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A systematic review of environmental intervention studies in offices with beneficial effects on workers' health, well-being and productivity

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ABSTRACT

An increased risk of developing stress, musculoskeletal and cardiovascular diseases, rhinitis, skin and eye irritations and headaches has been particularly reported among office workers. Some of these complaints have been linked to the existence of poor indoor environmental quality (IEQ) in the workplaces. In this context, intervention studies can offer new insights to tackle poor IEQ issues and to identify effective measures to reduce IEQ-related risks. This review summarizes the main characteristics of environmental intervention studies that have been performed in office settings and the respective findings on the beneficial effects on the promotion of health, well-being, comfort, and productivity among office workers. The study design followed PRISMA guidelines and the search for peer-review articles was conducted in Scopus, Web of Science, PubMed, and Cochrane Library databases. Firstly, 513 records were identified, resulting in 23 articles included in the review after the application of the study eligibility criteria and identification of additional important works within the subject. The revised experimental studies were mainly focused on changes in ventilation systems via replacement of air filters and modifications in the rate of outdoor air supplied or temperature set-points. Some studies also included interventions based on the implementation of air cleaning and biophilic strategies. Both objective (e.g., physiological examinations) and subjective (e.g., questionnaires) measures have been used to assess the effects on office workers' outcomes. Overall, the findings presented here confirm that interventions aiming at improving IEQ in offices can be effective in improving health, well-being and productivity among office workers.

1. Introduction

According to the Organisation for Economic Co-operation and Development (OECD), in 2018, 65.3% of the world population was within working age (OECD, 2021a). Moreover, for OECD countries, the latest information indicates an employment rate of 68.7% of the working-age population (OECD, 2021b). In fact, a significant percentage of the global population are workers who spend approximately one-third of their time at work (Sérafin et al., 2020). The World Health Organization (WHO) has stated that noncommunicable diseases represent 70% of the total disease burden from occupational risks (Wolf et al., 2018). To avoid occupational hazards, minimum requirements for health protection in the workplace are established internationally (Papkalla and Collison, 2017), addressing a wide range of chemical, biological, noise and vibration, radiation, ergonomic, psychosocial, and work environment risks.

Offices represent a workplace with high representability, in particular in urban areas, in which the number of office workers is large and it is expected to continue increasing (Bartzis et al., 2013). Modern office buildings are typically characterized by sealed facades and complex services systems, designed to provide adequate comfort for workers by controlling indoor conditions while reducing energy-related costs (Boerstra et al., 2012). However, several environmental factors, such as inadequate lighting, adverse thermal conditions and high concentration of hazardous chemicals and particulate matter can significantly affect the indoor environmental quality (IEQ) in offices and consequently

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impact workers' health (Bluyssen et al., 2011). Accordingly, an increased risk of development of headaches, rhinitis, irritations of skin and eyes (Sick Building Syndrome (SBS) symptoms), stress, musculoskeletal and cardiovascular diseases, asthma and allergic inflammations of the respiratory tract has been reported among office workers (Nezis et al., 2019; Wolf et al., 2018). Though most of these outcomes can be multifactorial in origin, indoor air pollution has been presented as an important risk factor in the development of health detriments (Horemans and Van Grieken, 2010). Although much work has been developed on the characterization of environmental conditions in office buildings (Aizlewood and Dimitroulopoulou, 2006; Alomirah and Moda, 2020; Bluyssen et al., 1996; Faria et al., 2016; Hwang and Kim, 2013; Mandin et al., 2017; Qiu et al., 2020), IEQ in offices remains less documented when compared with other indoor settings such as homes and schools (Sérafin et al., 2020). In addition, there is an increasing need for further work to investigate the direct influence of indoor air towards the possible consequences for health, comfort, and productivity (Sundell, 2017). In fact, IEQ is recognized as a determining factor for office workers' productivity and decision-making capacity (Allen et al., 2016; Bartzis et al., 2013; Wargocki et al., 2000a). For instance, as related by Wyon (2004), poor indoor air quality (IAQ) is associated with office work performance reduction of 6–9% and with a decrease in the ability of workers to focus on work tasks. In a literature review, Al Horr et al. (2016) identified IEQ factors, such as thermal conditions, indoor air pollution, office layout, location, biophilia and views, that showing a link to occupant's comfort and productivity.

Intervention studies can offer new insights on the impact of specific environmental factors on occupants' outcomes and identify effective corrective measures (Kristensen, 2005). By concept, an intervention is an action that is implemented in order to determine the effect of its exposure on the natural course of the following events. Works studying the impact of an intervention are also known as experimental studies, and imply that the researchers actively intervene at some point of the investigation work, at the environmental and/or participants level, through the implementation of several possible study designs (Aggarwal and Ranganathan, 2019). In terms of causal evidence, these types of studies can achieve more conclusive results than observational works (Kristensen, 2005). Another strength of intervention studies is that these can provide evidence of the most effective changes for improvement in specific environments, including workplaces, while facilitating the communication of the research results to target populations and relevant decision-makers. Generally, mutual learning and successful collaborations can be particularly achieved between researchers and workplaces actors (building managers and participants). Evidence shows that interventions – including action for promoting improved ventilation rates and/or elimination of sources of air pollution, i.e., source control-based strategies – can play an important role in IEQ improvement (Kelly and Fussell, 2019). For offices, interventions at the IEQ level may promote productivity and reduce the risk for the occurrence of office environment-related health complaints among workers.

This work reviews the existing literature on studies that implemented environmental interventions in office settings and evaluate their effectiveness in reducing the prevalence of health, well-being, comfort, and productivity-related complaints among office workers. This paper will thus summarize and explore the potential of the intervention approaches to contribute to sustained healthy and safe environments for workers.

2. Materials and methods

2.1. Search strategy and screening

A systematic review was carried out according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Moher et al., 2009). Scopus, Web of Science, PubMed, and Cochrane Library electronic databases were used to search for records with the set of keywords defined in Table 1. Four groups of keywords were defined (A – local, B – study typology, C – target of intervention, D – workers' outcomes), and the search was performed for all possible combinations, using the Boolean operators "OR" and "AND" to link terms within each column and line, respectively. The search was performed within article title, abstract and keywords in Scopus and Cochrane Library (Trials); article title and abstract in PubMed; topic in Web of Science. The screening only included peer-reviewed articles published in journals, in the English language and on the topic of intervention studies carried out in offices. The first phase of research was performed without date limitation. Mendeley was the software used to import all records and remove duplicates. Studies to include in the review were selected after applying eligibility criteria and after checking associated references and authors' publications to identify additional relevant works within the subject. The last article search was carried out on April 12th, 2021.

2.2. Eligibility criteria

Full-text articles were assessed to meet the following eligibility criteria: (1) research articles; (2) articles entirely written in English; (3) research work performed in office settings; (4) articles reporting intervention studies; (5) interventions regarding indoor air/environmental conditions; (6) "in situ" measurements; (7) studies that included assessment of office workers (workers as research subject/target); (8) articles published after 2000. The last eligibility criterion was defined considering publications published from 2000 to present, considering the date of WHO publication "The right to healthy indoor air" (WHO, 2000), a document that acts as a framework to direct and global guide for healthy indoor environments, based on fundamental principles of human rights, biomedical ethics and ecological sustainability.

