition, study showed that there was no association between indoor plants and productivity or job satisfaction in a longitudinal experiment [94].

3.4.4 Decoration

The nature poster can deliver a significant effect on emotion (anger) and stress for only male participants [39], while its marginally significant effects on mood and attention were exposed by other researchers [93]. Interior design took significant effects on occupants' mental health and stress recovery level [86]. Occupants' cognitive performance (working-memory, attention, response inhibition) can be improved when they worked in an office with the wooden interior [90]. There were clear differences in occupants' satisfaction and work performance before and after interior refurbishment [51]. In addition, occupants' satisfaction can be significantly affected by the quality of interior colour and texture (flooring, furniture, and surface finishes) [42, 67, 68], and the quality of overall interior design [86].

However, one study did not find significant effects of interior decorations (e.g., partition colour) on office workers' mood and attention [93].

3.4.5 Furniture and workstation

It can be found that the wooden furniture in workstations can reduce occupants' stress [74]. The quality of furniture had significant effects on mental well-being [80, 86], stress recovery [86], work performance [51], and satisfaction [42, 51, 67, 68, 80, 86]. Some studies explored the effects of workstations' architectural and functional features on occupants' mental health and performance. For architectural features, the high workstation partition delivered positive effects on perseverance [88] and satisfaction [96]. There was a strong association between workstation size and work performance [51]. Researchers found that the effect of workstation size on occupants' satisfaction was mediated by the organizational culture [97]. For functional features, workstation storage and adjustability had significant effects on work performance [40] and satisfaction [40, 42, 67, 68]. O'Neill (1994) further proved that effects of workstation storage and adjustability on employees' work performance and satisfaction were

mediated by privacy and support for communication [40].

However, the effects of the quality of furniture on well-being and stress recovery were not found as significant [74]. In addition, the association cannot be found between the partition height and problem-solving ability [88] or satisfaction [85]. In open-plan offices, office workers' satisfaction cannot be significantly affected by the interior furniture's quality [92] and adjustability [68].

3.4.6 Privacy

Two studies exposed significant effects of environmental privacy on well-being [78, 80]. One study found that the privacy was the mediator between architectural privacy and emotional exhaustion [84]. Another study showed that a high privacy level can improve employees' work performance [51]. Adequate communicational privacy and visual privacy can contribute to occupants' satisfaction [37, 38, 42, 51, 67, 80]. Some studies indicated that the effect of privacy on occupants' satisfaction was mediated by organizational culture [97]. Researchers found that effects of privacy on satisfaction varied in offices [92]. In an enclosed office, visual privacy and communicational privacy delivered significant effects on the satisfaction [92]. However, in an open-plan office, a significant effect on the satisfaction was only found for visual privacy [92]. Interestingly, the effect of privacy on cognitive performance was not clearly identified.

3.4.7 Cleanliness and maintenance

The mental workload (mental health and work performance) was significantly influenced by office cleanliness [41]. Two studies showed that there was a strong association between the quality of office cleanliness and maintenance and occupants' satisfaction [42, 67,68]. However, some researchers pointed out that the workspace cleanliness cannot deliver significant effects on occupants' satisfaction in enclosed shared offices and open-plan offices [68]. In general, effects of cleanliness and

maintenance on cognitive performance and productivity were rarely studied.

3.4.8 Lighting

For sunlight, one study [69] found that it can have negative effects on anxiety and depression while occupants' satisfaction can receive positive effects. The sunlight can also influence employees' well-being [53].

For artificial light, the quality of indoor lighting significantly affected occupants' mood [55, 82], motivation & tiredness [82], well-being [78, 86], stress recovery [86], mental workload [41], response inhibition [82], productivity [51, 82] and satisfaction [37, 38, 42, 67, 68, 80 ,86, 92]. In addition, the effect of light spectrum/colour was studied. Researchers concluded that a high level of circadian-effective light was associated with the reduction of depression [50]. Studies showed significant effects of indoor lighting with high correlated colour temperature on vitality, well-being, and productivity [54].

On the other hand, effects of indoor lighting on occupants' mental and work performances were not found as significant in several studies, including employees' well-being [53, 80], stress [63], attention [55], productivity [57] and satisfaction [85]. Moreover, researchers pointed out that an adjustable LED task lighting cannot deliver significant effects on work performance [52].

3.4.9 Temperature

It can be found that the air temperature was strongly associated with office workers' mental well-being [78], mood [82], motivation & tiredness [82], response inhibition [82], productivity [51, 57] and satisfaction [55, 67].

However, effects of temperature can still be found as non-significant in some studies, including mental workload [41], productivity [82] and satisfaction [42, 68, 85].

3.4.10 Air quality and ventilation

Like temperature, the indoor air quality had a clear effect on well-being [78, 80],

productivity [51, 57] and satisfaction [42, 67, 68, 80, 85]. Researchers identified that there was no significant effect of ventilation on occupants' satisfaction [37]. Based on the studies included, it could be still unclear for the association between air quality and employees' cognitive performance in offices.

3.4.11 Acoustics

One study revealed that the natural sound can reduce negative mood and thus increase satisfaction [70]. In addition, the natural sound had significant effects on cognitive performance (working memory, task-switching response inhibition) and satisfaction [70]. For indoor noise, high-quality office acoustic environment can help employees to achieve good mental well-being [78, 80, 86], positive mood and motivation [82], good work performance [51, 57, 82] and a high level of satisfaction [37, 38, 42, 51, 67, 68, 80, 86, 92]. In addition, reducing noise in offices can significantly lower occupants' stress [56, 86] and mental workload [41, 91]. The response inhibition [82] and attention [91] can also be associated with indoor acoustic quality.

On the other hand, some studies found office workers' anxiety was not significantly affected by the natural sound [70]. Furthermore, the effect of noise on productivity was found as non-significant [56].

3.5 Methodological quality of the studies

According to the National Institutes of Health quality assessment tool [44] mentioned in section 2.4.2, these 55 studies were rated as 'good quality', 'fair quality', 'poor quality', respectively (see appendices F, G and H).

For Appendix F (observational cohort and cross-sectional studies, n = 38), all studies used clear and reliable measures varying in amount or level and reported reliable and valid outcomes. Most studies (n = 37) provided appropriate sociodemographic information and clear selection eligibility criteria for the study population. All cohort

studies (n = 8) adopted sufficient timeframe which helped researchers to observe associations between interventions and outcomes, whilst they assessed interventions prior to outcome measurement. Seven of the eight cohort studies controlled potential confounders, while one cohort study did not strictly control the potential confounding variables (indoor climate) [79]. All cross-sectional studies (n = 30) did not report the analysis of potential confounders. Most studies (n = 37) lacked sample size justification and the protocol in which outcome assessors were blinded to the exposure status of the participants. For one cohort study [53], there were still some limitations according to an investigation in a normal office, i.e., data of participants working in a non-office environment (brew-house, bottling plant and warehouses) were included in the analysis. As given in Appendix G (controlled intervention studies, n = 13), all studies adopted proper experimental settings, including appropriate participants, low drop-out rate, valid and reliable measures of intervention and outcome, prespecified outcomes, and intention-to-treat analysis. However, most studies (n = 11) lacked the analysis of sample size. In addition, all studies (n = 13) did not report the method of randomization and treatment allocation and did not adopt the method in which study providers and outcome assessors were blinded to treatment group assignments.

Given Appendix H (before-after studies with no control group, n = 4), all studies had clear study questions, an appropriate study population, valid and reliable measures of intervention and outcome, and appropriate statistical methods. Two studies examined the sample size while they lacked a high follow-up rate [51, 94]. Two studies measured outcomes for multiple times [94, 95]. However, all four studies did not adopt the method in which outcome assessors were blinded to participants' interventions.

4. Discussion

4.1 Findings and discussions

This paper presents a systematic review of effects of perceived indoor environmental characteristics on occupants' mental well-being, cognitive performance, productivity, and satisfaction in workplaces, using 55 studies identified from a total of 14173 articles. Based on the results achieved in section 3, main findings shown in Figure 2 & Figure 3 are discussed as follows.

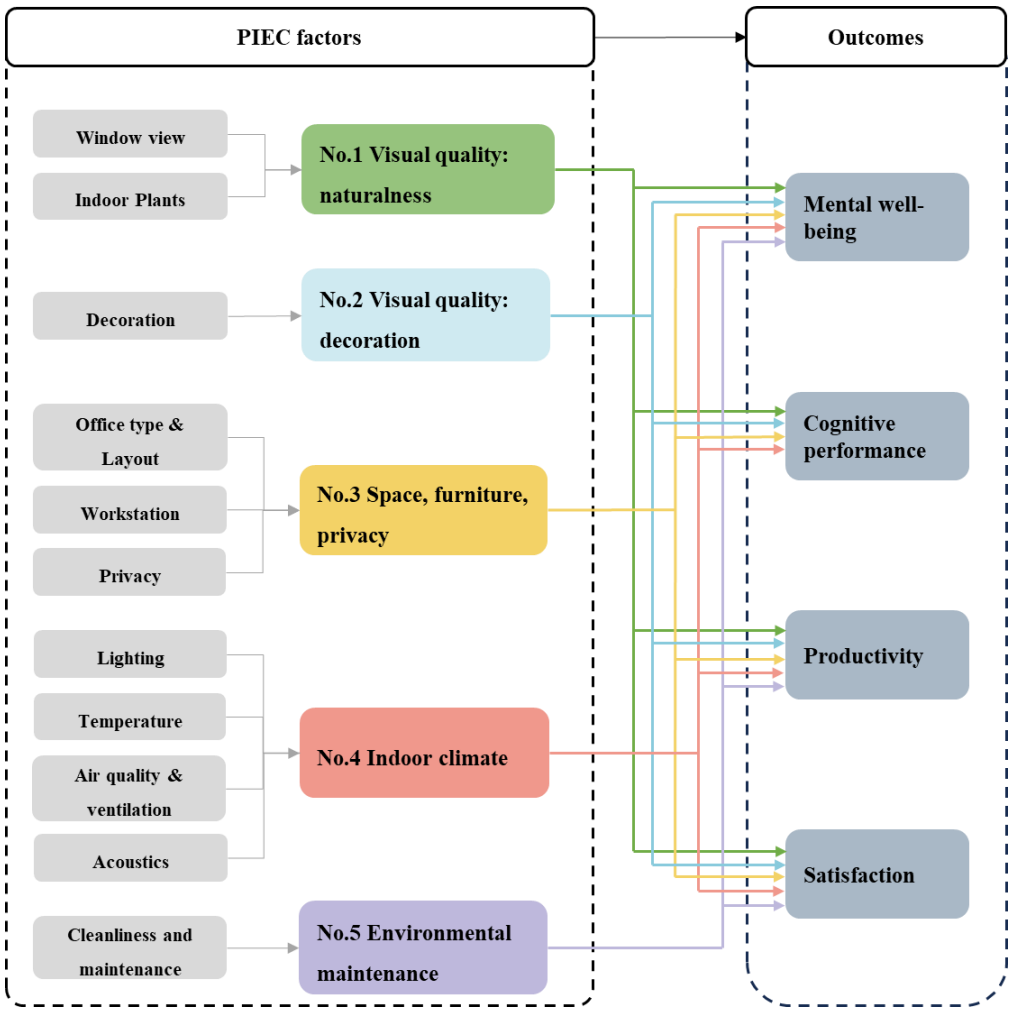

Figure 2. The achieved five PIEC factors and the relationships between them and four outcomes.

