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Systematic Review

Exploring Soundscape Assessment Methods in Office Environments: A Systematic Review

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Abstract: The application of the soundscape approach is becoming increasingly prevalent in the evaluation of indoor acoustic environments, including office environments. However, the formalisation and standardisation of soundscape assessment methods for offices remain in the early stages, highlighting the need for further development. This systematic review explores the methods and factors involved in soundscape assessments within office environments, which are intended to contribute to creating or improving comprehensive and widely accepted protocols. This review includes 41 studies, revealing that questionnaires (n = 36) are the most commonly used subjective tools, occasionally supplemented by interviews (n = 1). Some studies employ a combination of questionnaire and interview (n = 2), questionnaire and discussion (n = 1), or all three methods—questionnaire, interview, and discussion (n = 1). Meanwhile, direct acoustic measurements (n = 28) and cognitive tasks (n = 14) are often employed for objective evaluations. Additionally, the review categorises factors involved in objective and subjective soundscape assessments into acoustic and non-acoustic elements. It also identifies tools frequently used to assess the correlation between soundscapes and physical and psychological well-being. Collectively, this review underscores the critical factors for comprehensive soundscape assessments in office environments.

Keywords: indoor soundscape; office; office environment; soundscape assessment

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1. Introduction

The office environment is a critical space for employees, and is where they typically spend around eight hours each day [1,2]. It not only serves as a workspace but also profoundly influences productivity, collaboration, and overall well-being. However, these functions are often hindered by issues related to indoor environmental quality (IEQ), particularly acoustic challenges. Acoustics have been identified as the most common source of dissatisfaction in contemporary workspaces [3]. Numerous studies have demonstrated that poor acoustic conditions in the workplace can negatively impact both physical and psychological well-being. For instance, elevated noise levels and clear speech in the workplace can lead to increased fatigue, disturbance, stress, and annoyance, adversely affecting physical and psychological well-being [4–7].

Efforts to improve acoustic quality in open-plan offices (OPOs) typically focus on evaluating room characteristics based on physical acoustic measurement, following standards such as ISO 3382-3 and ISO 22955 [8,9]. However, objective measurements alone are insufficient to fully understand acoustic quality, as they fail to capture occupants' subjective experiences. Subjective perceptions, shaped by psychological and social factors, are essential for determining overall satisfaction with the acoustic environment [10]. Therefore, the improvement of acoustic quality requires a comprehensive approach that considers these subjective responses, as human perception cannot be fully represented by physical measurement alone [11].

The concept of the soundscape, first introduced in the 1960s [12–14], offers a valuable framework for understanding how people experience acoustic environments. This concept has gradually developed into a more nuanced understanding, with soundscapes recognised as complex auditory environments that profoundly shape human experiences and behaviours, rather than mere collections of sounds [14,15].

The application of the soundscape concept has increased steadily, particularly in research focused on urban environments [16,17]. The establishment of ISO 12913 marks a significant milestone in formalising and standardising soundscape concepts, especially within urban contexts. This set of standards provides a comprehensive framework for understanding, assessing, and managing soundscapes in various settings, including urban areas. ISO 12913 is divided into several parts, each addressing different aspects of soundscape research and application, thus enabling a systematic approach to soundscape management. The standards promote the use of descriptors such as "pleasantness" and "eventfulness" to characterise acoustic environments [18–20]. By viewing sound as an integral part of the urban experience rather than merely as noise, this approach enhances the quality of life in urban environments [21]. Acun and Yilmazer (2018) similarly observed that not all dominant sounds are disruptive; sounds like keyboard typing and mouse clicks may be viewed positively, as they signify activity, collaboration, and motivation [22].

The adoption of ISO/TS 12913-2 protocols reflects a growing trend in the application of soundscape methodologies to assess indoor acoustic environments [23,24]. Concurrently, research on the perceived acoustic quality of indoor spaces has been gaining momentum [25–28]. However, the application of the soundscape concept in this context is still in its early stages [29], despite increasing recognition of its potential to enhance occupants' health and well-being. This emphasises the need for a holistic approach that considers both acoustic and non-acoustic stimuli in user–building interactions [24,30]. The growing interest in the indoor soundscape, particularly concerning acoustic design and indoor environmental quality, indicates the potential for further exploration in this area.

In indoor environments like open-plan offices, several efforts have attempted to develop soundscape questionnaires, as demonstrated by recent research [11,29,31]. Jo and Jeon (2022) developed a questionnaire to assess indoor soundscape perception in open-plan offices by identifying perceptual dimensions of the previous literature and their study's objectives [11]. They adapted adjectives from prior studies, such as those by Torresin, Albatici et al. (2020) [25], to suit the open-plan office context. Similarly, Indrani et al. (2023) outlined a detailed process for developing an indoor soundscape questionnaire, which included a literature review, theoretical model development, a preliminary study using the GABO Questionnaire, and validation through data analysis using PLS-SEM to assess the impact of contextual factors on work behaviour [29].

Despite these efforts, soundscape questionnaires for office environments still require refinement to capture the nuances of sound perception effectively. Poor acoustic conditions significantly affect physical and psychological well-being, a critical issue impacting office workers worldwide. In the United Kingdom (UK) alone, the workforce from May to July 2024 was recorded at 33.07 million, with 28.83 million employed [32]. Many of these likely spend time in office environments.

Improving soundscape assessment by incorporating these dimensions could lead to more holistic evaluation tools that consider both auditory environments and their broader impact on well-being. This systematic review, therefore, explores existing soundscape assessment protocols in office environments to identify the methods, factors, and items used to evaluate soundscape perception. Consequently, the following research questions have been formulated:

- Which methods are currently employed to assess soundscapes in office environments?
- Which factors are typically included in subjective assessments to evaluate the perceived quality of soundscapes in office environments?
- Which assessment tools are commonly used to evaluate the physical and psychological well-being of office workers in relation to their perception of the sound environment?

- Which objective acoustic parameters are frequently involved in soundscape assessment in office environments?

2. Materials and Methods

A systematic literature search was conducted to identify studies that assess soundscapes in office environments, the study selection process in this review is illustrated in Figure 1. The search was performed using the Scopus database on 5 September 2024. The search strategy included combinations of key terms related to soundscapes, cognitive function, and assessment methods. The search was restricted to English-language publications, using the following search string:

("acoustic" OR "sound" OR "noise") AND ("soundscape" OR "percept*") AND ("office").

Initially, 553 studies were retrieved from the Scopus database. After applying filters for English-language publications and limiting the document types to articles and conference papers, the selection was narrowed to 476 documents.

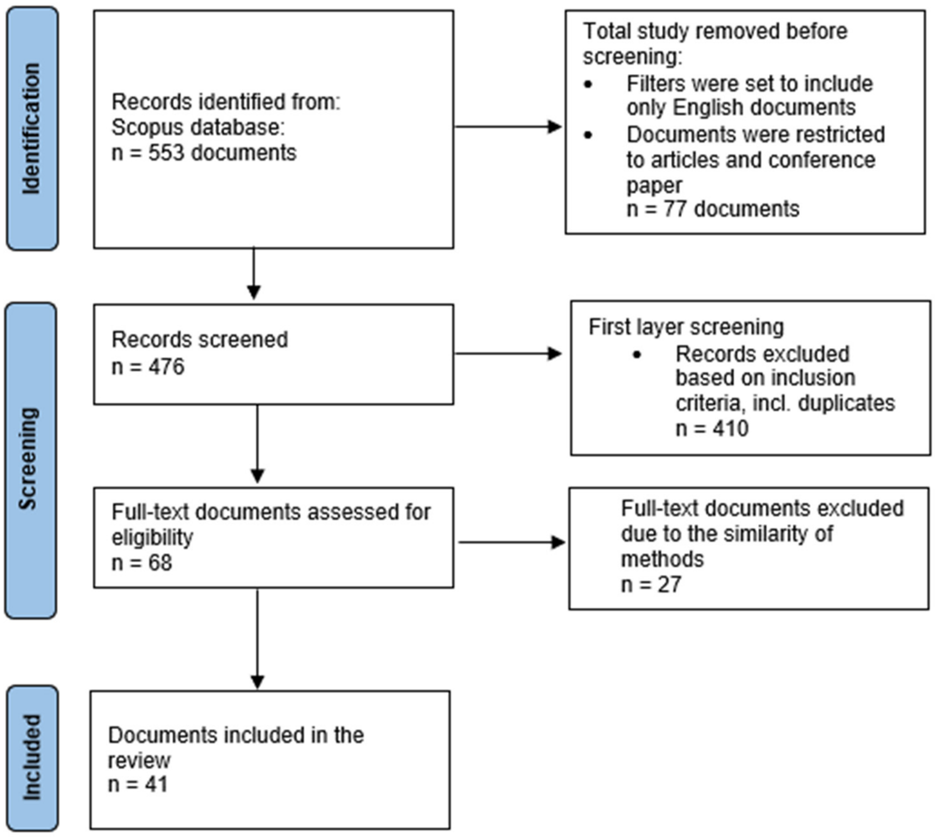

Figure 1. The process of the literature search, screening, and study selection.

These studies span various fields, including workplace design, indoor environmental quality, and human performance, with a particular focus on acoustics and noise control in office environments. Research topics included speech intelligibility, reverberation, and sound masking, and studies were often published in journals like *Applied Acoustics*. These studies examine the effects of acoustics on cognitive tasks, work performance, noise distraction, and employee well-being.

Fields such as architectural engineering and environmental design, seen in journals like *Building and Environment* and *Journal of Building Engineering*, focus on the impact of spatial arrangements, materials, and audiovisual elements on comfort, productivity, and satisfaction. Other interdisciplinary areas include thermal and acoustic environment interactions, biophilic design interventions, and the use of virtual reality to study environmental perception. Additionally, research in psychology, business research, and ergonomics explores how noise affects job satisfaction, coping strategies, and privacy in modern office designs.

The studies reviewed date back to 2009, marking the beginning of research focused on acoustics in open-plan offices. From 2011 to 2015, research expanded on the role of sound masking, noise distraction, and acoustic design in improving comfort. Between 2017 and 2020, there was a significant increase in the number of publications emphasising soundscapes, workplace productivity, and employee well-being, including the application of virtual reality- and activity-based office design assessments. More recent studies (2021 to 2024) explore innovative approaches like biophilic design, audiovisual content's impact on productivity, and adaptive sound masking systems, reflecting ongoing advancements toward optimising office soundscapes and overall comfort through multidisciplinary research.

This literature review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Studies were included if they met the criteria outlined in Table 1.

Table 1. Inclusion and exclusion criteria.

Inclusion Criteria	Rules	Example of Excluded Studies
Focused on office environments	The study must explicitly mention that it is conducted in office environments or similar workplace settings (e.g., corporate offices, open-plan offices, etc.).	Studies conducted in schools, factories, or hospitals.
Explores perceptual aspects of acoustic environments	The study must assess participants' subjective experience or perception of acoustic conditions, such as noise levels, office acoustic metrics, or soundscapes.	Studies that only measure noise objectively without linking to human perception.
Falls within the fields of acoustics, soundscapes, or noise studies	The study must fall within one or more of these fields: acoustics, soundscapes, or noise studies. The relevant terms must be mentioned in the methodology or objectives.	Studies on workplace productivity without mentioning acoustics or noise.
Participants without hearing impairments	The study must either state that participants have normal hearing, or it must not mention hearing status at all.	Studies involving participants with hearing impairments.
Collected primary data	The study must involve original data collection (e.g., surveys, experiments, interviews).	Review articles, theoretical papers, and studies that use data from existing databases.

In the first layer of screening, study titles and abstracts were reviewed against the predefined inclusion criteria, with duplicates removed. Full-text reviews were conducted for studies that appeared to be potentially eligible. After applying the inclusion criteria, 68 studies were deemed suitable for inclusion in the systematic review. During the final screening, studies that employed identical methodologies or lacked depth in terms of evaluating sound perception were excluded. This resulted in a total of 41 studies remaining for further analysis. From these, only the aspects relevant to the review's objectives were extracted and analysed based on the inclusion criteria.

3. Results and Analysis

Based on the 41 selected studies (Supplementary Materials), this systematic review extracted and summarised the assessment protocols used to investigate the perceptual aspects of soundscapes in office environments. A comprehensive summary of these assessment protocols is presented in Tables 2 and 3, where red 'X' denotes that the factor was not addressed in the study, and green 'V' indicates that the factor was discussed. In addition, the illustration of the number of acoustic and non-acoustic factors for both subjective and objective factors is shown in Figures 2 and 3.

Table 2. Acoustic and non-acoustic factors in subjective evaluation of office soundscapes.