2.3. Data extraction

For each article selected for the qualitative analysis, a set of comprehensive data were extracted, using an Excel spreadsheet specially designed for that purpose that includes the following categories of information: country, research subject and objectives, building information, study design, intervention, trial extent, population, exclusion criteria, target and control sample, quantitative measures, questionnaire type and validation, ethics committee approval, main findings, limitations and detected biases. The risk of bias of individual studies was assessed for methodologies and outcomes, while potential confounders, publication bias and limitations were addressed as bias across studies. In cases where information was missing, study design was estimated based on characteristics of some typical intervention designs (Aggarwal and Ranganathan, 2019), i.e.:

i) Randomized controlled trials (RCT): the participants of the study are randomly allocated into two separate groups, in which one is the concurrent control group (no intervention). Thus, comparisons are made between data obtained from intervention and control groups;

Table 1
Groups of keywords that were considered for searching the studies.

A	B	C	D
Office	Intervention "Pilot study" Trial Crossover	"Indoor air" "Indoor environment" IAQ IEQ Ventilation "Air pollution" "Air purification" "Pollut* removal" "Nature-based solution"	Health Comfort Productivity Performance Well-being Perception

IAQ, Indoor Air Quality; IEQ, Indoor Environmental Quality.

ii) Non-RCT: are similar to RCT studies, but the procedure of the subject's allocation is not randomized;

iii) Pre-post studies: require that the assessments are performed before and after interventions using only one study group (no control group); the results are analyzed based on the temporal association between measurements and interventions;

iv) Factorial studies: when two or more interventions are applied simultaneously. In these studies, participants are randomized through the possible combinations of interventions. For instance, considering two interventions (2 × 2 factorial design), participants may be located in A intervention group alone, B intervention group alone, A and B groups (receiving both interventions) or neither A nor B groups (control);

v) Crossover studies: when two or more interventions are applied consecutively. The simplest model is AB/BA, it normally involves randomization and implies that study subjects cross between intervention arms, i.e., participants allocated in AB arm receive intervention A first and then intervention B, and vice versa in BA arm (Sibbald and Roberts, 1998). It is recurrent to consider a washout period between the "crossing of the arms" to reach baseline conditions before the second intervention. In this study design, the participants themselves serve as controls, as data is analyzed before and after the interventions for each study subject.

Two researchers were involved in this task. One researcher performed the revision of titles and abstracts and later of the full-text articles for eligibility, while a second researcher checked the data extraction process.

3. Results

In the identification phase, 513 records were obtained in Scopus (n = 244), Web of Science (n = 148), PubMed (n = 48) and Cochrane Library (n = 73) databases. Since no date restrictions were applied, the records date from 1977 to present (Scopus) and 1992 to present (Web of Science, PubMed, and Cochrane Library). Throughout the screening process, and according to the criteria established for the type of document and source, language and topic, 391 records were excluded. After removing duplicates, 59 articles remained. Additionally, 13 records were identified through other sources (references and other publications of the authors of the selected papers). Overall, 72 records were assessed for eligibility, resulting in 49 articles excluded for not complying with the eligibility criteria described in subsection 2.2. being the reasons for exclusion detailed in Table 2. Fig. 1 shows the results obtained for each phase of the selection process (identification, screening, eligibility and inclusion). This process identified 23 eligible research articles that were included in this review.

The main information extracted from the publications selected for further characterization of the intervention studies is summarized in Table 3 (organized by chronological order of publication). 12 of the intervention studies were published between 2000 and 2005, while the remaining 11 publications dated from 2010 to 2020. All studies implemented interventions aiming at improving IEQ in offices and assessed subjective and/or objective workers' outcomes to measure the effectiveness of the implemented intervention(s). As most of the studies aimed to evaluate the impact of interventions at the level of study participants, only a few authors presented detailed information on the office buildings subject to the intervention studies. According to the available information, the number of offices and buildings intervened ranged from 1 to 24 and from 1 to 6, respectively.

Regarding the interventions implemented in the offices, most of the selected experimental works (57%) included interventions focused on inducing changes at the level of heating, ventilation, and air conditioning (HVAC) systems that served the indoor spaces under investigation. The actions behind the interventions included replacement of air

Table 2
Number of records excluded by not complying with eligibility criteria and reasons.

Eligibility criteria	Reason for exclusion	N
Research articles	Conference papers	4
	Reviews	2
	Summary of experiments	1
	Technical notes	1
Articles entirely written in English	Article written in Chinese	1
Research work performed in office settings	Experiments carried out in transports	1
	Experiments carried out in test chambers	1
	Experiments carried out in homes	4
Articles reporting intervention studies	Case-control	4
	Cross-sectional studies	4
	Articles reporting tool developments	4
Interventions regarding indoor air/environmental conditions	Interventions focused in energy consumption and ambient CO_2 emissions	2
"In situ" measurements	Works of emission modelling, benefits estimation of filtration and hygrothermal simulations	3
Studies that included assessment of office workers	Articles exclusively assessing environmental conditions	3
Articles published after 2000	Articles published before 2000	14
		49

N, number of articles excluded.

filters, and adjustments in the rate of outdoor air supplied by the ventilation system and in the temperature set-points. Some studies also included interventions based on the installation of air cleaning tools (e.g., electrostatic air cleaners) and implementation of biophilic strategies through the introduction of natural elements indoors, including plants and furniture/building materials (e.g., wood) perceived as more natural than other materials. Study participants were mostly office employees, with 16 out of the 23 studies referring to recruitment of this target population group. In the other cases, adults including students, university staff and women (without specifying if they are office workers or not) collaborated with the research teams. In general, the sample size of the study participants was quite varied (from 7 to 771), with a reported higher participation rate for female subjects.

In the revised articles, a series of self-reported parameters were assessed to study the effect of the interventions, encompassing participant complaints and perceptions on the office environment and thermal comfort, SBS symptoms, emotional state, productivity and concentration capacity. These assessments were carried out by application of different questionnaire forms, with 8 out of the 22 studies including a questionnaire validation step, that typically involves a statistical process performed before the questionnaire administration to ensure that the survey items measure what is intended to be measured and to achieve reliable results as well (Field, 2003). Nevertheless, some of the authors used pre-existing and published questionnaires. Burnard and Kutnar (2020) recorded well-being through "WHO-5 wellbeing index questionnaire" (WHO, 1998) and Evensen et al. (2013) used the "Indoor Climate Work Environment Questionnaire MM040NA" (Andersson, 1998) to gather information on self-reported health and environmental complaints. In addition, Lakeridou et al. (2012) evaluated satisfaction and environmental attitudes employing the Building Use Studies (BUS) post-occupancy survey (BUS, 2017) and the New Ecological Paradigm (NEP) questionnaire (Dunlap et al., 2000), respectively. Some of the authors analyzed the effect of the interventions by performing objective assessments that constitute impartial approaches normally employing well-established diagnostic tools. Some of the studies resorted to physiological examinations, particularly of eyes, nose and skin, assessments of cardiovascular and pulmonary functions (as heart rate and pulmonary peak expiratory flow), and stress estimation by measuring salivary cortisol. Objective productivity records were obtained by conducting cognitive tests (to assess creativity, response time and attention), tasks performance (including text typing and proofreading) or estimations