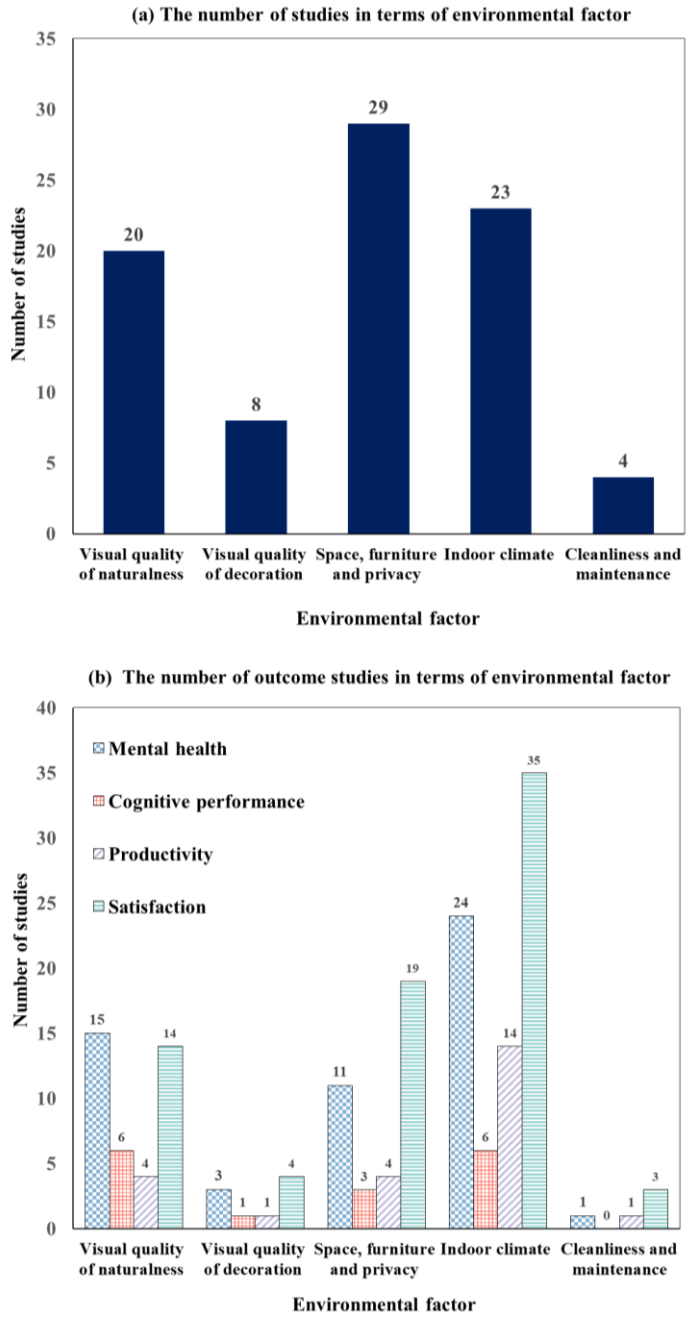

Figure 3. Summary of study numbers: (a) The number of studies in terms of environment factor; (b) The number of outcome studies in terms of environment factor.

As given in Table 4 & section 3.2, elven domains have been achieved for perceived indoor environmental characteristics in workplaces, such as office type & layout, windows & window view, indoor plants, decoration, furniture & workstation, cleanliness & maintenance, privacy, lighting, temperature, air quality & ventilation, and

acoustics. The analysis of effects of these domains can expose functional similarities among them. In previous studies, the beneficial effects of exposure to natural elements in offices have been well proved [61, 63, 65, 69, 70]. The natural elements were commonly assessed according to the amount and quality of visible outdoor nature through windows and/or the amount and quality of indoor plants [61, 63, 69]. In a study on an instrument of nature perception in workplaces [106], one subscale named as 'indoor nature contact' was defined as 'contact with natural elements inside a building such as live plants, natural light and windows with a view of the outside'. Thus, it could be reasonable to apply a new domain 'naturalness' as a combination of effects from window view and indoor plants [61, 63, 65, 69]. In addition, studies revealed that three domains (office type & layout, furniture & workstation, privacy) were strongly connected in offices as both the spatial density (office layout) and the amount of enclosure around workstations can adjust privacy [51, 84, 97, 107]. The 'privacy' can be thus applied as the representative of combined effects of the three factors. Moreover, all ambient factors (temperature, lighting, air quality & ventilation, acoustics) [108] can together produce signals of stimulus and affect human mental health and performance through sensory experience in workplaces [37, 82, 109, 110]. There were a growing number of studies which have investigated interaction of various ambient factors rather than one [37, 41, 42, 57, 67, 68]. Therefore, for studies of healthy workplaces, 'indoor climate' was commonly adopted as a factor to indicate four ambient conditions [111, 112, 113]. Based on these eleven domains' functional similarities, five environmental factors are applied to categorise these domains into: No.1 Visual quality of naturalness (indoor plants, window view), No.2 Visual quality of decoration (interior design), No.3 Space, furniture and privacy (office type & layout, workstation & furniture, privacy), No.4 Indoor climate (lighting, temperature, air quality & ventilation, acoustics), No.5

Environmental maintenance (cleanliness and maintenance). As shown in Figure 3, apparently, factors 3 & 4 are still the most popular topics studied in offices (for 3, n = 29; for 4, n = 23), which is consistent with previous reviews [9, 10]. Twenty studies focus on factor 1, whilst factors 2 & 5 receive the least attention (for 2, n = 8; for 5, n = 4). As given in Table 4 and appendices B-E, many studies (n = 31) adopt subjective measures, while objective measures are applied in only twelve studies. The application of both measures occurs in a minority of studies (n = 4).

For the visual quality of naturalness, its effects on occupants' mental well-being, cognitive performance, productivity, and satisfaction have been widely studied in offices (n = 20). First, the positive impact of naturalness (indoor plant and window view) on office workers' mental health is supported by twelve experiments and surveys, while seven surveys and experiments cannot find significant effects of window view or indoor plants on this outcome. It seems that there are still some inconsistencies occurring in several mental wellbeing indicators, such as stress, anxiety, emotional wellbeing, and work engagement according to the presence of natural elements. Second, the occurrence of natural elements in offices can positively improve cognitive performances indicated by working memory and response inhibition, but not the short-term memory, planning, and general performance (via filling, computational and creative tasks). However, its impact on attention expresses as ambivalent due to the contradicting findings from four studies [70, 83, 86, 94]. Third, given the limited results achieved (two studies with contradicting results), the association between office workers' productivity and naturalness could still be unclear. Forth, office naturalness can deliver significant satisfaction (environment and job) among occupants (seven 'supportive' studies vs one 'unsupportive' study). Fifth, in terms of the positive effects of naturalness, the optimal number of natural element (window view & indoor plants) may need more

investigations. As discussed in a study [83], increasing the number of indoor plants can lead to low cognitive performance and productivity in offices. This interesting finding might be explained by the fact that occupants were distracted by fascinating natural elements when they worked on high attention-demand tasks [114]. In addition, as discussed by Ulrich (1983), the association between complexity and preference & pleasantness showed an inverted-U curve [115]. A higher complexity brought by a larger number of natural elements in an office could deliver negative impact on occupants' psychological and work performances. Finally, it could be worthy studying the mediating effect of visual properties (e.g., coherence, prospect) of natural elements on their relationships with mental and work performances in offices. As preliminarily tested in a study, specific visual properties of window views can mediate its association with occupants' well-being [64].

For the visual quality of decoration, studies on its effects on occupants' performances in offices are apparently insufficient (n = 8). Occupants' mental wellbeing (emotion, stress, and mood) can be associated with the decoration (space interior design + wall poster) (two experiments and one survey), while only one experiment [90] has found the benefits of wooden interior for occupants' cognitive performance (working-memory, attention, response inhibition). A quasi-experiment can support significant effects of space colour on occupants' productivity [51]. Moreover, four cross-sectional studies have identified the significant effects of colour/texture and the quality of overall interior design on occupants' environmental satisfactions. It can be found that the general perception of interior design is the research focus in previous studies. However, the characteristics of office interior components (e.g., number, distribution, size, shape) may need a further investigation in terms of occupants' mental and work performances.

For the factor of space, furniture and privacy, over half of studies included in this review

have tested its effects on office workers' mental and work performances (n = 29). First, occupants' satisfaction (environment and job) is found as the most studied outcome (n = 19). Twelve studies have identified the significant effects of spatial characteristics (type of workspace, number of occupants, physical proximity, etc) on the satisfaction. Significant effects of workstation furniture and privacy on satisfaction are supported by twelve studies, while three studies cannot find the association between specific furniture properties (e.g., general quality, partition height, etc.) and satisfaction. Second, occupants' mental wellbeing has been broadly studied (n = 11), including general wellbeing, stress, emotional exhaustion, psychological comfort, burnout, perseverance, and motivation. These studies have pointed out significant effects of space, furniture and privacy on most mental health indicators, while there are still non-significant effects of specific factors (quality of furniture, office type, proximity to window) on burnout, motivation and psychological discomfort. Third, occupants' productivity and cognitive performance are the least studied outcomes (productivity, n = 4; cognition, n = 3). Four studies have exposed significant effects of office type, quality of furniture, workstation functions on occupants' productivity, while three studies cannot find any significant effects of spatial features of workspace and furniture on cognitive performance. It could be required to carry on more investigations on the effect of this factor on occupants' cognition. Fourth, as the perceived privacy can be the mediator between architectural privacy (determined by spatial and workstation characteristics) and mental wellbeing [84], it would be useful to conduct more investigations on the perceived properties of workspace and office furniture. Finally, for the workstation, current studies focus on both its functional features (e.g., personalization, storage and adjustability) [40, 42] and architectural features (e.g., partition height, workstation area) [51, 88]. However, effects of visual features of workstation, such as texture, colour and

material, have been rarely studied.