Author(s)	Method	Acoustic Factors										Non-Acoustic Factors					
		SI	ND	SEP	ASE	AQE	ACS	OAM	NC	ICs	NS	WP	SD	WH	SB	SSI	PPW
Abdalrahman and Galbrun (2017) [33]	Q	V	V	V	X	V	X	V	V	V	V	X	V	X	X	X	V
Acun et al. (2018) [22]	I	V	V	X	X	X	X	X	X	X	X	X	X	X	V	X	X
Ali (2011) [34]	Q	V	V	X	X	V	X	X	X	X	X	X	X	X	X	V	V
Appel-Meulenbroek et al. (2020) [35]	Q	V	V	X	X	X	X	X	X	V	X	X	X	X	X	X	X
Ayoko et al. (2023) [36]	Q	V	V	X	X	X	X	X	X	X	X	X	V	V	X	X	X
Bergefurt, Appel-Meulenbroek, and Arentze (2024) [37]	Q	X	V	X	X	X	X	X	V	V	V	V	X	X	X	X	V
Bourikas et al. (2021) [38]	Q	X	X	X	X	X	X	V	X	X	X	X	X	X	X	X	X
Castaldo et al. (2018) [39]	Q	X	X	V	X	X	V	V	X	X	X	X	V	V	X	V	X
Eşmebaşı et al. (2024) [40]	Q	X	X	X	V	V	X	X	X	X	X	X	V	X	X	X	X
Forooraghi et al. (2023) [41]	Q	X	X	X	X	X	X	V	X	X	X	X	V	X	V	X	X
Gatland et al. (2018) [42]	Q	V	V	X	X	X	V	X	X	X	X	X	X	X	X	X	X
Haapakangas et al. (2011) [43]	Q	X	V	V	X	V	V	X	V	X	X	V	X	X	X	X	V
Haapakangas et al. (2014) [44]	Q	X	V	X	X	V	X	X	V	X	V	X	X	X	X	X	V
Haka et al. (2009) [45]	Q	X	V	X	X	V	X	V	V	V	V	V	X	X	X	X	V
Hongisto et al. (2017) [46]	Q	X	V	X	X	V	V	V	V	X	X	V	X	X	X	X	V
Indrani et al. (2023) [29]	Q	V	V	V	X	V	V	V	V	V	V	X	V	V	X	X	V
Jeon et al. (2022) [47]	Q; I	X	X	X	X	V	V	V	X	X	X	X	X	X	X	X	X
Jiajun et al. (2017) [48]	Q; I	X	V	V	X	V	X	X	X	X	X	X	X	X	X	X	X
Jo and Jeon (2022) [11]	Q	V	X	X	X	X	X	X	X	X	X	V	X	X	X	X	X
Kang et al. (2017) [49]	Q	V	V	V	X	X	V	X	X	X	X	V	V	X	X	X	X
Kang et al. (2023) [50]	Q	X	X	X	X	X	X	V	X	X	V	V	X	X	X	X	X
Kim et al. (2020) [51]	Q	X	V	X	X	X	X	V	V	X	X	X	V	X	X	X	X
Latini et al. (2023) [52]	Q	V	V	X	X	V	X	X	X	X	X	V	V	X	X	X	V
Latini et al. (2024) [53]	Q	X	X	X	X	V	X	X	X	X	X	X	X	X	X	X	X
Lee et al. (2020) [54]	Q	X	V	X	X	X	X	X	X	X	X	V	X	X	X	X	X

Table 2. *Cont.*

Author(s)	Method	Acoustic Factors								Non-Acoustic Factors							
		SI	**ND**	**SEP**	**ASE**	**AQE**	**ACS**	**OAM**	**NC**	**ICs**	**NS**	**WP**	**SD**	**WH**	**SB**	**SSI**	**PPW**
Lenne, Chevret, and Marchand (2020) [55]	Q	V	V	X	X	X	X	X	X	V	V	X	X	X	X	X	V
Liang et al. (2014) [56]	Q	V	V	X	X	X	V	V	V	X	X	X	X	X	X	X	X
Mediastika and Binarti (2013) [57]	Q	X	X	X	X	V	X	V	X	X	X	X	X	X	X	V	X
Miterska and Kompała (2023) [31]	Q; RA	V	X	V	X	V	X	X	X	X	X	X	X	X	X	V	X
Oseland and Hodsman (2018) [58]	Q	V	V	X	X	X	X	X	V	V	X	V	X	X	X	X	X
Otterbring et al. (2021) [59]	Q	X	X	X	X	X	X	V	X	X	X	X	V	X	X	X	V
Park et al. (2020) [60]	Q	X	V	X	X	X	X	V	X	X	V	V	X	X	X	X	X
Peng et al. (2023) [61]	Q	X	V	X	X	V	X	X	X	X	X	X	X	X	X	X	X
Pierrette et al. (2014) [62]	Q	V	V	V	X	X	X	V	V	V	V	X	X	X	X	X	V
Renz et al. (2018) [63]	Q	X	X	X	X	V	X	X	X	X	X	X	X	X	X	X	X
Rolfö et al. (2017) [64]	Q; I; D	X	X	V	X	X	X	V	X	X	X	V	V	V	X	V	X
Vellenga et al. (2017) [65]	Q	X	X	X	X	V	X	X	X	X	X	X	X	X	X	X	X
Wang and Novak (2010) [66]	Q	X	V	X	X	V	X	X	X	X	X	X	X	X	X	X	X
Wen X et al. (2024) [67]	Q	X	X	X	X	V	V	X	X	X	X	X	X	X	X	X	X
Yadav et al. (2017) [68]	Q	X	V	X	X	V	X	X	X	X	V	X	X	X	X	X	X
Zhang, Ou, and Kang (2021) [69]	Q	X	V	X	X	X	V	X	V	X	V	X	X	X	X	X	X

Acronym: Questionnaire (Q); Interview (I); Discussion (D); Risk assessment (RA); Sound source identification (SI); Noise disturbance (ND); Sound environment perception and evaluation (SEP); Appropriateness of sound environment (ASE); Affective quality of sound environment (AQE); Acoustic comfort and satisfaction (ACS); Office acoustic metrics (OAM); Noise control (NC); Individual characteristics (ICs); Noise sensitivity (NS); Work performance (WP); Space dynamics (SD); Working habit (WH); Physical and psychological well-being (PPW); Social behaviour (SB); Suggestion for space improvement (SSI).

Table 3. Acoustic and non-acoustic factors in objective evaluation of office soundscapes.

Author(s)	Method	Acoustic Factors						Non-Acoustic Factors			
		NL	RT	SP	SI	PA	SIM	CT	PM	FA	OFN
Abdalrahman and Galbrun (2017) [33]	DM	V	X	X	X	X	X	X	X	X	X
Acun et al. (2018) [22]	DM; CS	V	X	X	V	X	X	X	X	V	V
Ali (2011) [34]	DM	V	X	X	X	X	X	X	X	X	X
Bergefurt, Appel-Meulenbroek, and Arentze (2024) [37]	DM	X	X	V	X	X	X	X	X	X	X
Bourikas et al. (2021) [38]	DM	V	V	X	X	X	X	X	X	X	X
Eşmebaşı et al. (2024) [40]	DM	V	X	X	X	X	X	X	X	X	X
Gatland et al. (2018) [42]	DM	X	V	X	V	X	X	X	X	X	X
Haapakangas et al. (2011) [43]	DM	V	X	X	V	X	X	V	X	X	X
Haapakangas et al. (2014) [44]	DM	V	X	X	V	X	X	V	X	X	X
Haka et al. (2009) [45]	DM	V	V	X	V	X	X	V	X	X	X
Hongisto et al. (2017) [46]	DM	V	X	V	X	X	X	X	X	X	X
Indrani et al. (2023) [29]	DM	V	V	X	V	X	X	X	X	V	X
Jeon et al. (2022) [47]	DM; CS	X	V	V	V	X	X	V	X	X	X
Jiajun et al. (2017) [48]	DM	V	X	X	X	X	X	V	X	X	X
Jo and Jeon (2022) [11]	DM; CS	V	X	V	X	X	X	V	X	X	X
Kang et al. (2023) [50]	DM; CS	X	V	V	V	X	X	V	X	X	X
Kim et al. (2020) [51]	DM	V	V	X	X	X	X	X	X	X	X
Latini et al. (2024) [53]	DM	V	V	X	X	X	X	V	V	X	X
Latini et al. (2023) [52]	DM	X	V	X	X	V	X	V	X	X	X
Lee et al. (2020) [54]	DM	V	X	X	X	X	X	V	V	X	X
Lenne, Chevret, and Marchand 2020 [55]	DM	V	V	V	X	X	X	X	X	X	X
Liang et al. (2014) [56]	DM	V	X	X	X	X	X	X	X	X	X
Mediastika and Binarti (2013) [57]	DM	V	X	X	X	X	X	X	X	X	X
Miterska and Kompała (2023) [31]	DM	V	X	X	X	X	X	X	X	X	X
Park et al. 2020 [60]	DM	V	V	V	X	X	X	X	X	X	X

Table 3. *Cont.*

Author(s)	Method	Acoustic Factors						Non-Acoustic Factors			
		NL	**RT**	**SP**	**SI**	**PA**	**SIM**	**CT**	**PM**	**FA**	**OFN**
Peng et al. (2023) [61]	DM	V	X	X	X	X	X	X	X	X	X
Renz et al. (2018) [63]	DM	V	X	X	V	V	X	V	X	X	X
Vellenga et al. (2017) [65]	DM	V	X	X	X	X	X	X	X	X	X
Wang and Novak (2010) [66]	DM	V	X	X	X	V	V	V	X	X	X
Wen X et al. (2024) [67]	DM	V	X	X	X	X	X	X	X	X	X
Yadav et al. (2017) [68]	DM	V	X	X	V	X	X	V	X	X	X
Zhang, Ou, and Kang (2021) [69]	DM	V	V	X	V	X	X	V	X	X	X

Acronym: Direct measurement (DM); Computer simulation (CS); Noise level (NL) metric; Reverberation time (RT) metric; Speech privacy (SP) metric; Speech intelligibility (SI) metric; Psychoacoustic (PA) metric; Sound insulation metric (SIM); Cognitive test (CT); Physiological measurement (PM); Floorplan analysis (FA); Observation and field notes (OFNs).

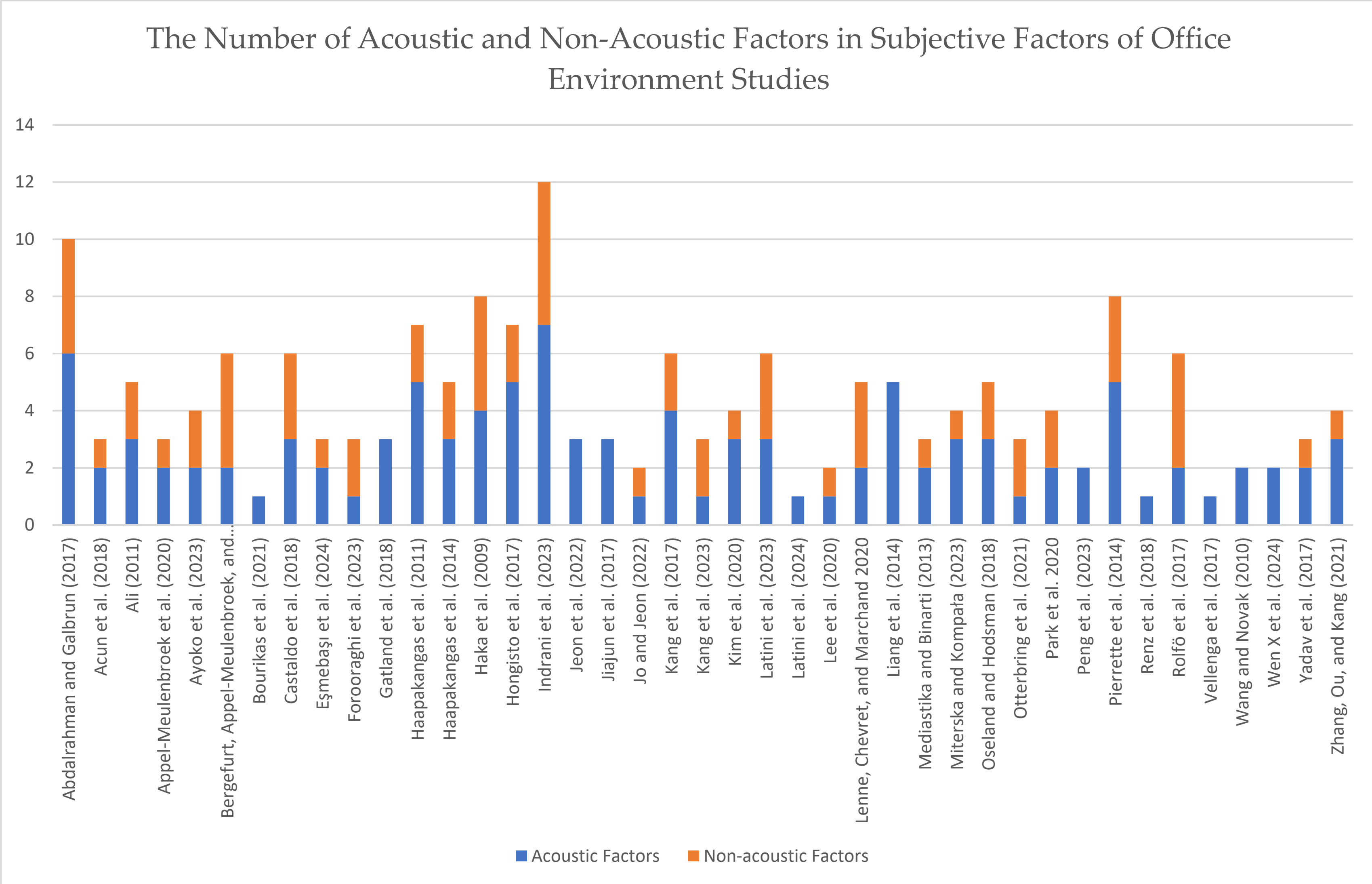

Figure 2. The number of acoustic and non-acoustic factors included in the subjective factors of office environment studies [11,22,29,31,33–69].