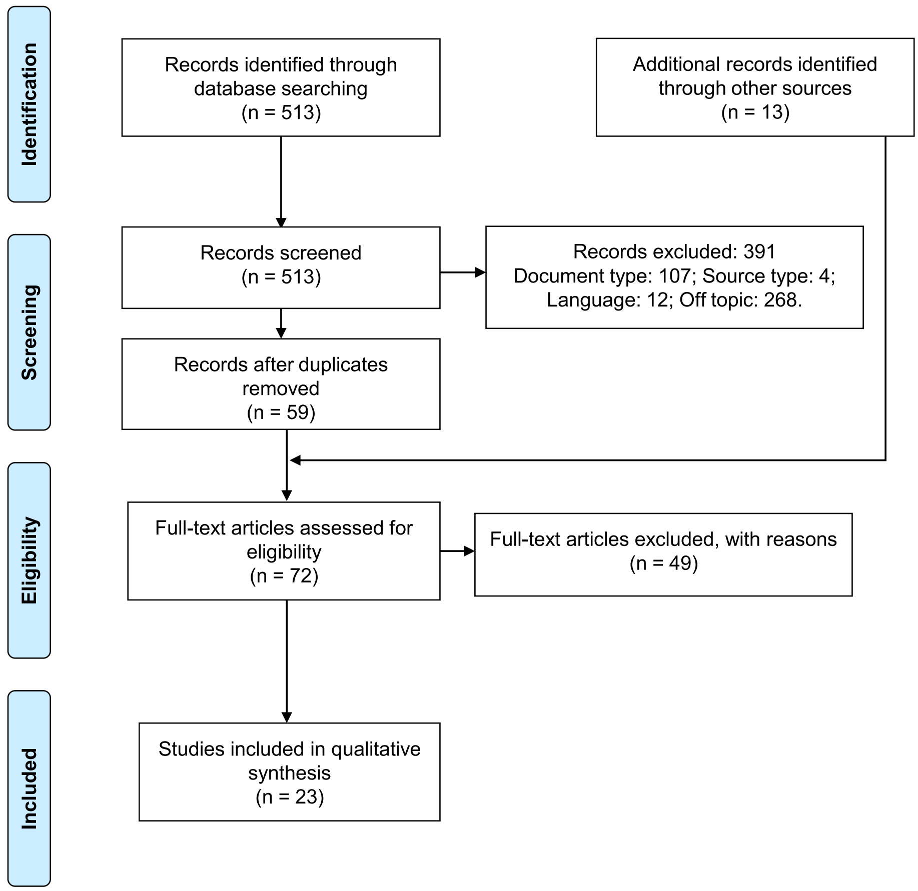

Fig. 1. PRISMA flow diagram (adapted from Moher et al. (2009)).

based on work outputs by working time and, in the case of call centers, mean talk-time (Wargocki et al., 2004).

Most of the reviewed studies (70%) reported the exclusive use of questionnaires, and one study (4%) was based only on clinical assessments. The remaining studies used a mixed approach employing both. Overall, the portion of studies reporting data from questionnaires and clinical examinations was 96% and 30%, respectively. Based on the information provided in the respective publications, ethical approval was obtained for all investigations with clinical assessments, except for the oldest study in this category (Pejtersen et al., 2001). Regarding the geographical distribution of the studies, the majority (67%) were carried out in Europe, mainly due to the contribution of works conducted in the Nordic countries, followed by America (25%) and Asia (8%). Studies of the same first author were found for Denmark (Wargocki et al., 2000b, 2004), Norway (Evensen et al., 2013, 2017; Skulberg et al., 2004, 2005) and the USA (Yin et al., 2018, 2019). Regarding the designs of the intervention study, crossover and pre-post studies were the most employed (8 and 7 out of the 23 included articles, respectively). In addition, among the sampled publications, 5 conducted RCT, 4 factorial and 1 non-RCT designs. In terms of quality assurance strategies considered in the study design, information on randomization and blinding of the interventions was also explored (Table 3). Although some of the included studies did not provide information about these study characteristics, the authors of 12 works report the use of a randomized approach and 10 blinded the participants with 4 of them also blinding the researchers (double blinding studies) for the intervention(s).

4. Discussion

4.1. Interventions for improving indoor air quality

4.1.1. HVAC component renovation and/or filter replacement

According to data collected in this review, ventilation systems (components, maintenance and settings) are a frequent target for designing environmental interventions that aim to improve well-being and health among office workers. In particular, the renovation of the HVAC system by exchange of ventilation ducts and cleaning and maintenance of all systems in a Brazilian office decreased the prevalence of self-reported respiratory symptoms such as naso-ocular symptoms and persistent cough among the occupants (Graudenz et al., 2004). Moreover, the installation of high-efficiency filters (non-specified filter with an estimated filtration of 95% for particles with a diameter of 0.3 μm) was linked to a better mental state and to a decrease of stuffy indoor air perception (Mendell et al., 2002). In fact, the use of high-efficiency filters was responsible for significantly reducing concentrations of small-size airborne particles ($PM_{0.3\text{-}0.5}$) by 94%, when compared to conventional filters. Wargocki et al. (2004) also investigated the replacement of filters (new vs. used – in place for 6 months) in addition to changes induced in the percentage of outdoor air supplied. The referred work emphasized the positive effects on health, comfort, and performance of replacing used filters for new ones while increasing rates of fresh air. Accordingly, the same research group found in other intervention study that an increase in the ventilation rate was associated with improvements in productivity, SBS symptoms and perception of air quality (Wargocki et al., 2000b). In a different study carried out in offices served by ventilation systems equipped with a F8 pre-filter, electrostatic precipitator (ESP) and high-efficiency particulate air (HEPA) filter, the temporary removal of either ESP alone or both ESP and of

Table 3
Summary characteristics of the 23 studies selected for the review.

Reference	Country	Year(s)[£]	Study design	Intervention (duration)	Study participants and characteristics	Assessment tools [¥]	Outcomes	Main findings reported by the authors
Wargocki et al. (2000b)	Denmark	1999	Crossover trial	Testing different ventilation rates: 3, 10 and 30 L/s per person (5 h in each condition – data collected during 5 weeks)	Women students n = 30 mean age: 23.5	Questionnaires	Perceived air quality, indoor climate, SBS symptoms, effort required to complete the tasks, thermal comfort and productivity	"Perceived air quality improved, the intensity of SBS symptoms decreased and productivity increased when the ventilation rate increased in a normal office with otherwise constant and neutral thermal, acoustic and visual conditions, subjects remaining thermally neutral. Overall productivity increased on average by 1.7% for every two-fold increase in the ventilation rate between 3 and 30 L/s per person." (p. 234)
Pejtersen et al. (2001)	Denmark	1996–1997	Pre–post study	Replacement of the carpet floor material for a low-emitting vinyl floor (with the renovation of the HVAC system, filters' change and set 100% outdoor air in both IG and CG) (14 months)	Office workers IG: Cellular offices n = 13 Open-plan offices n = 14 CG: Cellular offices n = 13 Open-plan offices n = 14	Questionnaires + Clinical assessments	Environmental and air quality perception, comfort and symptoms + Physiological examinations of eyes, nose (acoustic rhinometry) and lungs	"The occupants' complaints about thermal environment and air quality (…) together with the symptoms irritation in nose and throat, itchy hands, dizziness and concentration difficulties were significantly reduced by the intervention. (…) The positive effect of the intervention on occupants' self-reported perceptions and symptoms was not supported by the physiological measurements in the field." (p. 22)
Reinikainen and Jaakkola (2001)	Finland	1989	Crossover trial	Steam humidification of offices air (on average from 32.7 to 25.3%) (6 weeks)	Office workers Humidified period: n = 233 Non-humidified period: n = 230	Questionnaires	Symptoms of acute respiratory illness, dryness and the sensation of dryness	"Indoor temperature in excess of 21 °C or 22 °C is likely to increase dryness symptoms of the skin and upper airways and to increase the total number of symptoms than can be related to SBS syndrome. The sensation of dryness increased at higher indoor temperatures. Humidification alleviated dryness symptoms and the sensation of dryness." (p. 368)
Richardson et al. (2001)	United Kingdom	1998	Pre–post study	Use of an electrostatic air cleaning system to reduce fine particulate matter indoors (7 months)	Office workers n = 7	Questionnaires	Perception of IEQ - questions about IAQ parameters and symptoms usually related to poor IAQ – systemic, mucosal, dryness and the sensation of dryness	"The installation of an electrostatic air cleaning system reduced fine particulates by altering electrostatic forces within the office. This gave a reduction in PM_3 in addition to that achieved by the