Compared to other PIEC domains, effects of indoor climate in offices have been fully studied and comprehensively discussed (n = 23). Consistent with previous reviews [9, 10], this review proves that the indoor climate (temperature, lighting, air quality and ventilation, acoustics) can deliver significant effects on occupants, especially in relation to the mental wellbeing, productivity and satisfaction. Considering the indoor climate is a conventional topic that has been well investigated over 30 years, this review will not put much effort on the discussions of its effects on the three outcomes above. However, the outcome of cognitive performance may need more attention according to the following: 1) It could be necessary to conduct more experiments (controlled intervention study) for testing the association between lighting, acoustics and temperature on cognitions due to the lack of consistent results. 2) It is still unclear for the effect of air quality on office workers' cognitive functions.

For the environmental maintenance, there is a significant lack of studies of its effect on office workers' performances (n = 4). Three cross-sectional surveys have preliminary exposed the significant effects of office cleanliness on occupants' mental wellbeing, work performance, and overall satisfaction, while significant effect of cleanliness on overall satisfaction in shared offices cannot be supported by one cross-sectional survey [68]. The relationship between workplace cleanliness and cognitive performance/productivity might remain unclear. In addition, no experiments (controlled intervention studies) of environmental maintenance are available.

In addition, these five environmental factors above can interact with each other and sometimes deliver combined effects on occupants' mental health and performance. There were five studies which have explored the combined effect on occupants' satisfaction (n = 5). A cross-sectional survey revealed the relationship between the

integration of four factors (No. 2, 3, 4, and 5) and satisfaction [68]. A combined effect of three factors (No. 2, 3, and 4) on occupants' satisfaction was examined in a longitudinal survey [51]. Three studies investigated the combined effect of two factors (No. 3 & 4) on satisfaction [38, 80, 85]. For productivity, the longitudinal study [51] surveyed the combined effect of three factors (No. 2, 3, and 4). In addition, one study [78] explored the combined effect of two factors (No. 3 & 4) on mental well-being. It is worth noting that there could be no clear evidence to prove the combined effect of these factors on occupants' cognitive performance.

Moreover, several studies assessed the importance of environmental domains (n = 5) [42, 67, 68, 85, 86]. However, ranks of the importance of environmental domains were inconsistent in these studies. Three studies found that the office layout is the most important predictor for satisfaction, followed by acoustics and privacy [42, 67, 68]. Another study however revealed that the most important predictors for job satisfaction are air quality and office type [85]. One cross-sectional study [86] concluded that employees were most satisfied with the workspace furniture and most dissatisfied with workspace acoustics. However, more investigations could still be needed to further clarify the importance rank of five environmental factors on occupants' mental well-being, cognition and productivity.

Given research qualities of the studies included (section 3.5 & Appendices F, G, H), some facts are discussed as follows. First, the overall quality of these studies remains as 'fair' according to the protocol of the National Institutes of Health quality assessment tool [44]. However, there are still some possible biases which might be caused by the sample size setting. The included studies have a sample size ranging from 20 to 43021, whereas the validation analysis of sample size has not been clearly reported in some studies. This might reduce the generalizability of the achieved findings. Second, over

half of studies have adopted cross-sectional surveys to collect subjective evaluation of perceived environmental features via self-reported questionnaires. As discussed by Mann (2003), cross-sectional studies would be hard to provide strong evidence for the effects of specific interventions [116]. This might be caused by the research design focusing on subjective measures. On the other hand, controlled intervention experiments and longitudinal studies can be adjusted for variables that can influence outcomes [116]. Thus, it would be useful to enhance the application of the latter methods in office studies. Furthermore, experiments and longitudinal studies in the include studies have mainly explored effects of conventional environmental characteristics, such as spatial layout and indoor climate, while studies on other PIEC (e.g., decoration, naturalness, perceived privacy) have not received much attention.

4.2 Future research recommendations

Based on findings achieved from the present review, a conceptual framework is proposed to further explore the relationship between workplace-perceived indoor environmental characteristics and occupants' response, in terms of mental well-being, cognitive performance, productivity and satisfaction (Figure 4).

At the next stage, in addition to observation studies (e.g., cross sectional survey), more experimental studies (randomized controlled and quasi trials) should be encouraged to test occupants' response to PIECs in a real office environment. This would help overcome the limitations of cross-sectional studies and establish a more affirmative relationship between PIECs and occupants' mental and work performances. Several approaches could be considered to improve the research quality of future studies, including selecting appropriate sample size / controlling confounders, and considering the impact of various office environment factors in terms of long, medium and short terms.

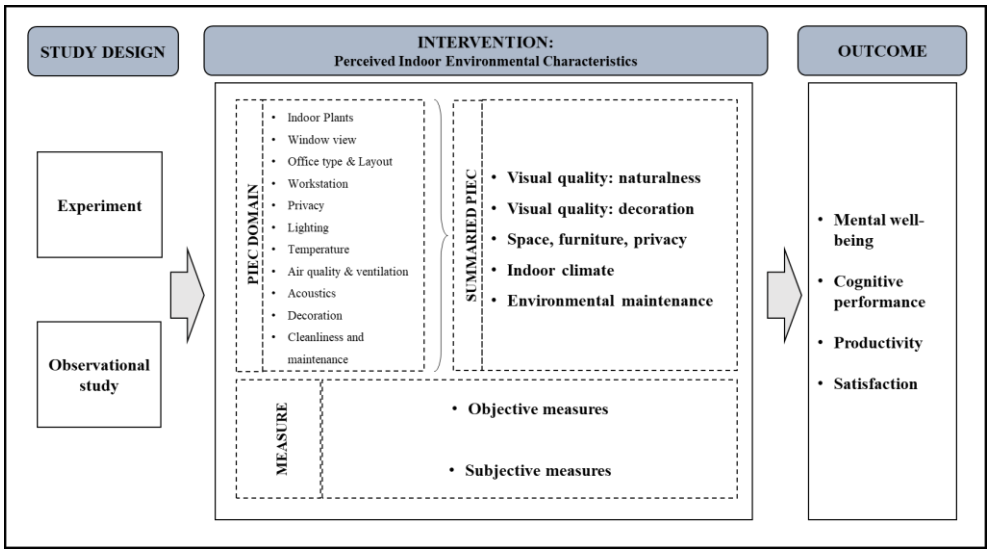

Figure 4. The conceptual framework to further test the relationship between perceived indoor environmental characteristics and occupants' mental wellbeing, cognitive performance, productivity, and satisfaction

For the intervention, environmental factors relating to visual quality may need more attention, especially for the less-studied domains (e.g., decoration, amount of naturalness, distributions/configurations of natural elements, perceived privacy). As a workplace can be considered as a complex psycho-physical system [7, 8], objective and subjective characteristics of this indoor environment will be able to predict occupants' mental and work performances. Therefore, it is recommended that when assessing occupants' response in future studies, both perceived and objective environmental qualities should be measured. Using dual measures can help researchers not only explore any mediating effects of perceptions on objective qualities, but also effectively build the dose-response relationships between PIEC and human performance to achieve a wellbeing-centred workplace design. Moreover, in a real workplace (one type of built environment), occupants' perceptions can be affected by multiple environmental factors [42, 68, 117]. It would be required to develop a new model which is capable of assessing the integrated effects of all key perceived indoor environmental factors on

occupants' mental and cognitive performances in offices.

4.3 Strengths and limitations

The main strengths of this systematic review include the use of two professional review protocols of PRISMA [43] and National Institutes of Health quality assessment tool [44], and multiple databases cross various fields (medicine/health/built environment/social). Different from other reviews, this review provides a synthesis of studies covering a full range of indoor environmental characteristics in workplaces (five key factors) and typical outcomes (mental well-being, cognitive performance, productivity, and satisfaction). The necessity to implement more investigations into effects of visual perception (decoration, naturalness, visual privacy) is emphasized and the current situation of studies on the cognitive performance caused by environmental perceptions among office workers is deliberately exposed.

However, there are still some potential limitations found in the present review and eligible articles reviewed. The articles published in non-English sources and the grey articles were not included. Some studies meeting the inclusion criteria may not be retrieved due to the search syntax used in this review. Although the terms in search syntax were defined through a cautious scrutiny from previous reviews and articles, there might still be a risk of having overlooked critical words. Moreover, although the eligible articles were evaluated by reviewers individually following a strict protocol of PRISMA, there were still some possible biases occurring in the process. Finally, due to overall research quality was assessed as 'fair', studies included in this review may still have some biases, which could influence the generalization and transferability of some findings.

5. Conclusion

This systematic review provides a synthesis of current studies on the relationship

between perceived indoor environmental characteristics (PIEC) and occupants' mental and work performances in workplaces. Eleven PIEC domains achieved from this review were summarised into five main environmental factors, including visual quality of naturalness, visual quality of decoration, space & furniture & privacy, indoor climate, and environmental maintenance. Key findings of this review can be found as follows. First, effects of three environmental factors (indoor climate, space & furniture & privacy, visual quality of naturalness) have been broadly studied in an office environment, while other factors (visual quality of decoration, environmental maintenance) have not received enough attention. Second, a number of studies can well support the significant effects of indoor climate, space & furniture & privacy, visual quality of naturalness on occupants' mental wellbeing, productivity and satisfaction. However, the impact of several factors (e.g., amount of naturalness, distributions/configurations of natural elements, perceived privacy) would still need further investigations. Third, new studies would be required to identify effects of visual quality of decoration and environmental maintenance on occupants' mental and work performances. Fourth, there is still a clear lack of consistency in the impact of the five environmental factors on cognitive performance. Finally, it would be necessary to promote experimental studies (randomized controlled and quasi) to test the association between these environmental factors and occupants' mental and work performances in offices.

Practical implications: Several implications can be considered according to the improvement of occupants' mental health, cognitive performance, productivity, and satisfaction in workplaces. 1) In addition to indoor climate, space & furniture & privacy, and naturalness, issues of decoration and environmental maintenance may need more considerations. 2) It would be required to apply more detailed design analyses of

naturalness, including amount of naturalness, and distributions/configurations of natural elements. 3) It would be necessary to provide more opportunities to adjust layout, workstation, furniture to improve perceived privacy. 4) The design of office environment for cognitive performance should be paid more attention.

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.