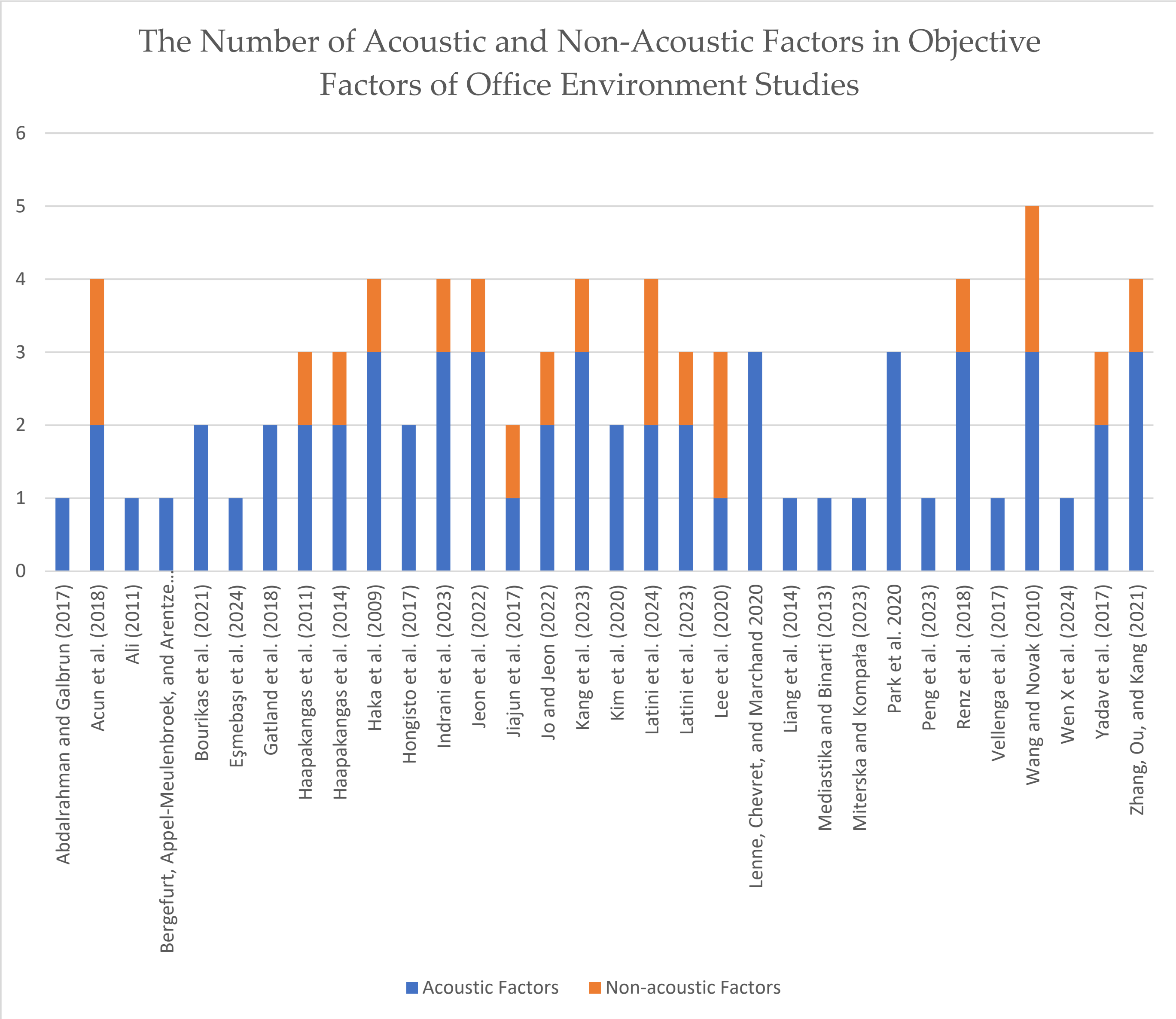

Figure 3. The number of acoustic and non-acoustic factors included in the objective factors of office environment studies [11,22,29,31,33,34,37,38,40,42–48,50–57,60,61,63,65–69].

3.1. *Soundscape Assessment Methods in Office Environments*

The assessment of soundscapes in office environments is essential, as the acoustic environment can significantly influence comfort, productivity, and overall well-being. This review of the literature reveals the wide range of methodologies used to evaluate soundscapes, highlighting the diversity of approaches employed with regard to this specific research focus and context.

In terms of subjective evaluations, the most commonly used methodology across the reviewed studies is questionnaires, with 40 studies employing this approach. Questionnaires enable researchers to capture participants' subjective evaluation of the acoustic environment. The use of scales in soundscape assessments is crucial for standardising responses and facilitating statistical analysis. The results indicate that various scales are employed, including 4-point, 5-point, 6-point, 7-point, 9-point, 10-point, 11-point, 35-point, and continuous scales. Besides scales, other response types, such as multiple-choice questions, yes/no questions, and short-form responses, are also utilised. The variation in the number of points on these scales allows for different levels of granularity in respondents' assessments.

Among these, 5-point and 7-point scales are most commonly used in soundscape assessments in office environments. These scales are preferred because they strike an optimal balance between providing sufficient detail and ensuring the ease of statistical analysis. Scales with too many options (e.g., 10-point or 11-point scales) can overwhelm respondents, while those with too few options (e.g., 3-point or 4-point scales) may fail to capture the full nuance of their perceptions.

In addition to questionnaires, qualitative methods such as interviews, discussions and risk assessment are also used to assess soundscapes in office environments. Overall, the methods used in soundscape assessments in office environments are illustrated in Figure 4. The figure indicates that studies employed only Questionnaire (n = 36), only Interview (n = 1), Questionnaire & Interview (n = 2), Questionnaire & Discussion (n = 1), and Questionnaire, Interview & Discussion (n = 1). In Figure 4, the risk assessment method is merged with the discussion method because it involves a discussion process with experts.

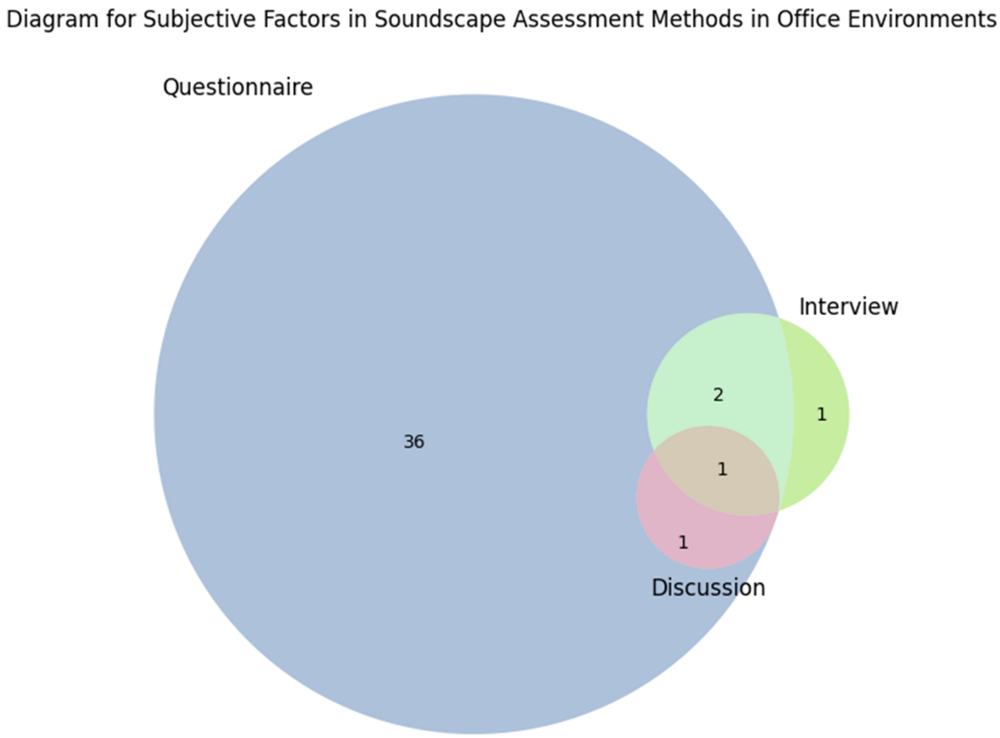

Figure 4. A diagram of subjective factors considered in soundscape assessment methods.

These approaches offer more in-depth insights into participants' perceptions and experiences, providing flexibility to adapt questions based on the given responses. While these methods require more time for data collection and analysis, they provide a deeper and more nuanced understanding of how participants perceive and experience soundscapes.

In objective evaluations, the most commonly used methodology for measuring acoustic physical parameters involves direct measurement, with 28 studies employing this approach, as shown in Figure 5. These measurements are based on applicable standards such as ASTM E2235-04, ASTM E336-17a, ASTM E413, ANSI/ASA S12.2, ANSI/ASA S1.13, ANSI/ASA S3.4, ASTM E1573-18, BS/EN 60268-16, ISO 3382-1, ISO 3382-3, ISO 532-1, UNI EN 12354-6, and NF S 31-199 [8,70–81]. In addition to direct measurements, 4 studies employ acoustic simulation software to assess physical acoustic parameters. This software is typically used to replicate the physical conditions of actual rooms for virtual experiments or to predict the acoustic properties of spaces targeted for improvement.

Moreover, a common approach to objective evaluation involving non-acoustic factors includes cognitive tasks designed to assess aspects of cognitive function, such as memory, attention, information processing, and cognitive flexibility, under different acoustic conditions. Other methods used for objective evaluation in soundscape assessment include physiological measurement, spatial analysis, and space observation.

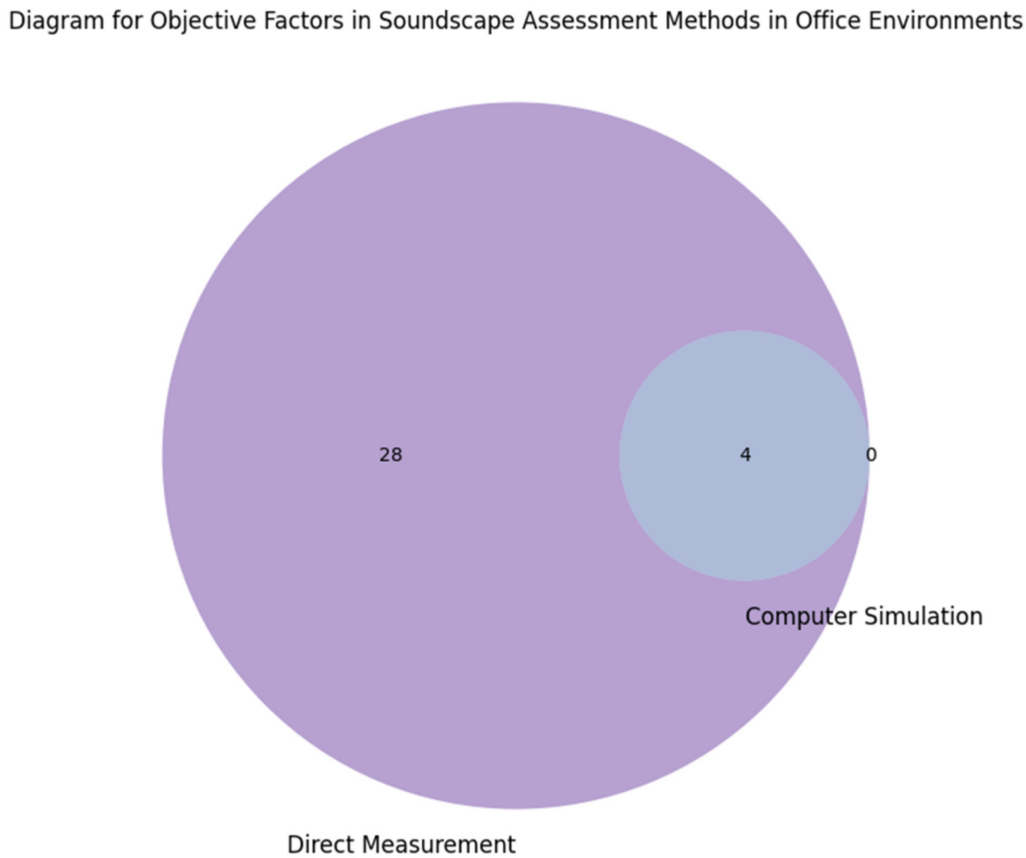

Figure 5. A diagram of the objective factors considered in soundscape assessment methods.

3.2. Subjective Factors in Soundscape Assessment Methods in Office Environments

We identified subjective factors from each assessment protocol used in the analysed studies and categorised them into two primary types of factor: acoustic and non-acoustic, as illustrated in Figure 6. This classification approach provides a comprehensive understanding of the elements influencing the perception and evaluation of the acoustic environment, distinguishing between factors directly related to sound and those influenced by contextual or individual variables.

3.2.1. Acoustic Factors

Sound Source Identification

The identification of noise sources is a crucial initial step in understanding the acoustic impact within office environments. This analysis allows for the implementation of more effective strategies with which to manage or mitigate these effects. Table 4 provides an overview of various sound sources commonly identified in soundscape assessments within these settings. These sound sources can be categorised into three main groups: machine and equipment, human activity and interactions, and other background noise.

Additionally, another type of question requires participants to list the sound sources they hear in their environment. This question is commonly posed during interviews, as demonstrated in a study by Acun et al. (2018) [22].