(continued on next page)

Table 3 (*continued*)

Reference	Country	Year(s)[£]	Study design	Intervention (duration)	Study participants and characteristics	Assessment tools [¥]	Outcomes	Main findings reported by the authors
								existing optimized equipment. The MM-Questionnaire indicated a relationship between the perception of IAQ and the recorded changes in physical environmental factors. The reduction of fine particulates in the office did change the perceived IAQ." (p. 154)
Niemelä et al. (2002)	Finland	n.p.	Pre–post study*	Installation of cooling units to lowering the high temperature registered indoors in summer (4 months)	Office workers n = 15 (100% female)	Questionnaires	Productivity** and indoor climate questionnaires: sensations of indoor air factors, symptoms related to the indoor air and the psychosocial environment of the workplace	"The productivity increase was 7% higher after the intervention. The finding is statistically significant." (p. 763)
Mendell et al. (2002)	United States of America	1996	Crossover trial	Replacement of standard particle filters by highly efficient filters on alternate floors, in separate ventilation systems on two floors (4 weeks)	Office workers n = 396 (60% female)	Questionnaires	Symptoms, performance-related mental states, aspects of environmental dissatisfaction and perceived environmental changes	"Enhanced filtration reduced concentrations of the smallest airborne particles by 94%. This reduction was not associated with reduced symptoms among the 396 respondents, but three performance-related mental states improved; for example, the confusion scale decreased. Most environmental dissatisfaction variables also improved. Cooler temperatures within the recommended comfort were associated with remarkably large improvement outcomes." (p. 296)
Menzies et al. (2003)	Canada	1999–2000	Crossover trial	Installation of UV germicidal lights in office ventilation systems (48 weeks)	Office workers n = 771 mean age: 43.1 (60% female)	Questionnaires	Systemic, mucosal, respiratory and musculoskeletal symptoms	"Use of ultraviolet germicidal lights was associated with significantly fewer work-related symptoms overall, as well as respiratory and mucosal symptoms than was non-use." (p. 1785)
Graudenz et al. (2004)	Brazil	2001–2002	Pre–post study	Renovation of the HVAC system: exchanging the ventilation ducts and cleaning and maintenance of the ventilation machinery (14 months)	Office workers n = 18	Questionnaires	Atopy, smoking status, respiratory symptoms, diagnosis of previous asthma or rhinitis, and work relation of the respiratory symptoms	"The prevalence of most building-related symptoms decreased substantially after the renovation of the air conditioning, and the respiratory complaints dropped to control levels. (…)Our results are in agreement with the concept that "cleanliness is next to healthiness,"

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Table 3 (*continued*)

Reference	Country	Year(s)[£]	Study design	Intervention (duration)	Study participants and characteristics	Assessment tools [¥]	Outcomes	Main findings reported by the authors
								specifically of the upper airways in this context." (p. 328)
Skulberg et al. (2004)	Norway	1998	RCT	Comprehensive cleaning of all surfaces in offices (vacuum-cleaning of the carpets using a canister with a rotating brush head that had an ordinary bag filter and micro filter, and cleaning of all walls, the ceiling, desks, bookshelves, and windows) (3 months)	Office workers IG: n = 56 92% ≥ 30 years-old (37% female) CG: n = 62 91% ≥ 30 years-old (38% female)	Questionnaires + Clinical assessments	Mucosal irritation symptoms + Nasal congestion (acoustic rhinometry) and screening allergy	"The intervention group reported a reduction in mucosal irritation complaints compared with no change in the control group. (…) Nasal congestion, measured by acoustic rhinometry, was also reduced in the intervention group. This experimental field trial shows that comprehensive cleaning reduces the airborne dust in offices, and also can reduce mucosal symptoms and nasal congestion." (p. 71)
Tham (2004)	Singapore	2003	Factorial 2 × 2 mixed design	Experimental plan for two levels of outdoor air supply rates (5 l/s/p and 10 l/s/p) at two temperature settings (22.5 °C and 24.5 °C) (9 weeks)	Office workers (call center operators) n = 56 mean age: 28 (100% female)	Questionnaires	Perception of the IEQ conditions and SBS symptoms: evaluation of thermal comfort, acceptability of IAQ, perceived odor level, irritation effects, perceived air warmness, stuffiness, and dryness, eye-, thermal-related and neurobehavioral symptoms and performance**	"Talk time was reduced significantly when the outdoor air supply rate was increased from 5 l/s/p to 10 l/s/p at 24.5 °C; this may be associated with the significant reduction in a principal component factor which includes intensity of dryness, aching eyes and nose-related symptoms. Decreasing the temperature from 24.5 °C to 22.5 °C at 10 l/s/p significantly increased talk time. Analysis of the principal component factor based on the neurobehavioral symptoms also revealed that temperature reduction led to an increased mean factor score of these symptoms." (p. 119)
Wargocki et al. (2004)	Denmark	2001	Factorial 2 × 2 mixed design	Experimental plan for two supply air filters (new and used) and two outdoor air supply rates (8% and 80%) (8 weeks)	Office workers (call center operators) n = 26	Questionnaires	Perceived air quality, environmental perceptions, SBS symptom intensity and productivity**	"Positive effects on some SBS symptoms and on some perceptions of the indoor environment were observed when outdoor air supply rates were increased with new supply air filters in place, and when used filters were replaced with new ones at the high outdoor air supply rate. Increasing outdoor air supply rate with a new filter in

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Table 3 (*continued*)

Reference	Country	Year(s)[£]	Study design	Intervention (duration)	Study participants and characteristics	Assessment tools [¥]	Outcomes	Main findings reported by the authors
								place improved operator performance, reducing talk-time by 6%; with a used filter in place, increasing the outdoor air supply rate reduced their performance, increasing talk-time by 8%. Replacing a used filter with a clean one improved operator performance at the high outdoor air supply rate, reducing average talk-time by about 10%, but it had no significant effect on operator performance at the low outdoor air supply rate." (p. 15)
Skulberg et al. (2005)	Norway	n.p.	RCT	Use of electrostatic air cleaner (6 weeks)	Office workers with airways symptoms IG: n = 41 92% ≥ 30 years-old (57% female) CG: n = 39 91% ≥ 30 years-old (51% female)	Questionnaires + Clinical assessments	General, skin and mucosal symptoms + nasal congestion (acoustic rhinometry) and pulmonary PEF	"Three of four indicators of nasal congestion were decreased in the intervention group, but the changes were small. PEF measurements showed a slight increase in the intervention group, compared with a small decrease in controls. Using multivariate analysis, there was a statistically significant increase in PEF-values in the intervention group compared with the control group." (pp. 158–159)
Kekäläinen et al. (2010)	Finland	n.p.	Pre–post study	Renovation of the HVAC system: cooling supply air for reduction of the high summertime indoor temperatures (3 months)	Office workers Before intervention: n = 118 After intervention: n = 133	Questionnaires	Symptoms, IEQ perception and productivity**	"After a major renovation, the percentage of subjects dissatisfied with the indoor temperature and indoor air quality, and those working below their average work efficiency, decreased statistically significantly. The prevalence of both neurobehavioural and irritation symptoms were also statistically significantly reduced. Objective productivity measurements showed a 4.4% improvement in summertime productivity." (pp. 264–265)
Raanaas et al. (2011)	Norway	2008–2009	RCT	The between-subjects variable was the presence or absence of plants (60 min – data collected during 5 months)	Students IG: n = 18 (72% female) CG: n = 16 (56% female)	Questionnaires	Attention capacity**	"Participants in the plant condition improved their performance from time one to two, whereas this was not the case in the no-plant condition. Neither group improved performance from time two to three.