Acknowledgement

The first author thanks for the fund support from the China Scholarship Council (No. 202208060062).

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Appendix A: MEDLINE search (via PubMed on 23th April 2023)

Search number	Search terms	Number of results
1	((((("Occupational Groups*"[Title/Abstract]) OR (Occupation*[Title/Abstract])) OR (Employee*[Title/Abstract])) OR (Personnel [Title/Abstract])) OR (Worker*[Title/Abstract])	491,095
2	(((Workplace*[Title/Abstract]) OR (Office [Title/Abstract])) OR (Workspace*[Title/Abstract])) OR (Workstation*[Title/Abstract])	136,058
3	((((((((((((((((((((((((("Environment Design*"[Title/Abstract]) OR ("Healthy Place*"[Title/Abstract])) OR ("Built Environment*"[Title/Abstract])) OR ("Environmental qualit*"[Title/Abstract])) OR ("Percevied environment*"[Title/Abstract])) OR ("Perception of the emvironment*"[Title/Abstract])) OR ("Environment perception*"[Title/Abstract])) OR ("Subjective environment*"[Title/Abstract])) OR (Perception*[Title/Abstract])) OR (Layout[Title/Abstract])) OR (Type[Title/Abstract])) OR (Decoration[Title/Abstract])) OR ("Interior Furnishing*"[Title/Abstract])) OR ("Interior Design*"[Title/Abstract])) OR (Furniture*[Title/Abstract])) OR (Plant*[Title/Abstract])) OR ("Window view"[Title/Abstract])) OR (Privacy[Title/Abstract])) OR (Facilit*[Title/Abstract])) OR (Controlled Environment*[Title/Abstract])) OR ("Indoor Climate"[Title/Abstract])) OR (Air[Title/Abstract])) OR (Heating[Title/Abstract])) OR (Humidity[Title/Abstract])) OR (Lighting[Title/Abstract])) OR (Temperature[Title/Abstract])) OR (Ventilation[Title/Abstract])) OR (Noise[Title/Abstract])	5,246,730
4	((((((((((((((("Mental Health"[Title/Abstract]) OR (Well-being[Title/Abstract])) OR ("Well being"[Title/Abstract])) OR (Wellbeing[Title/Abstract])) OR ("Mental well-being"[Title/Abstract])) OR ("Mental wellbeing"[Title/Abstract])) OR ("Work Performance*"[Title/Abstract])) OR ("Job Performance*"[Title/Abstract])) OR (Emotion*[Title/Abstract])) OR (Feeling*[Title/Abstract])) OR (Mood*[Title/Abstract])) OR (Satisfaction*[Title/Abstract])) OR (Preference*[Title/Abstract])) OR (Efficiency[Title/Abstract])) OR (Productivity[Title/Abstract])) OR (Cognition*[Title/Abstract])) OR (Stress*[Title/Abstract])) OR (Fatigue[Title/Abstract])	2,749,233
5	1 OR 2	590,771
6	5 AND 3 AND 4 *(Filters applied: Full text, English, Adult: 19+ years, Clinical Trial & randomized Controlled Trial)*	**623**

Appendix B: Characteristics of included studies (outcome: mental well-being, n=31).

Number	Author (year)	Country /Region	Study type	Population			Interventions			Outcome: Mental well-being	
				Sample size (N)	Age (years)	Female (%)	PIEC	Measures		Measures	Effect of PIEC
								Objective	Subjective		
1	An et al. (2016) [69]	US and India	Cross-sectional study	444	Mean= 31	53.4	• Natural view (from windows & indoor) • Lighting (Sunlight exposure)	-	• Perceived exposure to natural elements (via SRQ) • Perceived exposure to sunlight (via SRQ)	• Depression (via Centre for Epidemiological Studies Depression Scale) • Anxiety (via Beck Anxiety Inventory)	• Significant negative effects of natural elements and sunlight exposure on depression and anxiety ($p < 0.01$).
2	Aries et al. (2010) [58]	Netherlands	Cross-sectional study	333	Under 30 (23%), 30–39 (31%), 40–49 (25%), 50–59 (19%) and older than 60 (2%).	42	• Window view • Office type and layout	• Proximity to window (via SRQ) • Social density (via SRQ)	• Perceived view quality (via SRQ) • Window view type (via SRQ) • Environmental qualities (impression)	• Psychological discomfort (via TNO/RUL Chronic Fatigue and Work Questionnaire)	• Significant effects of window view type and quality ($p = 0.05$). • Significant effects of office layout (social density) ($p = 0.05$). • Nature window views reduced discomfort through office impressions. • Non-significant effect of proximity to window
3	Aristizabal et al. (2021) [70]	US	Longitudinal study	37	Mean (Cohort 1) = 41.85, Mean (Cohort 2) = 33.62, Mean (Cohort 3) = 33.73.	Cohort1:46.1, Cohort2:38.4, Cohort3:66.7.	• Natural view (indoor plant) • Acoustics (Natural sound)	-	-	• Stress (via heart rate, skin conductance level, amount of non-specific skin conductance responses (NS-SCRs), amplitude NS-SCRs) • Mood (via Positive and Negative Affect Schedule) • Job stress (via Job Stress Scale) • Anxiety (via State-Trait Anxiety Inventory)	• Significant effects of natural sound on negative mood, stress, and job stress ($p < 0.05$). • Significant effects of natural view on Stress (via NS-SCRs) ($p < 0.01$). • Marginal effect of natural view on job stress ($p = 0.071$). • Non-significant effects of natural view and sound on anxiety.
4	Bergström et al. (2015) [71]	Sweden	Longitudinal study	54	22 - 64	24.1	• Office type and layout	-	-	• Self-rated health (via Salutogenic Health Indicator Scale)	• Significant effect of office type ($p < 0.05$).
5	Bjørnstad.et al. (2015) [61]	Norway	Cross-sectional study	565	Mean = 48.5	47.3	• Indoor naturalness (plants, window view and sunlight)	-	• Amount: indoor plants, windows that lead directly to the outdoors (via Nature Contact Questionnaire) • Amount of natural elements from windows (via SRQ) • Perceived exposure to sunlight and unobstructed view outside (via Nature Contact Questionnaire)	• Stress (via Job Stress Survey) • Pseudo neurology (e.g., sleep problems, anxiety) (via Subjective Health Complaint inventory)	• Significant effect of indoor naturalness on stress ($p < 0.05$) and pseudo neurology health ($p < 0.01$).
6	Bringslimark et al. (2007) [62]	Norway	Cross-sectional study	385	24 - 66 (mean = 43.1)	37	• Indoor plants	-	• Amount of plant in view (via SRQ) • Amount of plant own (via SRQ) • Amount of plant nearby (via SRQ)	• Stress (via Perceived Stress Scale)	• Non-significant effect.
7	Burnard & Kutnar. (2020) [74]	Slovenia	Randomized experiment	61	Mean = 27.7	77	• Furniture	-	-	• Stress level and recovery (via salivary cortisol concentration) • Well-being (via WHO-5 well-being index)	• Significant effect of wood furniture on stress ($P = 0.015$). • Non-significant effect of wood furniture on well-being and stress recovery.
8	Danielsson & Bodin. (2008) [77]	Sweden	Cross-sectional study	491	21 - 64 (mean = 41)	74	• Office type and layout	-	-	• Emotional health (four subitems: efficiency, accuracy, and calm and harmony, motivation) (via SRQ)	• Significant effect on efficiency ($p = 0.048$), accuracy ($p = 0.004$), and calm and harmony ($p = 0.05$). • Non-significant effect on motivation.

Note: SRQ: self-report questionnaire.

Appendix B: Characteristics of included studies (outcome: mental health, n=31) (continued).

Number	Author (year)	Country /Region	Study type	Population			Interventions			Outcome: Mental well-being	
				Sample size (N)	Age (years)	Female (%)	PIEC	Measures		Measures	Effect of PIEC
								Objective	Subjective		
9	Dravigne et al. (2008) [65]	US	Cross-sectional study	552	-	-	• Window view • Indoor plants	-	• Presence of the window with view green space or Presence of the indoor plants (via SRQ)	• Quality of life (via Waliczek's Questionnaire)	• Significant effects of window natural view and indoor plants (P = 0.001).
10	Dreyer et al. (2018) [78]	Canada	Cross-sectional study	444	Mean= 31	53.4	• Indoor climate (lighting, temperature, and air quality & movement) • Privacy and acoustics • Window view	-	• Environmental qualities (via SRQ)	• Well-being (eudaimonic well-being, hedonic wellbeing, negative well-being) (via The Scale of Positive and Negative Experiences, single item of Newsham et al (2013), Flourishing scale, and Patient Health Questionnaire-4)	• Marginally significant effects of indoor climate on eudaimonic wellbeing and negative well-being ($p < 0.1$). • Significant effects of privacy and acoustic on eudaimonic wellbeing ($p < 0.01$). • Marginally significant effects of privacy and acoustic on hedonic wellbeing ($p < 0.1$). • Non-significant effect of window view.
11	Figueiro et al. (2017) [50]	US	Longitudinal study	109	-	63.3	• Lighting	• Circadian stimulus (via Daysimeter)	-	• Depression (via The Center for Epidemiologic Studies Depression Scale)	• High circadian stimulus level can significantly reduce depression (p = 0.016).
12	Genjo et al. (2019) [79]	Japan	Longitudinal study	36-43	-	25.5-30.5	• Indoor naturalness (plant)	-	-	• Stress (via Heart rate, Salivary amylase activity and Fingertip pulse waves) • Well-being (via Jikakusho shirabe questionnaire)	• Significant effect on well-being ($p < 0.05$). • Non-significant effect on stress.
13	Klitzman & Stellman. (1989) [80]	Canada and US	Cross-sectional study	1830	Mean (female) =34, Mean (male) =40	-	• Furniture • Acoustics • Privacy • Air quality • Lighting	-	• Environmental qualities (via SRQ)	• Psychological well-being (via Psychiatric Epidemiology Research Interview questionnaire)	• Significant effect of quality of furniture, acoustics, privacy and air ($p < 0.01$). • Non-significant effect of lighting.
14	Ko et al. (2020) [81]	US	Randomized experiment	86	-	50	• Window view	-	-	• Emotional state (via circumplex model) • Stress (via SRQ)	• Significant effect on emotions ($p < 0.01$). • Non-significant effect on stress.
15	Kweon et al. (2008) [39]	US	Randomized experiment	210	Mean = 19.3	47.6	• Decoration	-	-	• Emotion (anger (via State-Anger Scale)) • Stress (via Stress Adjective Checklist)	• Office with art posters had a significant effect on anger and stress for only males ($p < 0.05$).
16	Lamb & Kwok. (2016) [82]	New Zealand	Longitudinal study	114	Mean = 39.5	71.9	• Temperature • Lighting • Acoustic quality	-	• Environmental qualities (via SRQ)	• Fatigue (tiredness) (via Karolinska Sleepiness Scale) • Mood (via SRQ) • Motivation (via SRQ)	• All PIECs had significant effect on mood, tiredness and motivation ($p < 0.05$).