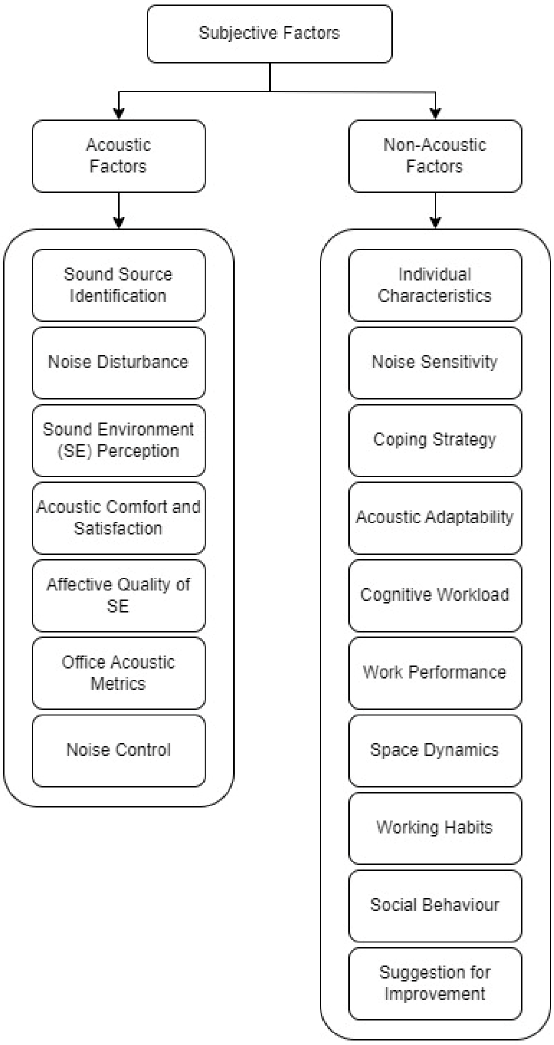

Figure 6. Subjective factors in soundscape assessment protocols in office environments.

Table 4. Identified noise sources.

Machine and equipment	Ventilation/air conditioning system	[11,29,33–35,42,52,55,58,62]
	Lighting system	[33,42,58]
	Office machine (computer, photocopy machine, keyboard, mouse, fax machine, shredder, telephones ringing, etc.)	[11,29,33–35,38–41]
Human activity and interactions	Conversation	[11,29,33,35,36,38–42]
	Telephone conversations	[29,33,35,38–40,42]
	Incomprehensible conversation	[29,33,36,55,62]
	Conversation in the communal area	[35,42,58]
	Discussions about work or conversations in other teams	[36,58]
	Monologue	[36]
	Laughter	[11,58]
	People walking/footsteps	[11,29,33,35,36,49,55,58,62]
	Use of furniture (drawers, doors, chairs, desks, etc.)	[11,29,33,49,55,62]
Other background noise	Noise from outside the building (human activity, equipment, traffic noise, construction, etc.)	[35,36,39,41,43]
	Entertainment/music/radio	[35,36,39,41,43]
	Kitchen appliances	[11]

Noise Disturbance

In the analysed studies, the identification of noise sources was closely linked to the evaluation of the distraction caused by these sources. For instance, Kang et al. (2017) and Park et al. (2020) employed a similar approach, where participants rated various noise sources based on their perceived level of disturbance [49,60]. Additionally, Zhang, Ou, and Kang (2021) explored the broader impact of sound disturbance within environmental contexts, specifically evaluating the effects of noise masking in office environments [69].

In contrast, Gatland et al. (2018) focused on the distraction caused by noise, while Ayoko et al. (2023) further investigated this by asking participants to describe situations that led to distractions in their surroundings [36,42]. Kim et al. (2020) concentrated their research on the frequency of distractions caused by interpersonal interactions [51]. Meanwhile, Liang et al. (2014) identified sources of dissatisfaction related to noise [56].

Further studies have examined how noise distractions influence work performance, focusing on productivity, concentration, health, and well-being. Research using the GABO Questionnaire—performed by Abdalrahman and Galbrun (2017), Indrani et al. (2023), Lenne, Chevret, and Marchand (2020), and Pierrette et al. (2014)—measured the overall noise disturbance intensity and its effects on work performance. These studies also explored which specific tasks, such as reading, writing, or phone communication, are most affected by noise [29,33,55,62].

Research on the impact of noise on work performance, such as the studies by Peng et al. (2023), Appel-Meulenbroek et al. (2020), Haka et al. (2009), Hongisto et al. (2017), Indrani et al. (2023), Latini et al. (2023), Lee et al. (2020), Yadav et al. (2017), Haapakangas et al. (2011, 2014), and Bergefurt, Appel-Meulenbroek, and Arentze (2024), assesses how noise affects workers' concentration and productivity. These studies used questionnaires to explore how noise disrupts tasks requiring high levels of focus, distracts workers, and diminishes their efficiency. These studies also evaluated the disturbances caused by conversations and background noise, as well as their effects on cognitive performance, including workers' ability to cope with noise distractions in the workplace [29,35,37,43–46,52,54,61,68].

A study by Acun et al. (2018) took a different approach, using interviews to evaluate how intelligible sounds, such as clear conversations, can significantly disrupt concentration, especially during tasks requiring intense focus. Conversely, other sounds, like keyboard typing, were sometimes viewed as motivational signals, indicating the work activity of others, although they could also be distracting depending on the context [22]. In a related context, Jiajun et al. (2017) examined whether soundscapes in a simulated office environment enhanced concentration or relaxation and how specific elements, particularly conversations, were perceived as distracting or unpleasant. The study also considered whether understanding the content of a conversation heightened its distracting effect [48].

In contrast, the questionnaires used by Oseland and Hodsman (2018) and Abdalrahman and Galbrun (2017) not only examined the impact of noise distraction on work performance but also explored its effects on workers' psychological and physiological well-being. These questionnaires assessed whether workplace noise contributes to increased stress, discomfort, and disruptions to mental and physical health [33,58].

Sound Environment Perception

The assessment of the sound environment has emerged as one of the key subjects in the analysed studies. The approaches used in these studies vary, ranging from general assessments to more specific evaluations of soundscapes, and from questionnaires to interviews. Each approach offers unique insights into how the sound environment influences daily experiences.

For instance, Pierrette et al. (2014), Abdalrahman and Galbrun (2017), and Indrani et al. (2023) employed the GABO Questionnaire to evaluate perceptions of noise in work environments [29,33,62]. Similarly, Kang et al. (2017) took a broader approach by assessing the overall acoustic environment in office environments [49]. Additionally, Jiajun et al. (2017) investigated participants' subjective experiences and opinions regarding the soundscapes generated by the SoZen system, an interactive system designed to enhance the sonic environment [48].

In a broader approach, Miterska and Kompała (2023) used questionnaires to evaluate soundscapes, categorising them into positive, negative, and neutral experiences [31]. Moreover, Castlado et al. (2018) also explored how respondents described their current acoustic sensations and whether these sensations were influenced by their office environment [39].

Conversely, Haapakangas et al. (2011) introduced the consideration of dynamics in the sound environment by investigating how individuals respond to sudden changes in their acoustic surroundings. This study also considered how the acceptance of the sound environment is linked to the tasks being performed [43].

In addition to conducting a questionnaire-based study, Eşmebaşı et al. (2024) evaluated the appropriateness of sound in the office environment by assessing participants' perceptions of its suitability [40].

Employing a different approach, Rolfö et al. (2017) used interviews to explore individuals' needs for silence, offering a deeper understanding of the significance of silence for personal well-being [64]. Another question regarding sound environment perception and evaluation, focusing specifically on certain factors, has already been grouped with other factors discussed in this review.

Acoustic Comfort and Satisfaction

The assessment of acoustic comfort and satisfaction in office environments involves using various approaches to capture individual experiences, whether through direct questioning or semantic scales. These methods help in understanding how sound affects comfort, facilitating the design of acoustically optimised environments that enhance concentration and overall performance.

Research by Castaldo et al. (2018), Liang et al. (2014), and Wen et al. (2024) evaluated acoustic comfort by directly asking respondents to rate their current level of comfort in relation to the acoustic environment [39,56,67]. This approach provides a straightforward assessment of how respondents perceive the surrounding sound conditions.

In contrast, Indrani et al. (2023) adopted a contextual and specific approach, focusing on comfort in particular scenarios, such as when colleagues are speaking near their cubicles, and considering general noise levels in office environments [29]. This method offers a more detailed evaluation of specific aspects of acoustic comfort by examining how individuals feel about the noise conditions in their immediate environment.

In the context of acoustic satisfaction, Kang et al. (2023), Zhang, Ou, and Kang (2021), Gatland et al. (2018), Hongisto et al. (2017), and Jeon et al. (2022) examined participants' satisfaction with the sound conditions they experienced, highlighting the importance of the overall acoustic environment in terms of influencing workers' comfort and productivity in office environments [42,46,47,50,69].

Affective Quality of Sound Environment

The perceived affective quality of the sound environment refers to how individuals subjectively interpret and experience the surrounding soundscape, including its impact on emotions, mood, and feelings. Based on the analysis of the reviewed studies, several descriptors were identified and grouped to effectively describe this concept:

1. Calmness/tranquillity: various terms, including "Calm" [40,52,53], "Tranquil" [29,65], and "Peaceful" [29], are used to describe the calmness of the sound environment [48], specifically referring to a "Calming" effect.
2. Pleasantness: the comfort and pleasantness of the sound environment are captured by terms such as "Pleasantness" [33,52] and "Pleasant" [40,43–46,53,68].
3. Noise distraction: The term "Distracting" [46,48] is used to measure the degree of noise distraction. Similarly, Wang and Novak (2010) employ "Distraction" to describe the disruptive nature of noise [66]. Previous sections have discussed additional studies on this descriptor.

4. Noise annoyance: The discomfort or irritation caused by noise is described as "Noise Annoyance" [34,40,61,63] and "Annoyance" [66]. This concept is also evaluated using statements like "The sound environment would not annoy me" [43] and the term "Annoying" [40,53]. Additionally, the "Level of annoyance" is used by Mediastika and Binarti (2013) to quantify the degree of discomfort experienced [57].
5. Loudness: the perceived intensity of sound is described as "Loudness" [31,66,67] and is indicated by statements like "The sound environment was loud" [43].
6. Excitement/liveliness: the excitement or liveliness of the sound environment is described using terms such as "Lively" [29,65], "Exciting" [29], "Energetic" [29], "Active" [48], and "Vibrant" [40,53].
7. Stress/anxiety: sound conditions that trigger stress or anxiety are indicated by terms like "Stressful" [46], "Distressed", and "Nervous" [48].
8. Naturalness: the natural quality of sounds is indicated by the term "Natural" [46] (Hongisto et al., 2017).
9. Boredom/interest: the sound environment can be perceived as boring or interesting, represented by the terms "Boring" [52], "Interesting" [48], and "Monotonous" [40,53].
10. Complexity/intensity: the complexity and intensity of sounds are described using the terms "Chaotic" [40,52,53], "Turbulent" [65], "Variable" [47], and "Uneventful" [40,53].
11. Reverberation: the degree of reverberation or echo in the sound environment is described as the "Reverberant" [47].
12. Other descriptors: additional terms used to describe various aspects of sound quality include "Tiring" or "Helpful" [46] and specific acoustic descriptors like "Rumble", "Roar", and "Hiss" [66].

This classification aims to enhance the understanding of how sound environments influence individuals' affective perceptions. By grouping these descriptors, it becomes easier to identify the specific emotional and psychological impacts of different acoustic conditions, enabling a more targeted approach to designing and managing soundscapes. This understanding helps researchers, designers, and urban planners create environments that not only minimise negative effects like stress and distraction but also promote positive experiences, such as calmness, comfort, and liveliness.

Office Acoustic Metrics

Office acoustic metrics refer to the perceived acoustic characteristics experienced by individuals in office environments. This review successfully identified several parameters associated with this factor, including noise levels, acoustic privacy, and sound intelligibility.

Noise level assessment in office environments involves evaluating how sound level influences individuals' effectiveness and experiences. Various studies have employed questionnaires to capture individuals' perceptions and satisfaction with the noise levels, each employing a slightly different approach to assess this aspect of the acoustic environment.

Several studies performed using the GABO Questionnaire, such as those of Pierrette et al. (2014), Abdalrahman and Galbrun (2017), Lenne, Chevret, and Marchand (2020), and Indrani et al. (2023), focused on the general perception of noise levels in the office environments, typically asking respondents to evaluate whether they consider the noise level in their office environment to be high [29,33,55,62]. Similarly, Bourikas et al. (2021) assessed individuals' perceptions of background noise levels, investigating how respondents perceive the ambient noise that is consistently present in their office environment [38].

Moreover, Mediastika and Binarti (2013) and Otterbring et al. (2021) examined the perception of noise levels more generally, assessing how individuals perceive the intensity and presence of noise in their environment [57,59].

Some studies take a more subjective approach by asking respondents to consider their ideal or desired noise levels. For instance, Castaldo et al. (2018) asked participants to reflect on their preferred noise level in their office environment [39].

Another important aspect of noise level assessment is satisfaction. Forooraghi et al. (2023) and Rolfö et al. (2017) evaluated satisfaction with noise levels in the office environment, focusing on both background noise and speech volume [41,64]. These studies help to determine whether current noise levels meet the expectations and needs of the individuals within these environments.

In addition to general noise level assessments, some studies explored specific noise sources and their impacts. For instance, Kim et al. (2020) examined the noise generated by conversations and non-speech background noise in office environments [51].