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Table 3 (*continued*)

Reference	Country	Year(s)£	Study design	Intervention (duration)	Study participants and characteristics	Assessment tools ¥	Outcomes	Main findings reported by the authors
								The present study confirms that natural elements can affect cognitive performance in an office work environment." (p. 99)
Lakeridou et al. (2012)	United Kingdom	2010	Pre–post study	Increase current cooling set-points: +2 °C from the usual set-point, bringing the overall floor set-point to 24 °C (2 weeks)	Office workers IG: n = 71 69% ≥ 30 years-old (52% female) CG: n = 58 57% ≥ 30 years-old (64% female)	Questionnaires	Comfort, satisfaction and occupants' environmental attitudes	"Increasing the set-point temperature led to the occupants feeling significantly warmer in comparison with the group at lower temperature settings. Nevertheless, this did not affect the self-reported thermal comfort of the occupants in the intervention group, as depicted by an insignificant difference between the two groups. It was also observed that there is a positive correlation between the occupants' tolerance of higher indoor air temperatures and their environmental attitudes." (p. 338)
Evensen et al. (2013)	Norway	2010–2011	Non-RCT	Installation of foliage plants and full-spectrum fluorescent lighting at the individual workstations (1 year)	Office workers IG: n = 8 mean age: 49.4 (50% female) CG: n = 7 mean age: 43.6 (57% female)	Questionnaires	Health and environmental complaints	"The intervention group maintained a lower level of reported environmental complaints even during the following winter, while the control group followed the expected pattern with more complaints during the following winter. (…) Despite the report of health and environmental complaints followed the same seasonal pattern, there was no significant correlation between the reduction in health and environmental complaints." (p. 75)
Nieuwenhuis et al. (2014)	United Kingdom and The Netherlands	n.p.	Study 1: Factorial 2 × 2 mixed design* Study 2: Factorial 2 × 3 mixed design*	Introduction of living plants Study 1 and 2: longitudinal field experiments (11 weeks and 3.5 months, respectively)	Office workers Study 1: n = 67 mean age: 30 (42% female) Study 2: n = 81 mean age: 35 (81% female)	Questionnaires	Study 1: Workplace satisfaction, concentration, air quality and subjective productivity Study 2: Workplace satisfaction, concentration, air quality and disengagement, productivity**	"A consistent pattern emerged whereby workers in green workspaces had a more positive orientation to their work environment and to their work than those in lean workspaces. (…) These improvements were sustained over both the short-term (Study 1) and the long-term (Study 2). Significant interactions were also found on four of six occasions. Crucially, enriching space also

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Table 3 (*continued*)

Reference	Country	Year(s)[£]	Study design	Intervention (duration)	Study participants and characteristics	Assessment tools [¥]	Outcomes	Main findings reported by the authors
								improved perceived productivity in Study 1 and actual productivity in Study 3." (p. 210)
Evensen et al. (2017)	Norway	n.p.	Study 1: RCT Study 2: Crossover trial	Exposure to 3 different interiors: one with plants (A), one with inanimate objects (B), and one with no added objects – control (C). Study 1: on-site assessment (1 day) Study 2: photo-based assessment (1 h)	Students Study 1: n = 56 (A:20, B:17, C:19) age range: 18–26 (82% female) Study 2: n = 46 (A:10, B:17, C:19) mean age: 22.9 (80% female)	Questionnaires	Open and semantic environmental description, perceived restorativeness scale and emotional response to the environment	"Indoor setting with plants was assessed more favorably than the setting without added objects. In the photo-based assessment, the presence of plants led to the setting being perceived as more fascinating than the control interior. The interior with plants produced the most positive emotional response, tapping into states of activation and orientation relevant to work productivity; it was also the preferred work environment." (pp. 143–144)
Day et al. (2018)	China	2014–2015	Pre–post study	Removal from the 3-part (F8- ESP- HEPA) air-handling system of either both ESP and HEPA filters (A) or ESP alone (B) (5 weeks)	Office workers A: n = 34 mean age: 31.7 (27% female) B: n = 52 mean age: 31.5 (31% female)	Clinical assessments	Pulmonary and cardiovascular function and pathophysiologic biomarkers	"No biomarkers were significantly associated with HEPA filter removal. In contrast, ESP removal (…) suggests reduced cardiovascular risks." (p. 360)
Richardson et al. (2018)	United States of America	2015	Crossover trial	Changes in thermoregulation environment at 2 conditions: thermoneutral/ control: 19 °C–20 °C) and warmer/ experimental: 26 °C–27 °C) (7 h in each condition – data collected during 6 months)	Women IG: n = 12 mean age: 23.8 CG: n = 13 mean age: 23.9	Questionnaires	Thermal comfort and productivity	"96% of the participants in the warm condition reported being comfortable compared with 32% in the control condition. More participants reported being as productive or more productive than usual in the warm condition than in the control condition." (p. 1826)
Yin et al. (2018)	United States of America	2017	Crossover trial	Biophilic interventions: physical exposure (plants, bamboo floor and external views of green space and a river) and virtual exposure (virtual reality) (1 h per experiment, - data collected during 2 months)	Adults n = 28 mean age: 26 (56% female)	Questionnaires + Clinical assessments	Emotion changes and cognitive tests (reaction time and creativity) + Physiological measures: blood pressure, heart rate, heart rate variability, and skin conductance level	"We found that even short exposure to a biophilic indoor environment was associated with lower systolic and diastolic blood pressure and skin conductance level in comparison to their baseline measures. In addition, participants in biophilic environment had 14% better performance in short-term memory and improved emotions compare to their performance in the non-biophilic environment. (…) Moreover, our findings indicate that participants could gain the similar acute

(continued on next page)

Table 3 (*continued*)

Reference	Country	Year(s)[£]	Study design	Intervention (duration)	Study participants and characteristics	Assessment tools [¥]	Outcomes	Main findings reported by the authors
								physiological and cognitive benefits of exposing to virtual biophilic indoor environment." (p. 262)
Yin et al. (2019)	United States of America	2018	Crossover trial	Biophilic interventions: 3 versions of designs in simulated open and enclosed office spaces in virtual reality (natural elements, natural analogues and combination of both) (80 min per experiment)	Students and staff n = 30 mean age: 26.3 (73% female)	Questionnaires + Clinical assessments	Cognitive tests (reaction time and creativity) + Physiological measures: blood pressure, heart rate, heart rate variability, and skin conductance level and eye-tracking (foveal attention)	"Participants in three spaces with biophilic elements had consistently lower level of physiological stress indicators and higher creativity scores. Biophilic interventions could help reduce stress and improve creativity. Moreover, those effects are related to both the types of biophilic elements and may be different based on the workspace type (open vs enclosed)." (p. 1028)
Burnard and Kutnar (2020)	Slovenia	n.p.	RCT	Two different furniture materials (oak and walnut) and control environment without wooden elements (75 min)	Healthy adults n = 61 mean age: 27.7 (77% female)	Questionnaires + Clinical assessments	Well-being + heart rate, salivary cortisol as an unobtrusive measure of stress	"Stress levels throughout the entire period and during the response period were significantly lower in the oak environment than in the control environment, but no differences were detected in the magnitude of the stress response or in the degree of recovery from it. No significant differences were detected for any tested response or recovery between the walnut environment and the control environment." (p. 328)

CG, control group; ESP, electrostatic precipitators; HEPA, high-efficiency particulate air; HVAC, heating, ventilation, and air conditioning; IAQ, indoor air quality; IEQ, indoor environmental quality; IG, intervention group; n.p., not provided; PEF, peak expiratory flow; PM, particulate matter; RCT, randomized controlled trial; SBS, sick building syndrome; UV, ultraviolet.