Note: SRQ: self-report questionnaire.

Appendix B: Characteristics of included studies (outcome: mental health, n=31) (continued).

Number	Author (year)	Country /Region	Study type	Population			Interventions			Outcome: Mental well-being	
				Sample size (N)	Age (years)	Female (%)	PIEC	Measures		Measures	Effect of PIEC
								Objective	Subjective		
17	Largo-Wight et al. (2011) [63]	US	Cross-sectional study	503	Mean = 42	92.9	• Indoor naturalness (plants, window view and sunlight)	-	• Amount: indoor plants, windows that lead directly to the outdoors (via Nature Contact Questionnaire) • Perceived exposure to sunlight and unobstructed view outside (via Nature Contact Questionnaire)	• Stress (via Perceived Stress Questionnaire)	• Non-Significant effect.
18	Laurence et al. (2013) [84]	US	Cross-sectional study	87	Mean = 38.6	77	• Task and communicational privacy • Office type	-	• Privacy level (via Oldham's scale (1988)) • Architectural privacy (via SRQ) • Workstation personalization	• Emotional exhaustion (via Maslach Burnout Inventory)	• Task and communicational privacy were the mediator between architectural privacy and emotional exhaustion ($p < 0.05$).
19	Leather et al. (1998) [53]	South Europe	Cross-sectional study	100	Mean = 41.8	34	• Window view • Lighting (sunlight)	• Illuminance (via Lux meter)	• Amount of sunlight penetration (via SRQ) • Amount of natural window view (via SRQ)	• Well-being (worn out and uptight & tense) (via General well-being questionnaire)	• Significant effect of sunlight penetration on worn out ($p < 0.05$) and uptight & tense ($p < 0.01$). • Marginal effect of natural window view on uptight and tense ($p = 0.09$). • Non-significant effect of illuminance.
20	Lusa et al. (2019) [86]	-	Cross-sectional study	91	Mean = 46	68	• Acoustics • Lighting • Decoration (office design) • Workspace furniture • Workstation	-	• Environmental qualities (via CBE occupant satisfaction questionnaire)	• Self-perceived health (via Finnish Work and Health interview) • Stress recovery (via Finnish Work and Health interview)	• Significant effect of all environmental qualities ($p < 0.01$).
21	Mills et al. (2007) [54]	UK	Randomized experiment	69	-	-	• Lighting	• Colour temperature (via lighting meter) • Illuminance (via Lux meter)	-	• Vitality and mental health (via SF-36)	• The lighting with high correlated colour temperature had significant effects on vitality ($p < 0.001$) and mental health ($p < 0.05$).
22	Rolo et al. (2010) [41]	-	Cross-sectional study	238	Mean = 37.5	65	• Lighting • Temperature • Acoustics • Office layout • Cleanliness	-	• Environmental qualities (via SRQ)	• Mental health (via Subjective Mental Workload Scale)	• Office layout and cleanliness had significant effects on mental health ($p < 0.05$).
23	Seddigh et al. (2014) [89]	Sweden	Cross-sectional study	1241	Mean = 47	60	• Office type and layout	-	-	• Cognitive stress (via Copenhagen Psychosocial Questionnaire) • Burnout (via Maslach Burnout Inventory)	• Significant effects on cognitive stress ($p < 0.001$). • Non-significant effect on burnout.
24	Seddigh et al. (2015) [56]	Sweden	Longitudinal study	145	Mean = 43.9	57	• Acoustics (Noise)	• Sound pressure level (via meter)	• Level of disruption in general (via SRQ) • Level of nearby disturbances (via SRQ) • Level of distant disturbances (via SRQ)	• Cognitive stress (via Copenhagen Psychosocial Questionnaire)	• Decreasing noise can significantly lower cognitive stress ($p < 0.05$).
25	Smith-Jackson & Klein (2009) [91]	-	Randomized experiment	54	Mean = 19.77	50	• Acoustics (Noise)	-	-	• Subjective workload (NASA-TLX)	• Significant effect ($p < 0.01$).

Note: SRQ: self-report questionnaire.

Appendix B: Characteristics of included studies (outcome: mental health, n=31) (continued).

Number	Author (year)	Country /Region	Study type	Population			Interventions			Outcome: Mental well-being	
				Sample size (N)	Age (years)	Female (%)	PIEC	Measures		Measures	Effect of PIEC
								Objective	Subjective		
26	Shin (2007) [66]	South Korea	Cross-sectional study	931	30-39 (46%) and 20-29 (41%).	28	• Window view	-	• Presence of forest view (via SRQ)	• Stress (via Stress at Work scale)	• Significant effect of forest view ($p < 0.001$).
27	Stone & English. (1998) [93]	US	Randomized experiment	112	18 - 45 (median = 19)	55.3	• Decoration (partition colour) • Decoration (poster presence)	-	-	• Mood (via Multiple Affect Adjective Check List)	• Posters had marginally significant effect on mood ($p < 0.1$). • Partition colour had non-significant effect on mood.
28	Thatcher et al. (2020) [94]	South Africa	Quasi-experimental Quasi-experimental	32 34	Mean = 31.62 Mean = 28.85	34.4 55.9	• Indoor plant	-	• Amount of plants (via SRQ)	• Work engagement (via Utrecht Work Engagement Scale) • Well-being (via Warwick Edinburgh Mental Well-being Scale and Kessler Psychological Distress Scale)	• Non-significant effect of presence and amount of plants on well-being and work engagement.
29	Toyoda et al. (2020) [95]	Japan	Quasi-experimental	69	Mean = 38.7	47.6	• Indoor plant	-	-	• Stress (via State-Trait Anxiety Inventory and pulse rates)	• Significant effect ($p < 0.05$).
30	van Esch et al. (2019) [64]	-	Cross-sectional study	303	Mean = 33	45	• Window view	-	• Amount of natural elements from windows (via SRQ) • Window view qualities (coherence, legibility, complexity, mystery, prospect, refuge)	• Emotional exhaustion (via Maslach 's 7-item scale) • Apprehension (anxiety) (via Gatersleben and Andrews' 6-item scale)	• Significant effect of natural view amount on emotional exhaustion and apprehension ($p < 0.001$). • The effect of natural view amount on emotional exhaustion can be mediated by window view coherence, complexity, refuge. • The effect of natural view amount on apprehension can be mediated by window view coherence, legibility, prospect, refuge.
31	Veitch et al. (2008) [55]	US	Randomized experiment	Study 1: 151 Study 2: 80	Mean (study 1) = 34 Mean (study 2) = 30.6	Study 1: 61.6 Study 2: 62.5	• Lighting	• Illuminance (via Lux meter)	• Perceived lighting quality (via NRC Lighting Quality scale)	• Mood (unknown)	• Significant effect ($p < 0.01$).

Note: SRQ: self-report questionnaire.

Appendix C: Characteristics of included studies (outcome: cognitive performance, n=14).

Number	Author (year)	Country /Region	Study type	Population			Interventions			Outcome: Cognitive performance	
				Sample size (N)	Age (years)	Female (%)	PIEC	Measures		Measures	Effect of PIEC
								Objective	Subjective		
1	Aristizabal et al. (2021) [70]	US	Longitudinal study	37	Mean (Cohort 1) = 41.85, Mean (Cohort 2) = 33.62, Mean (Cohort 3) = 33.73.	Cohort1:46.1, Cohort2:38.4, Cohort3:66.7.	• Natural view (indoor plant) • Acoustics (Natural sound)	-	-	• Directed attention (via Necker Cube Pattern Control task) • Working memory (via Operation Span test) • Response inhibition (via Stroop test) • Task switching (attention) (via Magnitude/parity test)	• Significant effect of natural view on working memory ($p < 0.01$) and response inhibition ($p < 0.001$). • Significant effect of natural sound on working memory, task switching and response inhibition ($p < 0.001$). • Non-significant effects of natural view and sound on directed attention.
2	Block & Stokes. (1989) [72]	US	Randomized experiment	169	18 - 22	50.8	• Office type and layout	-	-	• Attention (via collation file task)	• Non-significant effect.
3	Ko et al. (2020) [81]	US	Randomized experiment	86	-	50	• Window view	-	-	• Working-memory (via Token Search) • Response inhibition (via Double Trouble (Stroop test)) • Short-term memory (via Digit Span) • Planning (via Spatial Planning task)	• Window view can significantly improve working memory ($p < 0.01$) and response inhibition ($p < 0.05$). • Non-significant effect of window view on short-term memory and planning.
4	Lamb & Kwok. (2016) [82]	New Zealand	Longitudinal study	114	Mean = 39.5	71.9	• Temperature • Lighting • Acoustics	-	• Environmental qualities (via SRQ)	• Response inhibition (via Stroop test)	• Significant effects of three environment qualities ($p < 0.05$).
5	Larsen, et al. (1998) [83]	US	Randomized experiment	81	-	57	• Indoor plants	-	-	• Attention (via sorting task and letter identification productivity task)	• Number of indoor plants had a significant negative effect on attention ($p < 0.05$).
6	Raanaas et al. (2010) [87]	Norway	Randomized experiment	34	Mean (female) = 25, Mean (male) = 23.3	64.7	• Indoor plants	-	-	• Attention capacity (via Reading Span Task)	• Non-significant effect of plants.
7	Roberts et al. (2019) [88]	-	Randomized experiment	Study 1: 65 Study 2 & 3: 60	Study 1: 18-30 Study 2 & 3: 18-34	Study 1: 44.6 Study 2 & 3: 48.3	• Workstation (partition height)	-	-	• Perseverance and problem-solving ability (via frustration Tolerance Task, flicker change detection paradigm, object sorting task)	• Significant effects on perseverance ($p < 0.05$). • Non-significant effect on problem-solving ability.
8	Rolo et al. (2010) [41]	-	Cross-sectional study	238	Mean = 37.5	65	• Lighting • Temperature • Acoustics • Office layout • Cleanliness	-	• Environmental qualities (via SRQ)	• Cognitive demands (via Subjective Mental Workload Scale)	• Non-significant effects.
9	Shen et al. (2020) [90]	China	Randomized experiment	20	22 - 28	50	• Decoration (wood materials)	-	-	• Working-memory (via Meaningless Picture Recognition) • Sustained attention (via Visual Choice Reaction Time) • Attention (via Continuous Operation) • Performance (via Number Calculation) • Response inhibition (via Stroop test)	• Significant effects ($p < 0.05$).
10	Smith-Jackson & Klein. (2009) [91]	-	Randomized experiment	54	Mean = 19.77	50	• Acoustics	-	-	• Focused attention (via Proofreading tasks and Expanded Tellegen Absorption Scale)	• Significant effect on focused attention ($p < 0.05$).