Acoustic privacy is another crucial aspect of office environments, particularly in open-plan offices or shared spaces where the ability to have private conversations without being overheard is often compromised. Various studies have explored this dimension by capturing individuals' perceptions and satisfaction with their level of acoustic privacy.

Studies by Pierrette et al. (2014), Abdalrahman and Galbrun (2017), and Indrani et al. (2023) investigated the general possibility of having private conversations in office environments [29,33,62]. Moreover, Hongisto et al. (2017) measured the perceived lack of speech privacy, asking participants to rate how much they feel their privacy is compromised [46].

Jeon et al. (2022) examined more specific factors relating to acoustic privacy, such as the ability to have private conversations without being overheard [47], while Park et al. (2020) investigated the extent to which individuals can hear surrounding conversations, including colleagues chatting or taking phone calls [60].

Additionally, Forooraghi et al. (2023), Rolfö et al. (2017), and Kim et al. (2020) investigated levels of satisfaction with acoustic privacy in office environments. These studies asked respondents how satisfied they were with their ability to have private conversations in their office environments, assessing whether the current environment meets their privacy needs [41,51,64]. This approach provides valuable insights into how well the acoustic environment supports private communication. Moreover, Rolfö et al. (2017) examined satisfaction with the availability of private areas for conversations, phone calls, or focused work [64]. Abdalrahman and Galbrun (2017) also explored the impact of water features in terms of facilitating private conversations [33].

The assessment of speech clarity involves evaluating how well individuals can hear and understand spoken words in various settings. Different studies have used various types of questions to capture perceptions of speech clarity, offering insights into specific aspects of this crucial acoustic parameter.

Studies by Pierrette et al. (2014), Abdalrahman and Galbrun (2017), Lenne, Chevret, and Marchand (2020), and Indrani et al. (2023) investigated individuals' general ability to hear and understand speech in their environments. Particularly, the authors considered whether people can clearly hear and comprehend their colleagues' conversations in their office environments [29,33,55,62]. On a different scale, Haka et al. (2009) focused on quantifying speech clarity by asking participants to estimate the percentage of speech they could understand. This quantitative approach provides a direct measure of speech intelligibility, offering a clear metric for evaluating the effectiveness of communication in different settings [45].

Additionally, Rolfö et al. (2017) investigated changes in verbal communication effectiveness following a workplace relocation, asking respondents to compare the clarity of communication with their closest colleagues before and after the move [64]. This comparative approach highlights how changes in the physical environment can impact speech clarity.

Noise Control

Effective noise control is crucial for minimising the adverse impacts of noise in office environments. The studies reviewed in this article highlight various strategies for managing noise, many of which have been integrated into soundscape assessments.

In the studies conducted by Pierrette et al. (2014), Abdalrahman and Galbrun (2017), and Indrani et al. (2023), occupant satisfaction with noise management practices in office environments was measured using similar questionnaires [29,33,62]. Similarly, Indrani et al. (2023) assessed participants' comfort levels and expectations regarding noise control in their office environments using a different section of the questionnaire [29]. Oseland and Hodsman (2018) further contributed by evaluating how well individuals can screen out noise and distractions in their primary office environments, providing insights into personal strategies for managing acoustic challenges [58].

One fundamental approach to noise control involves passive measures, such as using materials with a high Sound Transmission Class (STC) to prevent noise transmission. For instance, Liang et al. (2014) evaluated inadequate sound insulation in windows, walls, and floors, identifying these factors as significant contributors to dissatisfaction [56].

Beyond passive noise control, active noise management techniques, such as noise masking systems, are also explored in research on soundscape assessment in office environments. For example, Hongisto et al. (2017) focused on evaluating the adequacy of noise masking levels, asking participants to rate whether the masking levels were too quiet or too loud [46]. Similarly, Abdulrahman and Galbrun (2017) investigated the use of water features as a form of noise masking and assessed participants' preferences for maintaining them permanently in office environments [33]. The use of noise masking systems is also discussed in other studies, including those by Bergefurt, Appel-Meulenbroek, and Arentze (2024), Zhang, Ou, and Kang (2021), Kim et al. (2020), Haapakangas et al. (2011, 2014), and Haka et al. (2009) [37,43–45,51,69].

3.2.2. Non-Acoustic Factors

Individual Characteristics

Individual characteristics are key factors used to understand how personality influences behaviour, perception, and interactions in various environments. To assess these characteristics, several studies utilised established assessment tools. For instance, Oseland and Hodsman (2018) employed the Big Five Inventory (BFI) with 44 sub-questions to measure personality traits [58]. Similarly, Bergefurt, Appel-Meulenbroek, and Arentze (2024) used a 10-item short version of the BFI [37], adapted from the research by Rammstedt and John [82]. The BFI covers the traits of extraversion, neuroticism, openness, conscientiousness, and agreeableness, using concepts derived from studies by Eysenck (1967), John et al. (1991), and John and Srivastava (1999) [83–85]. Commonly referred to as OCEAN, an acronym for the five dimensions involved, the BFI evaluates the following traits [58]:

1. Openness: reflects a tendency to be open to new experiences, characterised by creativity, curiosity, a broad range of interests, imagination, and artistic sensitivity.
2. Conscientiousness: pertains to responsibility, diligence, organisation, reliability, self-discipline, and perseverance.
3. Extraversion: indicates a preference for social interaction and gatherings, with traits such as impulsiveness, sociability, assertiveness, talkativeness, and a penchant for excitement.
4. Agreeableness: manifests in individuals who are cooperative, compassionate, kind-hearted, helpful, forgiving, caring, and trustworthy.
5. Neuroticism: relates to emotional instability, with a tendency to experience negative emotions, anxiety, and worry.

In addition, Indrani et al. (2023) performed a more specific investigation of personality traits by investigating introversion and extraversion [29]. Furthermore, Appel-Meulenbroek et al. (2020) further detailed this spectrum in their measurement of extraversion and neuroticism [35]. By contrasting statements like "extraverted, enthusiastic" with "reserved, quiet", their work allows for the more precise identification of where individuals might fall on these spectrums. Similarly, Haka et al. (2009) assessed introversion by evaluating preferences for maintaining a small number of close friends and a tendency to exhibit reserved behaviour, except when interacting with trusted companions [45]. The assessment also considered the extent to which individuals enjoy socialising, display outgoing behaviours, and seek out stimulating and lively environments. Moreover, studies performed using the GABO Questionnaire also posed questions related to individual characteristics, such as morale and self-confidence [29,33,37,55,62].

Noise Sensitivity

Noise sensitivity refers to the extent to which an individual is affected by noise in their environment; noise can significantly influence daily activities such as sleep and work, and can also impact one's overall well-being. Understanding this sensitivity is crucial for assessing the impact of noise on quality of life, and various tools and questionnaires have been developed for this purpose.

One of the primary instruments for measuring noise sensitivity is the NoiseQ Sensitivity tool, a psychometric assessment designed to evaluate an individual's sensitivity to noise. Yadav et al. (2017) adapted the original NoiseQ Sensitivity instrument [68], developed by Schütte, Marks et al. (2007); this consists of 35 items [86]. These items are divided into 5 domains: leisure (noise sensitivity in recreational settings), work (noise sensitivity in work environments), habitation (noise sensitivity in living areas), communication (noise sensitivity during conversations), and sleep (noise sensitivity during sleep) [86].

A shortened version, the NoiseQ-R Sensitivity, has been employed in studies utilising the GABO Questionnaire, as seen in the work of Pierrette et al. (2014), Abdalrahman and Galbrun (2017), Lenne, Chevret, and Marchand (2020), Indrani et al. (2023), and Bergefurt, Appel-Meulenbroek, and Arentze (2024) [29,33,37,55]. The short version of NoiseQ Sensitivity was used by Griefahn (2008), evaluating noise sensitivity across three key domains: sleep, habitation, and work [87].

Additionally, Haapakangas et al. (2014) utilised the work subscale from this questionnaire to assess participants' noise sensitivity [44]. Indrani et al. (2023) incorporated noise sensitivity into other sections of their questionnaire, alongside the GABO Questionnaire [29].

Besides the NoiseQ Sensitivity tool, Zhang, Ou, and Kang (2021) employed a questionnaire based on Weinstein's noise sensitivity scale [88], which evaluates an individual's sensitivity and responses to noise in various everyday contexts, assessing environmental preferences, noise tolerance, sensitivity during sleep, and the ability to concentrate in noisy settings [69]. Similarly, Kang et al. (2023) integrated the NoiseQ-R Sensitivity into their research using the methods recommended by ISO 22955:2021 [9,50].

Moreover, Haka et al. (2009) also included a noise sensitivity questionnaire in their study to assess how individuals' sensitivity to noise influences their ability to concentrate despite environmental disturbances and their capacity to adapt to noise [45]. Park et al. (2020) employed a noise sensitivity questionnaire consisting of five items, although the specific details of these questions were not disclosed in their study [60].

Coping Strategy

The analysis of the reviewed studies indicates that individuals develop various strategies to adapt to disruptive office environments. These strategies can be categorised as follows:

1. The use of headphones/earphones/earplugs: Studies by Acun et al. (2018), Appel-Meulenbroek et al. (2020), and Rolfö et al. (2018) [22,35,64] highlight the use of headphones, earphones, or earplugs as common coping strategies. These devices are not only used for listening to music but also as a means of isolating oneself from disruptive sounds, sometimes without even playing music.
2. Leaving the workspace: Temporarily leaving the workspace, moving to a quieter area, or working from home are strategies employed to avoid disruptive noise. This approach is noted in studies by Acun et al. (2018), Ali (2011), Appel-Meulenbroek et al. (2020), and Bergefurt, Appel-Meulenbroek, and Arentze (2024) [22,34,35,37].
3. Interaction with colleagues: discussing noise issues with colleagues is one way to cope with workplace noise, as observed in studies by Appel-Meulenbroek et al. (2020) and Bergefurt, Appel-Meulenbroek, and Arentze (2024) [35,37].
4. Work delay or interruption: Some workers delay tasks, adjust their work pace, or interrupt their workflow to cope with noise. This strategy also includes directly asking colleagues to lower their voices, as documented by Acun et al. (2018),

Appel-Meulenbroek et al. (2020), and Bergefurt, Appel-Meulenbroek, and Arentze (2024) [22,35,37].

5. Managing noise levels: Managing noise levels involves workers trying to be quieter themselves, using designated rooms for private calls, or stepping outside to take calls. This strategy is discussed in studies by Acun et al. (2018), Appel-Meulenbroek et al. (2020), and Bergefurt, Appel-Meulenbroek, and Arentze (2024) [22,35,37].
6. Reporting and interaction with management: reporting noise issues to management and proposing improvements to workplace acoustics are strategies used to address noise problems, as seen in studies by Ali (2011), Appel-Meulenbroek et al. (2020), and Bergefurt, Appel-Meulenbroek, and Arentze (2024) [34,35,37].
7. Other strategies: some workers choose to do nothing or make an extra effort as a way to cope with workplace noise, as noted in the work of Appel-Meulenbroek et al. (2020) [35].

These strategies highlight the diverse approaches that workers adopt to mitigate the impact of noise in office environments, emphasising the importance of understanding and addressing the varied needs of employees to enhance productivity and well-being.

Acoustic Adaptability

Acoustic adaptability refers to an individual's ability to adjust and become accustomed to their acoustic environment, which is crucial for maintaining productivity and well-being in office environments. Haka et al. (2009) investigated participants' ability to adjust to their surrounding sound environment [45], laying the groundwork for the subsequent research by Yadav et al. (2019) and Haapakangas et al. (2011, 2014) [43,44,68]. Similarly, Hongisto et al. (2017) and Kang et al. (2023) examined acoustic adaptability by assessing participants' capacity to adapt to general acoustic conditions [46,50].

Indrani et al. (2023) explored acoustic adaptability in noisy office environments by evaluating how well participants could adapt to and tolerate noise, whether this came from the surrounding environment or colleagues' behaviour [29]. The questionnaire also assessed participants' familiarity with these noisy conditions, probing whether they had become accustomed to the levels of noise and disruptive behaviour commonly encountered in their office environment [29]. Additionally, Lee et al. (2020) examined this adaptability by measuring participants' willingness to listen to various types of sound throughout the workday [54].

In a different approach, Jiajun et al. (2017) explained that the perception of conversational sounds as background noise or otherwise can influence an individual's ability to adapt to their acoustic environment, as revealed through interviews [48].

Cognitive Workload

Evaluating the impact of noise on work performance and cognitive well-being often involves measuring "cognitive workload", a crucial factor in understanding how noise influences mental capacity and cognitive efficiency in office environments. One commonly used tool in these studies is the NASA Task Load Index (NASA-TLX), which assesses how different acoustic conditions affect the cognitive load during task performance [44,50,68,69]. The NASA-TLX measures the workload across six subscales:

- Mental demand: the mental challenge posed by the task.
- Physical demand: the physical effort required to complete the task.
- Temporal demand: the pressure to complete the task within a certain time.
- Performance: the individual's perception of their success in achieving the task's goals.
- Effort: the perceived amount of work necessary to accomplish the task.
- Frustration: the level of frustration or satisfaction experienced during the task.

In addition to NASA-TLX, another assessment tool is used to capture the complexity of the mental workload. In 2020, a study by Lenne, Chevret, and Marchand used a comprehensive mental workload questionnaire based on the Individual Workload Activity (IWA) model developed by [55,89]. This model measures cognitive load across four dimensions:

- Intrinsic cognitive load: the cognitive load related to the inherent complexity of the task.
- Extraneous cognitive load: the cognitive load caused by the presentation of information and external factors, including work organisation and time management.
- Germane cognitive load: the cognitive load associated with the learning process and the construction of knowledge schemas.
- Available cognitive resources: the cognitive resources available to an individual while completing a task.