£ Year of the implementation of the intervention(s).

¥ The category was defined according to the tools used to measure the workers' outcomes: questionnaires, clinical assessments, and questionnaires plus clinical assessments.

*In addition to the intervention study(ies) an observational study was also conducted.

**Objective measures were also considered.

HEPA filters were the interventions induced to evaluate effects on cardiorespiratory health of office workers (Day et al., 2018). Among the subset of studies selected for this review, this was the only assessment of the effectiveness of interventions exclusively based on data from clinical evaluations. The exclusion of ESP alone was linked with a decrease of cardiovascular risks based on the assessments for blood pressure and thrombosis markers (plasma sCD62P and von *Willebrand factor (VWF))*, which according to the authors was possibly related to the reduction of ozone concentrations, a substance that may be generated by ESP. Although some associations between ESP removal and health detriments (adverse change in VWF for endothelial cell dysfunction) were also obtained, the respective results appeared to be weaker when compared to the health-related benefits of the intervention (ESP removal). The same study found that the removal of both ESP and HEPA filters did not cause significant changes in the levels of the several biomarkers of cardiorespiratory pathophysiology evaluated. In fact, environmental data concurrently collected showed that although $PM_{2.5}$ concentrations were found to be above the WHO global air quality guideline for a 24hr-period (15 μg/m^3 (WHO, 2021);) both before and after the intervention, the removal of HEPA filters from the ventilation systems resulted in the deterioration of IAQ conditions causing an increase of daily mean levels of $PM_{2.5}$ in about 47%.

4.1.2. *Installation of air cleaners or components for air disinfection*

To minimize airborne particle concentrations in office environments, Richardson et al. (2001) installed free standing electrostatic air cleaning system, based on the principle that electrostatically charged particles have limited circulation. As expected, the changing of electrostatic forces led to substantially diluted indoor particulate matter levels while data from questionnaires demonstrated that workers reported more positive perceptions in relation to indoor air. Nevertheless, since this kind of device can have ozone as a by-product (Guo et al., 2019), the findings from Day et al. (2018) presented above suggest that study designs including more objective measures may be more appropriate to assess health detriments in office workers. In this context, another study that installed electrostatic air cleaners in Norwegian offices where participants reported symptoms from upper or lower airways, considered inclusion of carbon filters in the intervention plan, in order to eliminate ozone levels produced by the air cleaners (Skulberg et al., 2005). Based on self-reported complaints, irritation (nose, throat, eyes or cough) and general symptoms (fatigue, heavy-headed, headache, nausea or concentration capacity problem) had a reduction in both intervention (air cleaners with an active electrostatic filter + carbon filters) and control groups (air cleaners with an inactive electrostatic filter + carbon filters), with no improvement being detected for the intervention arm comparing with the control group. However, results from clinical evaluations showed a small decrease in the prevalence of nasal congestion and a general improvement of respiratory health – according to the obtained pulmonary peak expiratory flow results – for the intervention groups.

Although ozone concentration was not monitored, the installation of electrostatic air cleaners in offices presented promissory results in reducing particulate matter levels in indoor air. For instance, Skulberg et al. (2005) observed a decrease of the concentrations of all particle size-fractions (<5 μm, 5–10 μm and >10 μm) by 46% in the intervention group, in contrast to the 18% of reduction observed for the control group (air cleaners with non-functioning electrostatic unit). Moreover, Richardson et al. (2001) showed that the optimization of existing air processing equipment combined with electrostatic forces created by air cleaners could reduce particle levels from outdoors to office environments by 40% (PM_3) and 70% (PM_7). In fact, it is currently known the effectiveness of air purification technologies in indoor pollution load reduction (Kelly and Fussell, 2019). These results are particularly relevant in the context of the COVID-19 pandemic, with air cleaning solutions explored as technological tools for reducing the risk of transmission of SARS-CoV-2. The spread of COVID-19 is described as mainly occurring within buildings (Pease et al., 2021), with the airborne transmission of SARS-CoV-2 through aerosol particles recognized as one of the main pathways of infection (WHO, 2020). In this regard, studies have investigated the potential of air purifiers in reducing airborne transmission of SARS-CoV-2 in indoor environments (Curtius et al., 2021; Dbouk et al., 2021; Zhai et al., 2021). The results from emerging research suggest that air purifiers, mainly those using HEPA filters and pre-filters to eliminate coarse particles, can be a promising complementary strategy for the reduction of the risk of airborne transmission of the virus.

Air disinfection was also studied in an intervention aiming at controlling microbial indoor air pollution in a crossover study through the installation of ultraviolet germicidal lights in the ventilation systems (Menzies et al., 2003). The use of ultraviolet germicidal lights resulted in an improvement of subjective respiratory and mucosal symptoms reported by the office workers, while reducing 99% of fungi, bacteria and endotoxin levels on exposed surfaces.

4.1.3. Intervention studies based on cleaning procedures and changes in the flooring material

Cleaning procedures are essential for the correct hygiene of spaces, and in particular for the control of indoor air pollutants, also related to flooring (Black and Mcintosh, 2011). In this context, Skulberg et al. (2004) implemented a comprehensive cleaning strategy in offices: carpets were vacuumed using a device with a microfilter – filtration efficiency of 99.98% for particles larger than 0.3 μm in diameter – and cleaning of walls, ceiling, desks, bookshelves and windows, finding a decrease of subjective and objective indicators of mucosal irritation, as well symptoms of nasal congestion. This intervention achieved a decrease in the airborne dust levels of 17 μg/m^3 (67 μg/m^3 before and 50 μg/m^3 after intervention), that was related to a consequent reduction of the worker' symptoms.

Pejtersen et al. (2001) concluded that a renovation of the HVAC system, change of filters and setting 100% outdoor air in tandem with other measured such as the replacement of carpet flooring material with a low-emitting vinyl floor positively impacted subjective measures of environmental perceptions (thermal environment, IAQ, noise and light) and sensory irritation in eye, nose and throat, skin irritation, neurotoxic and asthma-like symptoms; however, the clinical examinations (such as acoustic rhinometry, tear film stability and conjunctival epithelium damage) found no significant relations. Though, since the change of filters and setting 100% outdoor air affected both intervention and control groups, the interpretation of results can only be made for the effect of the replacement of the flooring material. In fact, carpets are well recognized indoor sources of volatile organic compounds (VOC) in modern offices (Campagnolo et al., 2017) and the results of Pejtersen et al. (2001) could be associated with the general reduction of VOC concentrations after the intervention. Moreover, carpets can also be a matrix for microbial agents' growth and proliferation. A recent study conducted in bedrooms of infant twins detected statistically significant higher levels of airborne fungi in rooms with small carpets than in rooms without small carpets (Felgueiras et al., 2022). Thus, the work of Pejtersen et al. (2001) would also benefit from an assessment of pollutant levels (as VOCs and microbiologicals) before and after the change of the flooring material to accurately assess the potential of the implemented intervention in promoting better IAQ conditions.