Note: SRQ: self-report questionnaire.

Appendix C: Characteristics of included studies (outcome: cognitive performance, n=14) (continued).

Number	Author (year)	Country /Region	Study type	Population			Interventions			Outcome: Cognitive performance	
				Sample size (N)	Age (years)	Female (%)	PIEC	Measures		Measures	Effect of PIEC
								Objective	Subjective		
11	Stone & English. (1998) [93]	US	Randomized experiment	112	18 - 45 (median = 19)	55.3	• Decoration (partition colour) • Decoration (poster presence)	-	-	• Attention (via Listening audiotapes and remembering address task)	• Posters had marginal effect on attention ($p < 0.1$). • Partition colour had non-significant effect on attention.
12	Stone & Irvine. (1994) [6]	US	Randomized experiment	180	18 - 45 (median = 19)	67.2	• Window and view	-	-	• Performance (via filing, computational, and creative task)	• Non-significant effect.
13	Thatcher et al. (2020) [94]	South Africa	Randomized experiment	120	Mean = 33.72	69.2	• Indoor plant	-	-	• Attention (via Card-sorting task and Reading task)	• Significant effect ($p < 0.001$).
14	Veitch et al. (2008) [55]	US	Randomized experiment	Study 1: 151 Study 2: 80	Mean (study 1) = 34 Mean (study 2) = 30.6	Study 1: 61.6 Study 2: 62.5	• Lighting	• Illuminance (via Lux meter)	• Perceived lighting quality (via NRC Lighting Quality scale)	• Attention (via Work structure task, Vigilance task, Typing task)	• Non-significant effect.

Note: SRQ: self-report questionnaire.

Appendix D: Characteristics of included studies (outcome: productivity, n=13).

Number	Author (year)	Country /Region	Study type	Population			Interventions			Outcome: Productivity	
				Sample size (N)	Age (years)	Female (%)	PIEC	Measures		Measures	Effect of PIEC
								Objective	Subjective		
1	Bergström et al. (2015) [71]	Sweden	Longitudinal study	54	22 - 64	24.1	• Office type and layout	-	-	• Perceived work performance (via questionnaire (Brennan et al. 2002))	• Significant effect ($p < 0.05$).
2	Brennan et al. (2002) [73]	Canada	Longitudinal study	21	-	-	• Office type and layout	-	• Environmental qualities (via SRQ)	• Perceived work performance (via SRQ)	• Significant effects ($p < 0.01$).
3	Bringslimark et al. (2007) [62]	Norway	Cross-sectional study	385	24 - 66 (mean = 43.1)	37	• Indoor plant	-	• Amount of plant in view (via SRQ) • Amount of plant own (via SRQ) • Amount of plant nearby (via SRQ)	• Productivity (via Clements-Croome and Kaluarachch's questionnaire)	• Significant effect of plant in view ($p < 0.05$). • Nonsignificant effect of plant owns and nearby.
4	Genjo et al. (2019) [79]	Japan	Longitudinal study	36-43	-	25.5-30.5	• Indoor plant	-	-	• Productivity (via response calls task and typing task)	• Non-significant effect.
5	Hongisto et al. (2016) [51]	Finland	Quasi-experimental	135	Mean = 44	85	• Acoustics • Temperature and air quality • Lighting (personal control) • Privacy • Furniture (ergonomics) • Interior design (colour) • Workstation (spatial density)	• Sound pressure level (via acoustic meter) • Temperature and CO2 concentration (via meters) • Illuminances (via lighting meter)	• Environmental qualities (via SRQ)	• Work performance (via SRQ)	• Significant effects of all environmental qualities ($p < 0.001$).
6	Humphreys & Nicol. (2007) [57]	France, Greece, Portugal, Sweden, UK	Cross-sectional study	4655	-	-	• Indoor temperature • Humidity • Air movement • Lighting • Acoustics • Air quality	• Temperature (via temperature meter) • Relative Humidity (via humidity meter) • CO2 concentration (via air quality meter)	• Environmental qualities (via SRQ)	• Productivity (via SRQ)	• Significant effects of five environmental qualities (indoor temperature ($p < 0.001$), air movement ($p < 0.001$), lighting ($p < 0.05$), acoustics ($p < 0.001$), air quality ($p < 0.001$)). • Nonsignificant effect of lighting.
7	Joines et al. (2015) [52]	US	Longitudinal study	95	Under 25 (3%), 26-35 (20%), 36-45 (29%), 46-55 (36%), 56 or older (12%)	89.5	• Lighting (type and level)	• Illuminance (via Lux meter)	-	• Perceived work performance (via Job Content Questionnaire)	• Non-significant effect of adjustable LED task lighting condition.
8	Lamb & Kwok. (2016) [82]	New Zealand	Longitudinal study	114	Mean = 39.5	71.9	• Temperature • Lighting • Acoustics	-	• Environmental qualities (via SRQ)	• Perceived work performance (via SRQ)	• Lighting ($p < 0.05$) and acoustic quality ($p < 0.01$) had significant effect. • Temperature had non-significant effect. • Poor environmental qualities can indirectly reduce work performance through mental well-being (motivation, tiredness, and distractibility) ($p < 0.05$).

Note: SRQ: self-report questionnaire.

Appendix D: Characteristics of included studies (outcome: productivity, n=13) (continued).

Number	Author (year)	Country /Region	Study type	Population			Interventions			Outcome: Productivity	
				Sample size (N)	Age (years)	Female (%)	PIEC	Measures		Measures	Effect of PIEC
								Objective	Subjective		
9	Mills et al. (2007) [54]	UK	Randomized experiment	69	-	-	• Lighting	• Colour temperature (via meter) • Illuminance (via Lux meter)	-	• Perceived work performance (via WHO-HPQ and Columbia Jet Lag Scale)	• The lighting with high correlated colour temperature had significant effects ($p < 0.001$).
10	O'Neill (1994) [40]	-	Cross-sectional study	541	-	-	• Workstation	-	• Workstation storage (via SRQ) • Workstation adjustability (via SRQ)	• Perceived work performance (via SRQ)	• Significant effects of storage and adjustability ($p < 0.05$). • Workstation type had indirectly effect through privacy and support for communication.
11	Rolo et al. (2010) [41]	-	Cross-sectional study	238	Mean = 37.5	65	• Lighting • Temperature • Acoustics • Office layout • Cleanliness	-	• Environmental qualities (via SRQ)	• Perceived work performance (via Subjective Mental Workload Scale)	• Except for temperature, other four environmental qualities had significant effects on work performance ($p < 0.05$).
12	Seddigh et al. (2015) [56]	Sweden	Longitudinal study	145	Mean = 43.9	57	• Acoustics (Noise)	• Sound pressure level (via meter)	• Level of disruption in general (via SRQ) • Level of nearby disturbances (via SRQ) • Level of distant disturbances (via SRQ)	• Productivity (via Maslach Burnout Inventory)	• Non-significant effect on professional efficacy.
13	Thatcher et al. (2020) [94]	South Africa	Quasi-experimental	32	Mean = 31.62	34.4	• Indoor plant	-	• Amount of plants (via SRQ)	• Perceived productivity (via Questionnaire (Thatcher & Milner, 2016))	• Non-significant effect of presence and amount of plants on perceived productivity.

Note: SRQ: self-report questionnaire.

Appendix E: Characteristics of included studies (outcome: satisfaction, n=26).

Number	Author (year)	Country /Region	Study type	Population			Interventions			Outcome: Satisfaction	
				Sample size (N)	Age (years)	Female (%)	PIEC	Measures		Measures	Effect of PIEC
								Objective	Subjective		
1	An et al. (2016) [69]	US and India	Cross-sectional study	444	Mean= 31	53.4	• Natural view (from windows & indoor) • Lighting (Sunlight exposure)	-	• Perceived exposure to natural elements (via SRQ) • Perceived exposure to sunlight (via SRQ)	• Job satisfaction (via Cammann, Fichman, Jenkins, and Klesh scale)	• Significant effects of view and sunlight ($p < 0.01$).
2	Aristizabal et al. (2021) [70]	US	Longitudinal study	37	Mean (Cohort 1) = 41.85, Mean (Cohort 2) = 33.62, Mean (Cohort 3) = 33.73.	Cohort1:46.1, Cohort2:38.4, Cohort3:66.7.	• Natural view (indoor plant) • Acoustics (Natural sound)	-	-	• Job satisfaction (via Cost-effective Open-Plan Environments Survey Questionnaire)	• Significant effects of natural view on satisfaction of aesthetic appearance, visual privacy, noise level ($p < 0.001$) and air movement ($p < 0.05$). • Significant effects of natural sound on satisfaction of aesthetic appearance and cleanliness ($p < 0.01$).
3	Block & Stokes (1989) [72]	US	Randomized experiment	169	18 - 22	50.8	• Office type and layout	-	-	• Environment satisfaction (via SRQ)	• Significant effect ($p < 0.05$).
4	Carlopio & Gardner. (1992) [75]	-	Cross-sectional study	228	Mean = 32	45.2	• Office type and layout • Furniture and device	-	-	• Job satisfaction (via Minnesota Satisfaction Questionnaire)	• Significant effect of office type ($p = 0.02$), ergonomic furniture ($p = 0.014$) and PC use ($p = 0.17$).
5	Danielsson & Bodin. (2008) [77]	Sweden	Cross-sectional study	491	21 - 64 (mean = 41)	74	• Office type and layout	-	-	• Job satisfaction (via Lindström et al., (1997); Söderberg, (1993); Vischer, (1996) Questionnaire)	• Marginally significant effect ($p = 0.057$).
6	Danielsson & Theorell. (2019) [76]	Sweden	Cross-sectional study	4352	-	55	• Office type and layout	-	-	• Environment and job satisfaction (via SRQ)	• Significant effect ($p < 0.001$).
7	Dravigne et al. (2008) [65]	US	Cross-sectional study	552	-	-	• Window view • Indoor plants	-	• Presence of the window with view green space or Presence of the indoor plants (via SRQ)	• Job satisfaction (via the Job Satisfaction Survey Questionnaire (Spector, 1997))	• Significant effects of window natural view and indoor plants ($P = 0.041$).
8	Frontczak et al. (2012) [67]	Australia, Canada, Finland, Italy, US.	Cross-sectional study	52 980	Under 30 (7%); 31-50 (18%); over 50 (10%); unknown (65%).	47	• Office layout • Furniture and decoration • Thermal comfort • Air quality • Lighting • Acoustics • Cleanliness and maintenance	-	• Environmental qualities (15 items): amount of work and storage space, visual privacy, ease of interaction with co-workers, comfort of furniture, adjustability of furniture, interior colour and texture, indoor temperature, air quality, amount of light, visual comfort of lighting, noise level, sound privacy, building cleanliness, cleaning service, building maintenance (via CBE occupant satisfaction questionnaire).	• Environment satisfaction (via CBE occupant satisfaction questionnaire)	• Significant effects of all environmental factors ($p < 0.001$). • Satisfaction of amount of space, noise level, and visual privacy are the most important predictors of occupant's satisfaction.