While both the NASA-TLX and the IWA model measure mental workload, they do so with different emphases. The NASA-TLX provides a broad assessment of workload across six dimensions: mental, physical, and temporal demands, performance, effort, and frustration. In contrast, the IWA model offers deeper insights into cognitive aspects, making each tool suitable for different research focuses.

Work Performance

Work performance in office environments is evaluated using various tools that capture different dimensions of employee effectiveness. In the study by Bergefurt, Appel-Meulenbroek, and Arentze (2024), work performance was assessed using a questionnaire derived from the Health at Work Survey published by the World Health Organization (WHO) [37]. This comprehensive survey provides insights into how workplace conditions influence employee output. Similarly, Kang et al. (2023) employed a subjective work performance questionnaire, asking participants to self-assess their performance during tasks [50]. This method highlights the importance of self-assessment in understanding individual work performance, capturing personal perceptions that might not be evident in objective measures.

Productivity is another aspect of work performance that is examined through various approaches. The Health at Work Survey used by Bergefurt, Appel-Meulenbroek, and Arentze (2024) included questions on productivity, evaluating how workplace health and environmental factors influence productivity [37]. A study by Kang et al. (2017) evaluated office productivity in university open-plan research offices (UOROs), assessing how the space design and organisational culture impact employees' efficiency [49]. Moreover, Jo and Jeon (2022) focused on perceived productivity, exploring how employees perceive their own productivity within their office environment [11]. Additionally, Rolfö et al. (2017) provided qualitative insights into productivity through interviews, asking employees if they felt productive [64].

Concentration, a critical factor in work performance, has been evaluated using various questionnaires and scales. A study by Bergefurt, Appel-Meulenbroek, and Arentze (2024) used the Checklist Individual Strength (CIS) approach to evaluate concentration with statements like "I can concentrate well" and "I have trouble concentrating". This standardised approach provides detailed insights into concentration in the office environment [37,90]. Latini et al. (2023) examined concentration difficulties related to cybersickness in digital work environments, while Oseland and Hodsman (2018) explored broader cognitive challenges, such as decision-making difficulties and memory lapses [52,58]. Additionally, Lee et al. (2020) examined the satisfaction with the concentration allowed by different types of noise in the office environment [54].

Motivation, a key driver of work performance, has been evaluated in various contexts. Jo and Jeon (2022) evaluated employee motivation in professional roles, specifically assessing their willingness to work [11]. This aspect of motivation is closely linked to job satisfaction and reflects an individual's readiness to engage with tasks. Haka et al. (2009) introduced the concept of speed motivation, exploring how time pressure influences motivation in fast-paced office environments. Additionally, they explored achievement motivation by examining individuals' preferences for goal-oriented tasks [45].

Job satisfaction, a key outcome of effective work performance, has been assessed through straightforward yet comprehensive questions. Hongisto et al. (2017) evaluated overall job satisfaction by asking employees how satisfied they were with their work, providing a broad measure of general employee contentment [46]. Park et al. (2020) explored specific dimensions of job satisfaction, including enthusiasm, enjoyment, and overall satisfaction with the current job [60]. This detailed approach offers a deeper understanding of the factors driving job satisfaction and its relationship with performance and motivation.

In addition to core areas like work performance, productivity, concentration, and motivation, other factors, such as efficiency, accuracy, and job characteristics, have also been evaluated. Haka et al. (2009) developed questions to assess how efficiently, quickly, and accurately employees performed their tasks, offering insights into the quality of work produced [45]. Park et al. (2020) examined job characteristics, including skill variety, task identity, task significance, and autonomy, linking these elements to overall job satisfaction and performance [60]. Furthermore, Bergefut, Appel-Meulenbroek, and Arentze (2024) addressed the nature of work tasks, particularly the challenges encountered in suboptimal environments [37]. This focus was adapted from the work of Budie et al. (2019) [91]. Haapakangas et al. (2011) focused on the perceived difficulty of tasks and the effort required to complete them, while Oseland and Hodsman (2018) explored cognitive challenges, such as decision-making difficulties and issues with clarity of thought [43,58].

Space Dynamics

Spatial dynamics refer to the complex interactions between the physical attributes of an environment—such as spatial configuration, workstation layout, density, and positioning—and their impact on the behavioural, cognitive, and social outcomes of individuals within that space. These dynamics influence interactions, task performance, cognitive load, privacy, and overall well-being.

The capacity of workstations plays a crucial role in shaping space utilisation dynamics in office environments. Studies by Abdalrahman and Galbrun (2017) and Indrani et al. (2023) explored the number of occupants in a room housing a workstation [29,33], while Castaldo et al. (2018) focused on the number of workstations within a specific workplace [39].

Spatial density is another factor that has been identified in the space dynamic context. Ayoko et al. (2023) assessed the overall density of office spaces [36], while Kim et al. (2020) examined the degree of enclosure, the distance between employees, and the adequacy of personal workspace [51]. Similarly, Kang et al. (2017) addressed the adequacy of personal space [49], while Rolfö et al. (2017) examined satisfaction with visitor space and the distance from colleagues [64]. These inquiries are designed to evaluate the perception and utilisation of space, particularly in terms of how crowded or spacious an environment feels.

The positioning of a workstation is also important in the context of space dynamics. Abdalrahman and Galbrun (2017), Indrani et al. (2023), and Pierrette et al. (2014) explored the physical location of workstations, while Kang et al. (2017) focused on specific seating positions, such as proximity to windows or doors [29,33,49,62]. These studies help to identify how workstation placement impacts the user experience. Additionally, Otterbring et al. (2021) analysed various office configurations, including cellular offices, shared-room offices, and open-plan offices, with an emphasis on cognitive perceptions of office environments [59]. Their assessment examined factors like office quality, questioning whether the layout represented the best or worst conceivable arrangement. The study that employed the GABO Questionnaire also explored the type of office used by the participants [29,33,62].

Privacy and workspace separation are essential for maintaining focus and minimising distractions in office environments. Forooraghi et al. (2023) and Rolfö et al. (2017) investigated satisfaction with the privacy levels provided by walls, panels, and furnishings surrounding workstations [41,64]. These questions assessed how well the workspace provided seclusion, supported concentration, and minimised distractions. Additionally, Ayoko et al. (2023) explored office privacy in terms of the availability of spaces for specific activities, such as online meetings or telephone conversations [36]. Rolfö et al. (2017) also explored employee experiences in shared workspaces through focus groups and individual interviews, offering a different perspective [64].

Inquiries regarding space usage and preferences, as conducted by Indrani et al. (2013), examined how individuals use available space, their preferences for specific spaces, and the frequency of use in terms of these spaces. These questions aim to understand how well the space meets users' needs and aligns with their preferences and work habits [29]. Additionally, Eşmebaşı et al. (2024) evaluated the participants' agreement with their perceived preference for their working space [40].

Virtual and augmented environments are becoming increasingly relevant, with Latini et al. (2023) introducing questions to evaluate spatial presence and immersion [52]. These questions explore whether individuals feel a sense of presence or immersion in virtual spaces, which is increasingly important as virtual workspaces gain prevalence.

Working Habits

Working habits refer to various aspects of individual behaviour in office environments, including attendance patterns, workplace movement, and adaptability to dynamic office environments.

Castaldo et al. (2018) developed a questionnaire to measure the duration of daily attendance at the workplace and typical working hours [39]. Additionally, questions related to finding suitable workspaces were integrated into the study by Rolfö et al. (2017) [64]. This study also assessed individuals' habits regarding the consistent use of the same workstation and the time spent daily searching for an appropriate workspace. Questions related to time spent in the office were also addressed by Ayoko et al. (2023) and Indrani et al. (2013) [29,36]. Furthermore, Rolfö et al. (2017) evaluated workplace movement through focus groups and individual interviews by measuring the frequency of workspace changes within a day and individuals' willingness to request workstation exchanges with colleagues [64].

Social Behaviour

Social interaction is another factor highlighted in studies analysing soundscapes. Understanding the dynamics of these interactions is crucial for organisations aiming to cultivate a collaborative and positive office environment.

Acun et al. (2018) explored how appropriate noise levels can create a dynamic office environment and enhance communication among employees through interviews [22]. Moreover, Forooraghi et al. (2023) evaluated intra- and inter-team collaboration, as well as the overall work atmosphere, through a series of questions designed to measure teamwork effectiveness, assess the office environment, and gauge employees' attachment to their workplace [41].

Additionally, Ayoko et al. (2023) examined relational conflicts in the workplace. Their research focused on the dynamics of everyday workplace conflicts, investigating direct interactions between employees, task-related disagreements, differing ideas, and non-work-related conflicts, such as social or personal issues [36].

Suggestion for Space Improvement

Several studies have explored the importance of improving the acoustic quality of environments, emphasising the significance of effective sound management in office environments. For instance, Mediastika and Binarti (2013) used a questionnaire to gather respondents' expectations for room improvements [57]. Additionally, Miterska and Kompała (2023) surveyed office workers to establish satisfactory changes to the acoustic environment and conducted a Delphi risk assessment with acoustic experts to rank the risks posed by different sound sources. This approach ensured that the high-risk sound sources identified by the experts were effectively mitigated, aligning with the issues raised by participants in the initial survey for improving acoustic environments [31].

Other studies used specific questions to solicit recommendations related to improving acoustic quality. For instance, Ali (2011) investigated methods for reducing office noise, with respondents advocating for the use of sound-absorbing materials on walls, ceilings, and floors. Additional suggestions included regulating air conditioning systems to achieve quieter operation, enforcing quiet zones or conversation rules, and installing partitions to minimise noise levels [34].

Castaldo et al. (2018) examined whether employees felt that their company's strategies effectively enhanced overall comfort, including acoustic improvements [39]. Rolfö et al. (2017), through focus group interviews, explored broader office environmental issues and asked participants for suggestions related to improving not only acoustics but also other aspects of the physical environment [64].

3.3. Tools for Examining the Physical and Psychological Well-Being of Workers in Office Environments

This review has identified tools used to assess physical and psychological well-being, as well as their impact on the perception of the sound environment. These tools are categorised into two groups: physical conditions and psychological conditions.

3.3.1. Physical Conditions

Physical conditions refer to an individual's physical state, influenced by various factors in office environments. These conditions encompass aspects such as physical and mental fatigue, bodily pain, sleep difficulties, and the impact of environmental factors like noise.

Several studies have assessed overall perceptions of health. For example, Abdulrahman and Galbrun (2017), Indrani et al. (2023), Lenne, Chevret, and Marchand (2020), and Pierrette et al. (2014) used questionnaires to evaluate individuals' self-perception of health and compared it with the results from a previous year [29,33,55,62]. Similarly, Bergefurt, Appel-Meulenbroek, and Arentze (2024) evaluated the overall physical condition using the WHO's Health at Work Survey [37].

Fatigue and physical exhaustion are frequently highlighted as significant physiological conditions. Studies by Bergefurt, Appel-Meulenbroek, and Arentze (2024) and Lenne, Chevret, and Marchand (2020) assessed these conditions using various tools, including the Checklist Individual Strength [37,90] and the Multidimensional Fatigue Inventory [55,92]. Indrani et al. (2023) also specifically examined fatigue levels at the end of the workday in office environments [29].

Pain and physical discomfort were other significant aspects explored in the analysed studies. These aspects were investigated by Abdulrahman and Galbrun (2017), Indrani et al. (2023), Lenne, Chevret, and Marchand (2020), and Pierrette et al. (2014), who conducted detailed investigations into various types of pain, including back, neck, and headache pain [29,33,55,62]. Latini et al. (2023) also explored related symptoms, such as eye strain and vertigo, in virtual reality experiments [52]. Abdalrahman and Galbrun (2017) uniquely highlighted an increase in toilet visits due to the presence of a water feature, with broader physical discomfort implications regarding daily life [33].

Other aspects that have been successfully investigated include sleep quality and alertness, which are critical for physiological well-being and are often linked to daily functioning and long-term health. Abdulrahman and Galbrun (2017), Indrani et al. (2023), Lenne, Chevret, and Marchand (2020), and Pierrette et al. (2014) addressed sleep difficulties [29,33,55,62], while Bergefurt, Appel-Meulenbroek, and Arentze (2024) used the Single-Item Sleep Quality Scale (PSQ) and the WHO's Health at Work Survey to measure sleep quality [37,93]. Haapakangas et al. (2014) investigated sleep during the preceding night [44], while both Haka et al. (2009) and Otterbring et al. (2021) focused on alertness levels [45,59]. Additionally, Haapakangas et al. (2011) employed the modified Karolinska Sleepiness Scale (KSS) [94] to measure both sleep during the preceding night and arousal [43].

3.3.2. Psychological Conditions

The psychological conditions in office environments have been extensively studied, with various instruments employed to assess stress and anxiety levels. For instance, Abdulrahman and Galbrun (2017), Indrani et al. (2023), Lenne, Chevret, and Marchand (2020), and Pierrette et al. (2014) utilised questionnaires to measure work-related stress [29,33,55,62]. Additionally, Bergefurt, Appel-Meulenbroek, and Arentze (2024) employed the PHQ-4, the Four-Item Patient Health Questionnaire for Anxiety and Depression [95], which assesses anxiety and depression symptoms through questions exploring nervousness, anxiety, difficulty controlling worry, feelings of sadness or hopelessness, and a loss of interest or pleasure in daily activities [37]. Haka et al. (2009) distinguished between trait anxiety (a general predisposition to anxiety) and state anxiety (anxiety in specific situations) [45]. The questions addressed feelings of happiness and contentment to assess trait anxiety and calmness or worry to assess state anxiety, providing a comprehensive understanding of an individual's anxiety levels.