4.2. Interventions for improving thermal comfort/hygrothermal conditions

4.2.1. Air temperature adjustments

Thermal comfort in offices is an important parameter that may affect workers' performance and health (Wolkoff et al., 2021). In regions with temperate or cold climates, indoor temperatures ranging from 22 °C to 24 °C have been reported as ideal for promoting good indexes of productivity. For the heating season, indoor temperatures below 18 °C have been linked with an increase in risk of developing cardiovascular and respiratory outcomes. In turn, temperatures above 26 °C can aggravate acute symptoms such as fatigue and low concentration. Respiratory health may also be particularly affected when values are above 30 °C (Wolkoff et al., 2021). In terms of thermal comfort, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) provided guidelines for indoor air temperature that should range approximately around 20 and 27 °C (ASHRAE, 2017). Additionally, although in the context of IAQ, the Occupational Safety and Health Administration (OSHA) recommends that air temperature in offices should be maintained within the range 20–24 °C (OSHA, n.d.). Following those considerations, some intervention studies related to temperature regulation were also included in the review. According to the findings of the study conducted by Tham (2004) in a call center located in Singapore with indoor temperature of 24.5 °C, adjusting outdoor air supply rates from 5 to 10 l/s/person can significantly reduce the talk time duration of call center operators, which has been used as a relevant indicator of workers' performance for this kind of activity. Furthermore, an intervention based on maintaining the same ventilation rate (10 l/s/person) but reducing indoor air temperature (from 24.5 to 22.5 °C), resulted in a decreased productivity (increased talk time) among workers. Although this intervention was based on a temperature set-point (22.5 °C) that is commonly defined in office buildings located in tropical climates, the fact that the intervention caused a higher difference between indoor temperature and the typical outdoor temperatures (that may be substantially higher than indoors) are likely to explain the reported findings. Two studies performed in different climatic zone, in Finland, investigated the impact of reducing the high indoor temperatures observed during summer (mean of 25.1 °C) on worker's productivity, symptoms and indoor environment perceptions, through the installation of cooling units in ventilation systems or cooling ceilings in offices (Kekäläinen et al., 2010; Niemelä et al., 2002). Niemelä et al. (2002) found a 7% increase in productivity after the intervention that caused a reduction of mean air temperature from 25.1 to 22.6 °C in the offices. The intervention study carried out by Kekäläinen et al. (2010) achieved a mean temperature of 23.9 °C that resulted in a significant reduction of dissatisfaction rate related to indoor temperature and IAQ perception among office workers, and on the prevalence of neurobehavioral (especially fatigue) and irritation (dry throat and cough) symptoms. In line with the results obtained by Niemelä et al. (2002), productivity also increased by 4.4% (Kekäläinen et al., 2010). In a different study conducted in offices located in the mid-western US (hot summer region), in which standard particle filters were replaced by highly efficient filters on alternate floors (also referred in section 4.1.1.), it was also observed that for every 1 °C decrease of temperature within the recommended range (22.2–25.6 °C) a decrease of chest tightness was observed (Mendell et al., 2002). Though in the study of Richardson et al. (2018), carried out in simulated offices located in the USA, where women were exposure to thermoneutral conditions (control, 19–20 °C) and to conditions above the thermoneutral zone (intervention, 26–27 °C), participants described to be more comfortable and productive in warmer than in lower temperature control conditions. Some peculiarities of this work, namely the fact that the study was focused on food intake variables, involved a particular population of young females, and short-term experiments (7 h for each condition while other studies lasted for a longer period of time) and the low temperatures used in the control conditions are likely to have influenced the results. In another study, Lakeridou et al. (2012) increased the indoor air temperature set-points in UK offices during the warm season from 22 °C to 24 °C (change in the thermostat of each floor) and, although office workers described a warmer environment, self-reported comfort and satisfaction didn't show remarkable changes.

4.2.2. Changes induced on air humidification levels

In addition to interventions related to indoor temperature settings, the works selected for this review included the study of Reinikainen and Jaakkola (2001) that investigated the effect of steam humidification on air dryness of Finnish offices (during January and February). Results showed that both dryness and SBS symptoms were aggravated in non-humidified conditions (on average 25.3% of relative humidity). The values of humidity were within the recommended range of 20–60% stated for office environments by OSHA in the IAQ context (OSHA, n.d.). The most recent ASHRAE recommendations stated that relative humidity levels in occupied spaces should be kept less than 65% in order to control microbial growth (ASHRAE, 2016), however no lower limit is defined. Nevertheless, studies have demonstrated an association between the risk of development of adverse health effects and the exposure to relative humidity levels lower than 30% (Wolkoff, 2018). Particularly for office environments, recent findings show that workers who spend the majority of time in relative humidity conditions between 30 and 60% were 25% less stressed than workers in drier conditions (Razjouyan et al., 2020). Thus, and according to the findings of Reinikainen and Jaakkola (2001), low relative humidity percentages should be avoided to protect human health.

4.3. Biophilic interventions

4.3.1. Introduction of natural elements

In order to assess self-reported symptoms, environmental perceptions and emotional responses, some studies addressed biophilic interventions in office spaces (Evensen et al., 2013, 2017; Nieuwenhuis et al., 2014). Evensen et al. (2013) included foliage plants and full-spectrum lights (to simulate daylight) in offices. One year after the intervention, a reduction in health complaints, including neuropsychological and mucous membrane symptoms and skin irritation problems, was observed. This study was conducted in Norway mostly during the winter seasons, when the number of daylight hours is very low, ranging from 6 to 8hr. In fact, the simulation of daylight in Nordic countries is recommended for offices during the dark season. Thus, this type of study is important to dilute seasonal variation in self-perceived health and well-being, while contributing to reduction in health complaints during the dark winter season. The same author, in a more recent study, also explored how natural elements are experienced by the workers by performing assessments in real offices and through photo-based experiments (panoramic photos presented to the participants in a sound and light proof theater) to examine emotional responses and environmental descriptions (Evensen et al., 2017). The results demonstrated that settings with plants, showing more positive emotional responses (tapping into states of activation and orientation relevant to work productivity favorable to work productivity), were considered the preferred workplaces. In addition, in the photo-based assessment, office settings with plants were perceived as more fascinating than the control. Nieuwenhuis et al. (2014) reached very similar conclusions in short and long-term studies, referring that "green" offices (with plants) were found to be more enjoyable and to make the workers more positively oriented to work than offices without natural elements. Changes in the attention capacity of office workers through biophilic office environments were also explored by Raanaas et al. (2011). Participants were requested to execute reading tasks, to obtain a more objective measure for the cognitive assessment. Findings showed a performance improvement between baseline (immediately after participants entering the room) and 15 min of tasks completed, which suggested a beneficial effect of the existence of plants in the cognitive performance of the study office workers. In this category, two research articles also included interventions based on the use of virtual reality (Yin et al., 2018, 2019). The work of Yin et al. (2018) combined exposure in real office environments and in virtual reality. Participants demonstrated a decrease in blood pressure and an increase in positive emotions and performance when experiencing both types of biophilic interventions. Further, subjects' physiological and cognitive responses were alike for real and virtual offices. A year later, the same authors carried out an additional study employing interventions resorting exclusively to virtual reality (Yin et al., 2019). Results showed an improvement in participants' creativity and reduction of stress for virtual "green" settings. However, as described by the authors, the magnitude of the results is likely to differ according to the office typology, i.e., open and enclosed offices; for instance, the observation of reduced stress in workers, measured by indicators of blood pressure, heart rate, heart rate variability and skin conductance, was more evident in open spaces and creativity development was particularly promoted in enclosed spaces.