Note: SRQ: self-report questionnaire.

Appendix E: Characteristics of included studies (outcome: satisfaction, n=26) (continued).

Number	Author (year)	Country /Region	Study type	Population			Interventions			Outcome: Satisfaction	
				Sample size (N)	Age (years)	Female (%)	PIEC	Measures		Measures	Effect of PIEC
								Objective	Subjective		
9	Hongisto et al. (2016) [51]	Finland	Quasi-experimental	135	Mean = 44	85	• Acoustics • Temperature and air quality • Lighting (personal control) • Privacy • Furniture (ergonomics) • Interior design (colour) • Workstation (spatial density)	• Sound pressure level (via acoustic meter) • Temperature and CO2 concentration (via meters) • Illuminances (via lighting meter)	• Environmental qualities (via SRQ)	• Environmental satisfaction (via SRQ)	• Significant effects of all environmental factors (expect Illuminances, temperature and indoor air) ($p < 0.001$).
10	Hua & Yang. (2014) [60]	-	Cross-sectional study	26	25 - 64	69.2	• Office layout	• Distance to shared service spaces	-	• Overall environmental satisfaction (via SRQ)	• Significant effect ($p = 0.0019$).
11	Klitzman & Stellman. (1989) [80]	Canada and US	Cross-sectional study	1830	Mean (female) =34, Mean (male) =40	-	• Furniture • Acoustics • Privacy • Air quality • Lighting	-	• Environmental qualities (via SRQ)	• Job satisfaction (via Quality of Employment Survey Questionnaire)	• Significant effects of all environment factors ($P < 0.01$).
12	Kim & De Dear. (2012) [42]	Australia, Canada, Finland and US	Cross-sectional study	43021	-	-	• Office layout • Furniture and decoration • Thermal comfort • Air quality • Lighting • Acoustics • Cleanliness and maintenance	-	• Environmental qualities (15 subitems): amount of work and storage space, visual privacy, ease of interaction with co-workers, comfort of furniture, adjustability of furniture, interior colour and texture, indoor temperature, air quality, amount of light, visual comfort of lighting, noise level, sound privacy, building cleanliness, cleaning service, building maintenance (via CBE occupant satisfaction questionnaire).	• Overall environmental satisfaction (via CBE occupant satisfaction questionnaire)	• Significant effects of all environment factors ($P < 0.01$).
13	Kim & De Dear. (2013) [68]	-	Cross-sectional study	42764	Under 30 (7%); 31-50 (18%); over 50 (10%); unknown (65%).	47	• Office layout • Furniture and decoration • Thermal comfort • Air quality • Lighting • Acoustics • Cleanliness and maintenance	-	• Environmental qualities (15 subitems): amount of work and storage space, visual privacy, ease of interaction with co-workers, comfort of furniture, adjustability of furniture, interior colour and texture, indoor temperature, air quality, amount of light, visual comfort of lighting, noise level, sound privacy, building cleanliness, workspace cleanliness, building maintenance (via CBE occupant satisfaction questionnaire).	• Overall environmental satisfaction (via CBE occupant satisfaction questionnaire)	• Significant effects of all environment factors in private office ($P < 0.05$). • In enclosed shared office, non-significant effect of visual comfort, building cleanliness and workspace cleanliness. • In open-plan office with partitions, non-significant effect of workspace cleanliness. • In open-plan office without partitions, non-significant effects of adjustability of furniture and building cleanliness.
14	Leather et al. (1998) [53]	South Europe	Cross-sectional study	100	Mean = 41.8	34	• Window view • Lighting	• Illuminance (via Lux meter)	• Amount of sunlight penetration (via SRQ) • Amount of natural window view (via SRQ)	• Job satisfaction (via SRQ)	• Significant effect of sunlight penetration ($p < 0.05$). • Non-significant effect of natural view.

Note: SRQ: self-report questionnaire.

Appendix E: Characteristics of included studies (outcome: satisfaction, n=26) (continued).

Number	Author (year)	Country /Region	Study type	Population			Interventions			Outcome: Satisfaction	
				Sample size (N)	Age (years)	Female (%)	PIEC	Measures		Measures	Effect of PIEC
								Objective	Subjective		
15	Leder et al. (2016) [85]	Canada and US	Cross-sectional study	Study 1: 779 Study 2: 230	Mean (study 1) = 36.2 Mean (study 2) = 39.5	Study 1: 47.6 Study 2: 64.6	• Workstation (Partition type) • Workstation (Partition height) • Office type • Window • Ventilation • Temperature and humidity • Lighting • Air condition	• Air movement (via meter) • Temperature (via meter) • Humidity (via meter) • Air quality (via meter) • Illuminance (via Lux meter)	• Environmental qualities (via SRQ) • Presence of window	• Overall Environmental and Job Satisfaction (via SRQ)	• Significant effects of air quality and office type on Job satisfaction ($p < 0.05$).
16	Lottrup et al. (2015) [59]	Denmark	Cross-sectional study	402	Under 30 (13.9%); 31-40 (30.6%); 41-50 (30.8%); over 50 (24.6%).	59.7	• Window view • Indoor plants • Office type	-	• View type (via SRQ) • View satisfaction (via SRQ) • Amount of indoor plants (via SRQ)	• Job satisfaction (via SRQ)	• Significant effects of view type and indoor plants on view satisfaction ($p < 0.05$); non-significant effects of office type. • Significant effect of view satisfaction on job satisfaction ($p < 0.05$).
17	Lusa et al. (2019) [86]	-	Cross-sectional study	91	Mean = 46	68	• Acoustics • Lighting • Decoration (office design) • Workspace furniture • Workstation	-	• Environmental qualities (via CBE occupant satisfaction questionnaire)	• Overall Environmental Satisfaction (via SRQ)	• Significant effect of all environmental qualities ($p < 0.01$).
18	Newsham et al. (2009) [37]	US	Cross-sectional study	95	Mean = 39.7	49.5	• Lighting • Privacy /acoustics • Ventilation	• Sound pressure level and noise criterion (via meter) • Humidity (via meter) • Temperature (via meter) • Air velocity (via meter)	• Environmental qualities (via SRQ)	• Overall Environmental Satisfaction (via SRQ)	• Significant effects of lighting, privacy/acoustics, workstation ($p < 0.001$). • Non-significant effect of ventilation.
19	O'Neill. (1994) [40]	-	Cross-sectional study	541	-	-	• Workstation		• Storage (via SRQ) • Adjustability (via SRQ)	• Overall Environmental Satisfaction (via SRQ)	• Significant effects of storage and adjustability ($p < 0.05$). • Workstation type had indirectly effect through privacy and support for communication.
20	Shin. (2007) [66]	South Korea	Cross-sectional study	931	30-39 (46%) and 20-29 (41%).	28	• Window view	-	• Presence of forest view (via SRQ)	• Job satisfaction (via Park's 26-item scale)	• Significant effect ($p < 0.001$).
21	Spreckelmeyer. (1993) [92]	-	Quasi-experimental	70	-	-	• Lighting • Furniture • Worksation • Communicational privacy • Visual privacy • Acoustics	-	• Environmental qualities (via SRQ)	• Overall environmental satisfaction (via SRQ)	• Significant effects of all environment factors in enclosed offices ($p < 0.01$). • Significant effects of qualities of lighting, acoustics, and visual privacy in open plan offices ($p < 0.05$). • Non-significant effects of workstation size and arrangement, furniture quality and communicational privacy in open plan offices.
22	Thatcher et al. (2020) [94]	South Africa	Quasi-experimental	34	Mean = 28.85	55.9	• Indoor plants	-	• Amount of plants (via SRQ)	• Job satisfaction (via SRQ)	• Non-significant effect.

Note: SRQ: self-report questionnaire.

Appendix E: Characteristics of included studies (outcome: satisfaction, n=26) (continued).

Number	Author (year)	Country /Region	Study type	Population			Interventions			Outcome: Satisfaction	
				Sample size (N)	Age (years)	Female (%)	PIEC	Measures		Measures	Effect of PIEC
								Objective	Subjective		
23	van Esch et al. (2019) [64]	-	Cross-sectional study	303	Mean = 33	45	• Window view	-	• Amount of natural elements from windows (via SRQ) • Window view qualities (coherence, legibility, complexity, mystery, prospect, refuge)	• Job satisfaction (via Global Indicator of Worker Job Satisfaction Questionnaire)	• Significant effect of natural elements amount in window view ($p < 0.001$). • The effect of natural view amount on satisfaction can be mediated by window view coherence, refuge.
24	Veitch et al. (2007) [38]	Canada and US	Cross-sectional study	779	Mean = 36.2	47.6	• Privacy /acoustics • Ventilation/ indoor temperature • Lighting	-	• Environmental qualities (via SRQ)	• Overall environmental satisfaction (via SRQ)	• Significant effects of all environment factors ($p < 0.01$).
25	Yildirim et al. (2007) [96]	Turkey	Cross-sectional study	41	18-29 (68%), 30-65 (32%)	41	• Window Proximity • Partition height	-	-	• Environmental satisfaction (via SRQ)	• Significant effects of all environment factors ($p < 0.01$).
26	Zerella et al. (2017) [97]	-	Cross-sectional study	202	25-34(63.4%), 18-24 or 65-74 (36.6%)	69.8	• Privacy • Layout • Workstation	-	• Environmental qualities (via SRQ)	• Job satisfaction (via questionnaire (Yang, et al., 2009; Hackman & Oldham, 1975)	• Privacy, perceived proximity and workstation equality had indirect effect on job satisfaction through organizational culture ($p < 0.05$).