Indrani et al. (2023) further investigated how noise disturbances contribute to stress, asking specific questions about the psychological effects of these disturbances by the end of the workday [29]. Other studies, such as Ali (2011), examined negative psychological impacts like anger, decreased motivation, and low job satisfaction [34]. Ayoko et al. (2023) measured individuals' emotional responses to unpleasant work situations, focusing on negative emotional states [36].

Affective well-being and mood have also been assessed using various instruments. Otterbring et al. (2021) utilised bipolar scales featuring word pairs like "Bored–enthusiastic" and "Fed up–engaged" to measure affective well-being [59]. Additionally, Bergefurt, Appel-Meulenbroek, and Arentze (2024) employed the UWIST Mood Adjective Checklist to evaluate hedonic tone and tense arousal, providing insights into individuals' emotional states in the office environment [37,96]. They also used the Oldenburg Burnout Inventory-Based Questionnaire to evaluate work-related fatigue and engagement, focusing on respondents' physiological and psychological conditions. This questionnaire measures two primary aspects: exhaustion, which reflects how tired and drained an individual feels from their work, and disengagement, which indicates how involved or motivated an individual is in their work. The questionnaire included statements about tiredness before starting work, speaking negatively about work, emotional exhaustion, and how well an individual copes with work pressure while maintaining energy for outside activities [97].

In addition to disengagement, Ayoko et al. (2023) investigated employee withdrawal behaviour, both physical and psychological [36]. Participants were asked about their desire to distance themselves from coworkers and their wish to be left alone in the workplace.

Mental fatigue and motivation were assessed by Lenne, Chevret, and Marchand (2020) using the Multidimensional Fatigue Inventory (MFI-20), which provides insights into how fatigue affects motivation and work performance [55]. Additionally, Haka et al. (2009) evaluated the locus of control, assessing individuals' perceptions of their personal control over their own lives [45].

3.4. Objective Factors in Soundscape Assessment Protocols in Office Environments

In parallel with the evaluation of subjective factors, the objective factors identified in each assessment protocol taken from the analysed studies were systematically categorised into two primary groups: acoustic and non-acoustic factors, as illustrated in Figure 7.

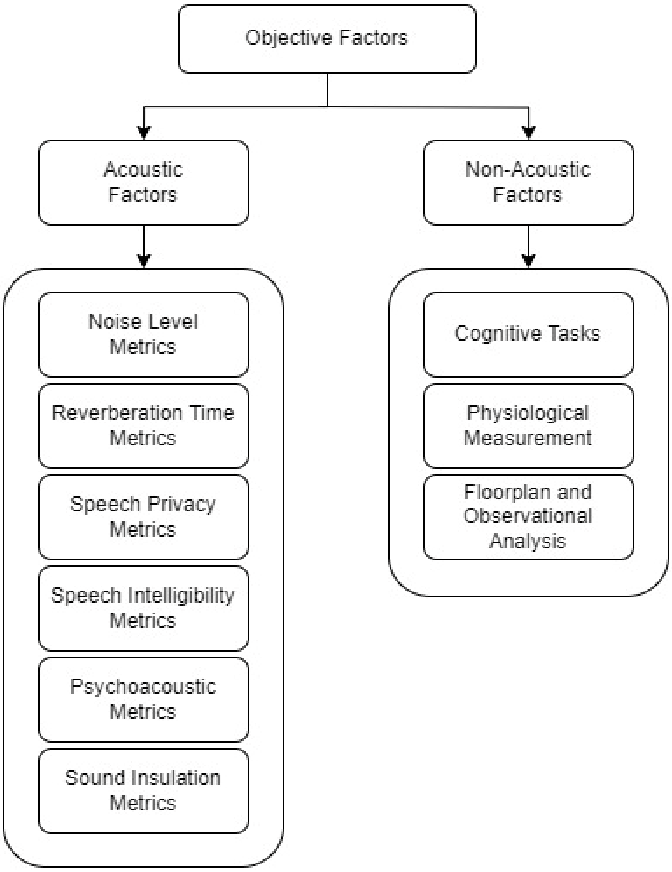

Figure 7. Objective factors used in soundscape assessment protocols in office environments.

3.4.1. Acoustic Factors

Noise Level Metrics

Research on noise in office environments underscores the importance of various parameters for assessing the impact of noise on comfort, productivity, and well-being. Below is an analysis of noise measurements from key studies, which are categorised by the parameters measured and their applications.

Abdalrahman and Galbrun (2017) measured the sound pressure level (SPL) to evaluate noise from indoor water features (45.5 dBA) [33], while Kim et al. (2020) (45–47 dBA) used SPL to understand baseline sound intensity in open-plan offices and its effects on worker comfort and productivity [51]. Similarly, Zhang, Ou, and Kang (2021) examined SPL in open-plan offices to analyse noise from target and masking sounds (55 $\pm$ 0.4 dBA under each condition) [69]. Liang et al. (2014) also used noise levels to evaluate acoustic quality as part of an indoor environmental quality (IEQ) assessment in office buildings (with the maximum at 65 dB) [56].

Eşmebaşı et al. (2024) used traffic noise levels to control the presentation of sound levels based on direct measurements (50–65 dBA), ensuring precise and consistent conditions for their study [40]. Latini et al. (2024) calibrated the sound levels in the virtual environment to closely match real-world conditions, introducing variations in different scenarios (45 dBA and 54 dBA) [53]. Similarly, Lee et al. (2020) used A-weighted sound levels (dBA) in open-plan offices to assess the effect of different sounds on cognitive performance and comfort (44–45 dBA) [54].

Equivalent Continuous Sound Level (LAeq) is a key parameter used to measure average noise levels under various environmental conditions. Studies by Renz et al. (2018), Haapakangas et al. (2011, 2014), Jo and Jeon (2022), and Miterska and Kompała (2023) demonstrate that LAeq is widely employed in workplace settings to assess the impact of noise on comfort, speech privacy, and worker productivity (46.8 dBA, 45–48 dBA, 33–45 dBA, 49.9–59.3 dBA, and 34.7–56.9 dBA, respectively) [11,31,43,44,63]. Additionally, Lenne, Chevret, and Marchand (2020) utilised LAeq to gauge the effectiveness of sound masking systems in reducing noise and enhancing acoustic comfort (below 45 dBA) [55]. Similarly, Haka et al. (2009) highlighted the importance of maintaining consistent LAeq (48 dBA) across experimental conditions to ensure the impact of speech intelligibility on cognitive task performance and subjective disturbance [45]. Moreover, Wang and Novak (2010) and Yadav et al. (2017) applied LAeq (44–53 dBA and 42 dBA, respectively) to evaluate the relationship between noise levels, subjective perception, and cognitive performance in various open office scenarios [66,68]. Furthermore, Abdalrahman and Galbrun (2017), along with Hongisto et al. (2017), illustrated how LAeq (39.3 dBA and 43–35 dBA, respectively) is used to compare noise levels and ensure consistent masking sound, which are critical tasks in acoustic office design [33,46].

Some studies focus on measuring LAeq over specific periods to capture noise variations within a defined timeframe. For instance, Vellenga et al. (2017) measured LAeq for 5 min (35 dBA and 55 dBA) in an open-plan office to study its impact on worker concentration [65], while Mediastika and Binarti (2013) measured Leq for 7 h (58 dBA) to determine greenery's effect on noise reduction [57]. Additionally, Ali (2011) and Park et al. (2020) used LAeq for 8 hours (72 to 93 dBA) to assess compliance with noise regulations and its effect on productivity [34,60]. Moreover, Bourikas et al. (2021) extended the measurement period to 16 hours to perform long-term noise exposure (60 dBA) analysis in office environments [38]. Furthermore, Wen et al. (2024) used variations of LAeq (55 dBA, 65 dBA, 75 dBA) in their experiment to represent different noise conditions: a quiet environment, a moderate noise level, and a noisy office setting [67].

Statistical noise descriptors such as Lmax, Lmin, L10, L50, and L90 provide deep insights into noise patterns in various environments. Lmax and Lmin, measured by Ali (2011) (Lmax = 101 dB, Lmin = 68 dB) and Miterska and Kompała (2023) (Lmax = 84.5 dBA, Lmin = 34 dBA), identify noise peaks and stable background noise in open-plan offices [31,34]. High noise peaks (Lmax) can be a significant source of disturbance, while Lmin reflects a stable background noise level. Furthermore, in the study by Miterska and Kompała (2023), L5 (84.5 dBA) was used to measure noise levels that exceeded 5% of the measurement period, indicating intense but infrequent sound events [31]. Additionally, L10 (50 dB) was employed by Bourikas et al. (2021) to capture noise peaks occurring within 10% of the time period, highlighting more frequent noise disturbances [38]. Similarly, L90 (43 dBA) was used in a study by Lenne, Chevret, and Marchand (2020) to represent stable background noise, which is crucial for long-term comfort [55]. In addition, the variation between LA10 and LA90, as shown in the studies by Jo and Jeon (2022) (2.7 to 12.6 dB) and Renz et al. (2018) (LA10 = 45 dBA, LA90 = 35 dBA), indicates temporal fluctuations in noise, where greater variations are correlated with increased disturbances [11,63]. Moreover, Wang and Novak (2010) measured broader noise fluctuations, examining L1–L99 (33.4–57.7 dB), to understand their impact on perception and task performance [66].

Noise criterion (NC) and related parameters such as room noise criterion (RNC), preferred noise criterion (PNC), and balanced noise criterion (NCB) are used to ensure optimal indoor acoustic quality. Kim et al. (2020) applied NC to verify whether work environments met acoustic standards [51]. Meanwhile, Hongisto et al. (2017) evaluated NC, RNC, PNC, and NCB, which were set within the range of 40–45 dB, to determine the most suitable sound spectrum for acoustic comfort, focusing on participants' subjective responses to different sound masking strategies [46]. Wang and Novak (2010) and Yadav et al. (2017) used RNC (38–60 dB in various frequencies; 31 dBA; respectively) to assess noise fluctuations, low-frequency fluctuations, which can affect comfort and productivity [66,68]. Wang and Novak (2010) also explored NCB (29–41) and RC/RC-Mark II (30–44) to understand subjective perceptions of noise characteristics like rumble and hum, providing insights for effective acoustic design [66].

In addition to the previously mentioned parameters, several studies have explored other metrics to further understand and optimise acoustic environments. For instance, Kim et al. (2020) and Lenne, Chevret, and Marchand (2020) evaluated sound masking levels (between 40 dBA and 45 dBA) to assess sound masking effectiveness in open-plan offices [51,55]. Peng et al. (2023) analysed Lden (53 dB) and Lnight (45 dB) to examine the impact of external noise, like traffic, on thermal comfort in naturally ventilated and air-conditioned buildings [61]. Moreover, Hongisto et al. (2017) investigated speech interference levels (43–45 dB LAeq) and low-frequency noise levels (40 dB) to determine how sound masking can improve speech privacy and overall comfort in open offices [46]. Jiajun et al. (2017) explored the sound intensity level (55–60 dBA) and receiving loudness level (55–60 dBA) to evaluate the effectiveness of sound masking systems [48].

Reverberation Time Metrics

Reverberation time (RT) refers to the time it takes for a sound to decay to an inaudible level after the source stops, making it a critical parameter in assessing the acoustic quality of various spaces, including office environments. Studies that assess reverberation time using different methods and referenced standards contribute significantly to the understanding and enhancement of acoustic quality in office environments.

RT60 is the most commonly used parameter in this regard, representing the time it takes for sound to decrease by 60 dB after the sound source ceases. Gatland et al. (2018) measured RT60 to evaluate the acoustic quality of open spaces before and after spatial reconfigurations in both traditional and LEED-certified buildings (0.6 s for the traditional building, and a higher RT for the LEED building) [42], adhering to the ASTM E2235-04 standard [70]. Similarly, Kim et al. (2020) employed RT60 to evaluate acoustic quality in open-plan offices and enclosed spaces after renovations aligned with the WELL Building Standard (some samples exceeded the WELL standards of 0.6 s for conference rooms and 0.5 s for open workspaces), emphasising the importance of a healthy acoustic environment [51].

RT60 has been used in other studies for various purposes. Latini et al. (2023) measured RT60 to evaluate the acoustic characteristics of virtual rooms (around 1.2 s for low frequencies and 0.8 s for higher frequencies) [52], following the UNI EN 12354-6:2006 standard [80]. Lenne, Chevret, and Marchand (2020) used RT60 to assess open-plan office acoustics (0.48 s–0.59 s), particularly focusing on the impact of sound masking systems [55], in line with the NF S 31-199:2016 standard [81].

In addition to RT60, RT20 and RT30 provide further insights into the acoustic characteristics of spaces. Park et al. (2020) utilised RT20 to understand the acoustic properties of open-plan offices (0.3 s–0.54 s), a task that is essential for evaluating speech privacy [60]. RT30 was also utilised by Bourikas et al. (2021) to estimate RT60 [38] and by Jeon et al. (2022) to assess and validate acoustic conditions in various room configurations (lower than 1 s; 0.6 s; respectively) [47], following the ISO 3382-1 standard [78]. Latini et al. (2024) measured the RT30 in a real office environment to ensure that the acoustic properties of the virtual office were accurately represented [52]. Additionally, Kang et al. (2023) validated RT30 (measurement: 0.77 s and simulation 0.76 s) simulation results in office environments by comparing them with field measurements.