4.3.2. Exposure to distinct furniture materials

Using objective measures, one of the intervention studies examined the effect of exposing participants to office environments with different furniture materials (oak and walnut wood) (Burnard and Kutnar, 2020). The main parameters evaluated in the study were related to well-being status, assessed with the WHO-5 wellbeing index questionnaire (WHO, 1998), and stress, using salivary free cortisol concentration as the indicator. The results indicated that the workers in environments with oak wooden furniture presented lower stress levels than the control group (offices without wooden elements) whereas recovery from stress (assessed as the difference between the maximum cortisol level registered at minutes 35, 45, 60 and 75 and the obtained cortisol level at minute 75) was similar between participants in oak and walnut environments. Regarding the results from the questionnaire, no significant differences were found for well-being within-subjects.

4.4. Bias risk

Factors related to the characteristics of the employed study design that can contribute to risk of bias in the reported data were identified at intra-study. In particular, the small sample size (both in terms of the number of participants and buildings/indoor spaces) disclosed by some authors (Evensen et al., 2013; Mendell et al., 2002; Nieuwenhuis et al., 2014; Richardson et al., 2018) can be a limitation affecting the representativeness of the results, and the validation of some of the statistical analyses conducted. In addition, study designs that did not consider the randomized allocation of subjects within groups and the blinding of the participants for interventions can also represent a declared source of bias. As example, office workers who are aware of a renovation of the HVAC system are expected to be positively affected (psychologically) by this type of intervention (Graudenz et al., 2004). However, it is important to recognize that not all interventions can be masked. An example of interventions that are easily visually identified is the introduction of plants in the rooms as discussed by Yin et al. (2018). Additionally, some interventions may be difficult to implement due to occupants' complaints. For instance, in the work of Lakeridou et al. (2012), temperatures were changed back and intervention was limited to only 2 days. In fact, the short duration of interventions is also recognized as a study limitation by some of the authors (Lakeridou et al., 2012; Wargocki et al., 2000b). Long-term interventions are important to accurately validate the study hypotheses based on robust results and to reduce collateral effects of other potential limitations such as not blinding studies (Evensen et al., 2013; Kelly and Fussell, 2019). In addition, defining well-established baseline/control conditions is crucial to properly understand the impact of environmental interventions. In this regard, as example, low baseline air contaminants levels, such as microbial (Menzies et al., 2003) and particulate matter (Mendell et al., 2002) contamination may limit the assessment of the potential benefits resulting from interventions based on strategies to reduce air pollution. Moreover, some authors refer the lack of baseline measurements, including baseline filtration conditions for intervention studies inducing changes in the ventilation systems (Day et al., 2018). Quantification of indicators for workers' outcomes should also be performed before the implementation of interventions, since a learning effect can occur (for instance, in the case of cognitive tests) which can be eliminated with baseline information, as disclosed by Yin et al. (2019). It is also important to have in mind that workers' outcomes are multifactorial in origin and, therefore, other contributing factors can affect the results.

For the sample of studies selected for this review, comprehensive inter-study evaluation is difficult to conduct due to the substantial differences in the characteristics of the study designs, even for studies employing similar interventions. Some substantial differences were identified, such as participant's characteristics, mainly regarding the heterogeneity of populations investigated and, consequently, the different ages of the groups, as well the sample size. Additional factors of heterogeneity included climatic and geographic peculiarities, insufficient details in the definition of criteria for the interventions, timing and duration of the intervention period.

Moreover, in accordance with the eligibility criteria defined for this review, only research papers published in the selected databases were considered, which can be a source of publication bias. The selection of research articles written in the English language also consist in a study limitation.

Finally, it is also important to disclose that putative detrimental impacts of environmental interventions were not covered in this review. However, the implementation of environmental interventions might have collateral non-desirable effects that should be, ideally, controlled along with the beneficial effects. One example that was briefly mentioned in this work is the installation of some air purification technologies that are effective in decreasing the levels of airborne particles and biocontaminants but that can also generate harmful byproducts (e.g., ozone), and exert collateral adverse effects on health. As another example, an intervention involving the installation of a more effective air conditioner and/or ventilation system can improve thermal comfort and health but can eventually produce undesirable noise that can affect working activities. Thus, it is of major importance that intervention plans (employed for real-life or research purposes) are carefully designed to assess both the beneficial and negative impacts of implemented corrective measures.

5. Conclusion

This review provides evidence that environmental interventions in offices can significantly induce positive effects on office workers' health, comfort, and productivity. In terms of indoor pollution load, environmental interventions based on strategies to reduce air pollutant levels, in particular the use of high-efficiency filters for reducing air levels particles and of ultraviolet germicidal lights to avoid microbial contaminants were linked to positive effects on health, comfort, and performance. Although some promissory findings were presented, the installation of cleaning solutions based on electrostatic forces were the interventions with less conclusive results. Findings presented in this review also show that adjustments in indoor temperatures set points should be explored at regional level, considering the local climate and occupants characteristics, to maximize the effects on office workers satisfaction and productivity, and the reduction in irritation symptoms at work. Regardless of the type of outcome assessed, a decrease in office workers' health symptoms and an increase in performance levels can be achieved through the implementation of specific biophilic designs, and with the improvement of filtration conditions of ventilation systems. In fact, green working environments seemed to be the preferred workplace promoting higher indexes of creativity and concentration capacity and lower stress levels, when compared with offices without natural elements.

The main practical recommendations to office building managers in order to promote health, well-being and productivity at workplaces are the following:

- Include in their routine office building management plan the control of a comprehensive panel of IEQ parameters (including both comfort, ventilation and air pollution indicators) in order to verify the compliance with the exposure limit values defined by local, national, or international regulations. This plan should also include a questionnaire on the occupant perception and satisfaction with their daily working environment.
- In case of obtaining levels of environmental parameters that do not comply with the recommended ranges or occupants' complaints, the building managers should consider to execute an extensive inspection of building/indoor spaces and services/systems for identification of possible risk factors, in order to design effective corrective measures to improve indoor conditions and mitigate putative related risks to occupants.
- The implementation of corrective measures (e.g., installation of air cleaners or components for air disinfection, regulation of indoor air temperature, introduction of natural elements in offices), as well as any major building renovation works (namely those include insulation components) and changes on the ventilation system design and/or operation must be followed by a comprehensive assessment in order to assess either the respective beneficial or detrimental impacts on IEQ and on occupants well-being, health and productivity.

Although the main goal of most of the intervention studies reviewed was to effectively improve office workers' health comfort and productivity using strategies that improve the IEQ, it could be important to include assessments to understand if the experiments had a measurable effect on promoting better indoor environmental conditions, by decreasing indoor pollutant concentrations. This kind of evidence was reported only in a few studies in this review. Indeed, the simultaneous monitoring of indoor environmental parameters would be a great opportunity to make an association between IEQ levels and the measured office workers' outcomes and to better support the need for optimization of intervention strategies. In fact, this review also identifies existing research gaps in the field of intervention studies in office environments. According to the findings, further studies would benefit from longer-term intervention periods with adequate baseline information and well-established criteria for selecting environmental interventions. Moreover, since most of the existing studies present their conclusions only based on the subjective measures collected through questionnaires, further studies considering a study design with mixed approach (questionnaires and clinical assessments) would provide more comprehensive and putatively complementary data to improve the robustness of the results.

Author statement

Fátima Felgueiras: Conceptualization, Data curation, Investigation, Writing – original draft, Funding acquisition; Liliana Cunha: Methodology, Supervision, Writing – review & editing; Zenaida Mourão: Supervision, Validation, Writing – review & editing, Funding acquisition; André Moreira: Supervision, Validation, Writing – review & editing, Funding acquisition; Marta Fonseca Gabriel: Conceptualization, Validation, Supervision, Writing – review & editing, Funding acquisition.

Declaration of competing interest

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

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