Note: SRQ: self-report questionnaire.

Appendix F. Results of the methodological quality assessment of the individual studies (observational cohort and cross-sectional studies, n = 38).

	Criteria items														
Author (year)	1. Was the research question or objective in this paper clearly stated?	2. Was the study population clearly specified and defined?	3. Was the participation rate of eligible persons at least 50%?	4. Were all the subjects selected or recruited from the same or similar populations (including the same time)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?	5. Was a sample size justification, power description, or variance and effect estimates provided?	6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?	7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?	8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?	9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	10. Was the exposure(s) assessed more than once over time?	11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	12. Were the outcome assessors blinded to the exposure status of participants?	13. Was loss to follow-up after baseline 20% or less?	14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?	**Quality rating (Good, Fair, or Poor)**
An et al. (2016) [69]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Aries et al. (2010) [58]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Aristizabal et al. (2021) [70]	Y	Y	Y	Y	NR	Y	Y	Y	Y	N	Y	N	Y	Y	**Good**
Bjørnstad.et al. (2015) [61]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Bringslimark et al. (2007) [62]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Bergström et al. (2015) [71]	Y	Y	Y	Y	NR	Y	Y	Y	Y	N	Y	N	N	Y	**Fair**
Brennan et al. (2002) [73]	Y	Y	Y	Y	NR	Y	Y	Y	Y	N	Y	N	N	Y	**Fair**
Carlopio& Gardner. (1992) [75]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Danielsson & Bodin (2008) [77]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Poor**
Danielsson & Theorell. (2019) [76]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Dravigne et al. (2008) [65]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Dreyer et al. (2018) [78]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Figueiro et al. (2017) [50]	Y	Y	Y	Y	NR	Y	Y	Y	Y	Y	Y	Y	Y	NR	**Good**

Note: Y: YES; N: NO; CD: cannot determine; NA: not applicable; NR: not reported.

Appendix F. Results of the methodological quality assessment of the individual studies (observational cohort and cross-sectional studies, n = 38) (continued).

Author (year)	Criteria items														
	1. Was the research question or objective in this paper clearly stated?	2. Was the study population clearly specified and defined?	3. Was the participation rate of eligible persons at least 50%?	4. Were all the subjects selected or recruited from the same or similar populations (including the same time)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?	5. Was a sample size justification, power description, or variance and effect estimates provided?	6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?	7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?	8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?	9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	10. Was the exposure(s) assessed more than once over time?	11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	12. Were the outcome assessors blinded to the exposure status of participants?	13. Was loss to follow-up after baseline 20% or less?	14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?	**Quality rating (Good, Fair, or Poor)**
Frontczak et al. (2012) [67]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Genjo et al. (2019) [79]	Y	Y	Y	Y	NR	Y	Y	Y	Y	N	Y	N	Y	N	**Fair**
Hua & Yang (2014) [60]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Humphrey& Nicol (2007) [57]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Joines et al. (2015) [52]	Y	Y	Y	Y	NR	Y	Y	Y	Y	N	Y	N	Y	Y	**Good**
Kim & De Dear (2012) [42]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Kim & De Dear (2013) [68]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Klitzman& Stellman (1989) [80]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Lamb & Kwok (2016) [82]	Y	Y	Y	Y	NR	Y	Y	Y	Y	Y	Y	N	NR	Y	**Good**
Largo-Wight et al. (2011) [63]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Laurence et al. (2013) [84]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Leather et al. (1998) [53]	Y	N	Y	N	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Poor**
Leder et al. (2016) [85]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**

Note: Y: YES; N: NO; CD: cannot determine; NA: not applicable; NR: not reported.

Appendix F. Results of the methodological quality assessment of the individual studies (observational cohort and cross-sectional studies, n = 38) (continued).

	Criteria items														
Author (year)	1. Was the research question or objective in this paper clearly stated?	2. Was the study population clearly specified and defined?	3. Was the participation rate of eligible persons at least 50%?	4. Were all the subjects selected or recruited from the same or similar populations (including the same time)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?	5. Was a sample size justification, power description, or variance and effect estimates provided?	6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?	7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?	8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?	9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	10. Was the exposure(s) assessed more than once over time?	11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	12. Were the outcome assessors blinded to the exposure status of participants?	13. Was loss to follow-up after baseline 20% or less?	14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?	**Quality rating (Good, Fair, or Poor)**
Lottrup et al. (2015) [59]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Lusa et al. (2019) [86]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Newsham et al. (2009) [37]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
O'Neill. (1994) [40]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Rolo et al. (2010) [41]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Seddigh et al. (2014) [89]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Seddigh et al. (2015) [56]	Y	Y	Y	Y	NR	Y	Y	Y	Y	Y	Y	N	N	Y	**Fair**
Sop Shin (2007) [66]	Y	Y	Y	Y	NR	N	N	NA	Y	N	Y	NA	NA	NR	**Fair**
van Esch et al. (2019) [64]	Y	Y	Y	Y	Y	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Veitch et al. (2007) [38]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Yildirim et al. (2007) [96]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**
Zerella et al. (2017) [97]	Y	Y	Y	Y	NR	N	N	Y	Y	N	Y	NA	NA	NR	**Fair**

Note: Y: YES; N: NO; CD: cannot determine; NA: not applicable; NR: not reported.

Appendix G. Results of the methodological quality assessment of the individual studies (controlled intervention studies, n = 13).

	Criteria items														
Author (year)	1. Was the study described as randomized, a randomized trial, a randomized clinical trial, or an RCT?	2. Was the method of randomization adequate (i.e., use of randomly generated assignment)?	3. Was the treatment allocation concealed (so that assignments could not be predicted)?	4. Were study participants and providers blinded to treatment group assignment?	5. Were the people assessing the outcomes blinded to the participants' group assignments?	6. Were the groups similar at baseline on important characteristics that could affect outcomes (e.g., demographics, risk factors, co-morbid conditions)?	7. Was the overall drop-out rate from the study at endpoint 20% or lower of the number allocated to treatment?	8. Was the differential drop-out rate (between treatment groups) at endpoint 15 percentage points or lower?	9. Was there high adherence to the intervention protocols for each treatment group?	10. Were other interventions avoided or similar in the groups (e.g., similar background treatments)?	11. Were outcomes assessed using valid and reliable measures, implemented consistently across all study participants?	12. Did the authors report that the sample size was sufficiently large to be able to detect a difference in the main outcome between groups with at least 80% power?	13. Were outcomes reported or subgroups analyzed prespecified (i.e., identified before analyses were conducted)?	14. Were all randomized participants analyzed in the group to which they were originally assigned, i.e., did they use an intention-to-treat analysis?	**Quality rating (Good, Fair, or Poor)**
Block & Stokes. (1989) [72]	Y	NR	NR	N	N	Y	Y	Y	Y	Y	Y	NR	Y	Y	**Fair**
Burnard & Kutnar. (2020) [74]	Y	NR	NR	N	N	Y	Y	Y	Y	Y	Y	NR	Y	Y	**Fair**
Ko et al. (2020) [81]	Y	NR	NR	N	N	Y	Y	Y	Y	Y	Y	NR	Y	Y	**Fair**
Kweon et al. (2008) [39]	Y	NR	NR	N	N	Y	Y	Y	Y	Y	Y	NR	Y	Y	**Fair**
Larsen et al. (1998) [83]	Y	NR	NR	N	N	Y	Y	Y	Y	Y	Y	NR	Y	Y	**Fair**
Mills et al. (2007) [54]	Y	NR	NR	N	N	Y	Y	Y	Y	Y	Y	NR	Y	Y	**Fair**
Raanaas et al. (2010) [87]	Y	NR	NR	N	N	Y	Y	Y	Y	Y	Y	NR	Y	Y	**Fair**
Roberts et al. (2019) [88]	Y	NR	NR	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	**Fair**
Shen et al (2020) [90]	Y	NR	NR	N	N	Y	Y	Y	Y	Y	Y	NR	Y	Y	**Fair**
Smith-Jackson & Klein (2009) [91]	Y	NR	NR	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	**Fair**
Stone & English, (1998) [91]	Y	NR	NR	N	N	Y	Y	Y	Y	Y	Y	NR	Y	Y	**Fair**
Stone & Irvine (1994) [6]	Y	NR	NR	N	N	Y	Y	Y	Y	Y	Y	NR	Y	Y	**Fair**
Veitch et al. (2008) [55]	Y	NR	NR	N	N	Y	Y	Y	Y	Y	Y	NR	Y	Y	**Fair**

Note: Y: YES; N: NO; CD: cannot determine; NA: not applicable; NR: not reported.

Appendix H. Results of the methodological quality assessment of the individual studies (before-after studies with no control group, n = 4).

Author (year)	Criteria items												
	1. Was the study question or objective clearly stated?	2. Were eligibility/selection criteria for the study population prespecified and clearly described?	3. Were the participants in the study representative of those who would be eligible for the test/service/intervention in the general or clinical population of interest?	4. Were all eligible participants that met the prespecified entry criteria enrolled?	5. Was the sample size sufficiently large to provide confidence in the findings?	6. Was the test/service/intervention clearly described and delivered consistently across the study population?	7. Were the outcome measures prespecified, clearly defined, valid, reliable, and assessed consistently across all study participants?	8. Were the people assessing the outcomes blinded to the participants' exposures/interventions?	9. Was the loss to follow-up after baseline 20% or less? Were those lost to follow-up accounted for in the analysis?	10. Did the statistical methods examine changes in outcome measures from before to after the intervention? Were statistical tests done that provided p values for the pre-to-post changes?	11. Were outcome measures of interest taken multiple times before the intervention and multiple times after the intervention (i.e., did they use an interrupted time-series design)?	12. If the intervention was conducted at a group level (e.g., a whole hospital, a community, etc.) did the statistical analysis take into account the use of individual-level data to determine effects at the group level?	**Quality rating (Good, Fair, or Poor)**
Hongisto et al. (2016) [51]	Y	Y	Y	Y	Y	Y	Y	N	N	Y	N	NA	**Fair**
Spreckelmeyer (1993) [92]	Y	Y	Y	Y	NR	Y	Y	N	Y	Y	N	NA	**Fair**
Thatcher et al. (2020) [94]	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	NA	**Good**
Toyoda et al. (2020) [95]	Y	Y	Y	Y	NR	Y	Y	N	Y	Y	Y	NA	**Good**

Note: Y: YES; N: NO; NA: not applicable; NR: not reported.