Another key metric is Early Decay Time (EDT), which is essential for evaluating speech clarity within a room. Haka et al. (2009) and Zhang, Ou, and Kang (2021) employed EDT (0.31 s; 0.57; respectively) to calculate the Speech Transmission Index (STI), a key indicator of speech transmission quality in office environments [45,69].

Speech Privacy Metrics

The measurement of speech privacy metrics based on the ISO 3382-3 standard is critical for evaluating acoustic quality in open-plan offices. This standard specifies various parameters with which to assess how conversational sound propagates and is attenuated within the workspace, influencing the levels of privacy, disturbance, and acoustic comfort perceived by workers.

Several studies have focused on the key metrics such as the A-weighted sound pressure level at a distance of 4 m from the sound source (Lp,A,S,4m), the background sound level (Lp,A,B), and the spatial decay rate of the A-weighted speech level (D2,S). For instance, Bergefurt, Appel-Meulenbroek, and Arentze (2024) evaluated the effectiveness of sound masking in reducing disturbances from audible conversations in open-plan offices, with Lp,A,B ranging from 28.7 dBA to 42.6 dBA, Lp,A,S,4m between 48.7 dBA and 49.7 dB, and D2,S ranging from 4.9 s to 5.2 s [37]. These measurements help to understand how conversational sound can be managed to minimise disruptions. Similarly, Hongisto et al. (2017) measured Lp,A,S,4m (45.3 dB), D2,S (7.0 dB), and the distraction distance (rD) (4 m)—the distance at which conversations can still cause disturbances [46]. These parameters were measured to assess the acoustic quality in open-plan offices, focusing on mitigating conversational disruptions, a key source of discomfort in such environments.

Jeon et al. (2022) and Jo and Jeon (2022) used a combination of Lp,A,S,4m, D2,S, and rD measurements to assess the acoustic impact of open-plan offices on worker satisfaction and task performance, focusing on conversational privacy and acoustic comfort [11,47]. Jeon et al. (2022) reported Lp,A,S,4m measurements of 49.4 dB (simulation: 48.8 dB), D2,S measurements of 4.6 dB (simulation: 4.5 dB), and an rD of 11.1 m (simulation: 11.3 m), while Jo and Jeon (2022) found similar results [11,47]. Kang et al. (2023) applied the same approach, measuring Lp,A,S,4m at 53.8 dBA (simulation: 50.9 dBA) and D2,S at 3.6 dBA (simulation: 3.4 dBA), using both in situ assessments and simulations. This approach was employed to evaluate how conversational sound propagates and decays in open-plan offices, which is essential for understanding its impact on work performance and the perception of the acoustic environment [50].

Meanwhile, Lenne, Chevret, and Marchand (2020) focused on D2,S (5.5 dBA to 7.3 dBA) and Dn (workstation-to-workstation attenuation) (3 dB to 3.8 dB), which are metrics crucial for understanding sound propagation dynamics in open-plan offices [55]. Their study examined how these dynamics affect noise disturbance levels and evaluated the effectiveness of sound masking systems.

Additionally, Park et al. (2020) integrated measurements of D2,S (4.2 dB–7.9 dB), Lp,A,S,4m (45.8 dB–51.9 dB), rD (9.7 m–16.5 m), and Lp,A,B (33.9 dB–40.3 dB) to offer a comprehensive overview of acoustic conditions in open-plan offices [60]. This study emphasised the importance of a thorough understanding of how these acoustic conditions affect conversational privacy, noise-induced disturbance levels, and employee job satisfaction.

Speech Intelligibility Metrics

Speech intelligibility refers to how clearly and easily spoken words can be understood by listeners in an acoustic environment. It is a critical factor in designing spaces such as workplaces, classrooms, or public areas. Poor speech intelligibility can lead to distractions, reduced performance, and diminished comfort. Various acoustic parameters are commonly used to evaluate speech intelligibility, including the Speech Transmission Index (STI) and Definition Index (D50).

The Speech Transmission Index (STI) is one of the most widely used methods for assessing speech transmission quality. For example, Acun et al. (2018) measured STI in open-plan offices, using the Odeon Room Acoustics software 13.10 to evaluate speech transmission quality and privacy (Architecture Office: 0.36–0.64; Engineering Office: 0.52–0.67) [22]. These studies highlight the importance of STI in assessing acoustic comfort and privacy in open workspaces, where noise and speech intelligibility are primary concerns.

Gatland et al. (2018) extended the use of STI to map the "distraction distance"—the distance at which speech becomes disruptive—to help in the design of acoustically comfortable spaces STI < 0.50, 0.50 ≤ STI ≤ 0.60, and STI > 0.60) [42]. Meanwhile, Haapakangas et al. (2011, 2014) assessed the impact of masking sounds on speech intelligibility and cognitive performance (with 2 m from the desk registering at 0.00–0.80 and 6 m from the desk registering at 0.00–0.60, 0.00–0.62, respectively), emphasising the importance of using standards such as ISO 3382-3 for accurate measurement [43,44]. Renz et al. (2018)

investigated how various acoustic metrics, such as STI (0.1–1), are used to assess acoustic quality in open-plan offices [63].

In another approach, Yadav et al. (2017) critiqued the limitations of STI, particularly in environments with multiple speakers. They introduced the multi-resolution envelope power-based (mr-sEPSM) model, which improves the prediction of speech intelligibility in complex multi-speaker scenarios by considering modifications in the spectrotemporal envelope of speech. This model's output is the signal-to-noise ratio in the envelope power domain (SNRev), ranging from 0 dB to 43.4 dB [68]. This model provides a more accurate prediction of how background noise affects speech intelligibility in open-plan offices, where multiple speakers are often present.

Similarly, Zhang, Ou, and Kang (2021) focused on STI, examining how variations in STI (0.00–0.66), influenced by the signal-to-noise ratio (SNR) (−6.6 dB–4.8 dB) and sound masking techniques, impact cognitive performance in tasks like serial recall [69]. This study aimed to understand the effectiveness of sound masking techniques in reducing speech intelligibility and related distractions, such as pink noise or air conditioning noise, which is crucial for enhancing focus and productivity in open-plan offices.

The speech clarity metric (D50) is essential for understanding how well speech can be heard and understood under different acoustic configurations, demonstrating the relevance of speech clarity in office environments. For instance, Jeon et al. (2022) validated D50 (0.89) simulation results in office environments by comparing them with field measurements [47].

Psychoacoustic Metrics

Psychoacoustic metrics, including loudness, sharpness, and fluctuation strength, are employed in various studies to evaluate and understand the impact of acoustic characteristics on human perception and performance in office environments.

Loudness is a measure of how loud a sound is perceived to be by an individual, and is often associated with levels of disturbance or discomfort. Latini et al. (2023) explored whether loudness (88.3 phones (Channel dx) and 88.1 phones (Channel sx)) in virtual office environments can disrupt focus and reduce cognitive performance [52]. Wang and Novak (2010) also examined how loudness (5.3–11.4 sones) influences the perception of disturbance in indoor environments, highlighting its importance in evaluating current noise assessment methods [66].

Sharpness measures the dominance of high frequencies in sound, and is often associated with sharp and potentially disturbing noises. Latini et al. (2023) extended the application of this metric (1.76 acum (Channel dx) and 1.75 acum (Channel sx)) by evaluating its impact on cognitive performance in virtual office environments, discovering that sharper sounds can be more disruptive and reduce productivity [52].

Fluctuation strength relates to the perception of temporal variations in sound, which can cause disturbances, especially in environments requiring high levels of concentration. Latini et al. (2023) assessed the impact of fluctuation strength (0.034 vacil (Channel dx) and 0.031 vacil (Channel sx)) on acoustic comfort and performance in virtual environments [52]. Moreover, Renz et al. (2018) highlighted the importance of fluctuation strength (0.0069 vacil–0.34 vacil) in the context of irrelevant background sounds, such as conversations, which were found to impair working memory performance [63].

Sound Insulation Metric

Sound insulation refers to the ability of building elements, such as walls or floors, to reduce sound transmission between spaces. In the study by Wang and Novak et al. (2010), Sound Transmission Class (STC) was used to evaluate how effectively room structures attenuate sound transmission (STC 47), particularly at low frequencies, which is often a significant source of disturbance and discomfort in office environments [66].

3.4.2. Non-Acoustic Factors

Cognitive Tasks

Cognitive tasks are specialised activities designed to assess various facets of cognitive function, including memory, attention, and problem-solving. This section discusses the cognitive tasks employed in the reviewed studies to evaluate cognitive performance under different acoustic conditions, providing insights into how the brain processes, stores, and utilises information.

The serial recall task, examined in studies by Kang et al. (2023), Zhang, Ou, and Kang (2021), Renz (2018), and Haapakangas et al. (2011, 2014), measures short-term memory by challenging participants to remember and sequentially repeat a series of presented items [43,44,50,63,69]. Similarly, the Operation Span Task and related tasks, explored by Latini et al. (2023, 2024), Haka et al. (2009), and Haapakangas et al. (2014), test both information storage and processing by asking participants to perform mathematical problem-solving while maintaining several items in their memories [44,45,52,53]. Haka et al. (2009) also emphasised the importance of other tasks, such as the Number Series Task, which involves recalling a sequence of numbers in serial order, and the Dot Series Task, which tests memory for virtual presented positions [45]. Latini et al. (2024) explored these memory and processing (M-P) tasks, which assess short-term memory, recall, and processing speed [53].

Furthermore, Jeon et al. (2022) employed the Auditory Backward Digit Span Task to evaluate short-term verbal memory in an audio-visual work environment [47]. Similarly, Yadav et al. (2017) and Jo and Jeon (2022) utilised the backward digit span task in various environments featuring stimuli to quantify work performance [11,68].

The Magnitude-Parity Test designed by Latini et al. (2023) assesses a person's task-switching ability, requiring participants to switch quickly between tasks that require different cognitive processes [52]. Similarly, Haapakangas et al. (2014) examined people's Working Memory Capacity by asking them to recall words that had been displayed after solving a mathematical equation. The Text Memory Task involves remembering details from a previously read text and provides deeper insights into how individuals process and store textual information [44].

The N-back task, including the Shape N-back task investigated by Haapakangas et al. (2014) and Lee et al. (2020), measures cognitive flexibility by requiring participants to identify whether the current item matches one presented several steps earlier [44,54]. The Flanker Task and Stroop Task, both explored by Lee et al. (2020) and Latini et al. (2024), test the ability to control attention and process interfering information, measuring how well individuals can focus on relevant information while ignoring distractions [52,54].

Proofreading and creative tasks, examined by Haapakangas et al., (2011) assess error detection and idea generation, highlighting the complexity of measuring cognitive abilities [43]. Haka et al. (2009) also emphasised proofreading tasks and reading comprehension, which involve understanding a text and identifying errors [45].

Moreover, Jiajun et al. (2017) included a cognitive task requiring participants to transfer data from physical printouts to a digital spreadsheet, demanding precision in typing or manual data entry [48]. Similarly, Wang and Novak (2010) employed several cognitive tasks, including a Typing Test, a Grammatical Reasoning Test, and a Math Test, to assess cognitive performance under various noise conditions [66]. Besides grammatical reasoning, Yadav et al. (2017) also utilised the Double Trouble task to assess reasoning abilities, where participants had to select the correct ink colour of a word from two options [68]. Moreover, concentration skills were evaluated using test rotation tasks to assess visuospatial perception, while the Feature Match test examined attention to detail and pattern recognition. Yadav et al. (2017) further assessed planning abilities with the Hampshire Tree Task, which tested strategic planning and problem-solving, and the Spatial Slider, which evaluated spatial awareness and strategic planning [68].

Physiological Measurements

Objective physiological measurement is infrequently employed in research. However, it remains essential for obtaining a more accurate understanding of physiological responses to various stimuli or conditions, complementing subjective data collection.

Lee et al. (2020) conducted a study using a range of physiological measurements to assess participants' responses during cognitive tasks. Blood pressure was measured using the UA-767F automated monitor produced by A&D Medical, ensuring accuracy by averaging two readings taken at each time point after a five-minute relaxation period. Pulse oximetry was monitored with the MightySat, produced by Masimo SET®, which tracked heart rate, oxygen saturation, respiratory rate, pleth variability index, and the perfusion index. Data were transmitted in real-time to an iPad Pro. Electrodermal activity (EDA) was measured with the E4 wristband, produced by Empatica, a medical-class device that also monitored heart rate, temperature, and movement. Skin conductance was sampled four times per second to detect changes in physiological arousal [54].

Latini et al. (2024) employed several physiological measurements to assess participants' responses to different environments. Electrodermal activity (EDA) was measured to track skin conductance, which reflects sweat gland activity and is sensitive to stress and arousal levels. A higher EDA indicates increased psychological or physiological arousal, which is often linked to stress. The pulse rate (PR) was monitored to measure heart rate, providing insights into how blood pulses through the arteries; changes in pulse rate often reflect stress levels and emotional responses, with an increased rate typically associated with negative emotions or stress. Skin temperature (ST) was measured to observe changes in peripheral blood flow, where stress or negative emotions usually cause a decrease in skin temperature due to reduced peripheral circulation, while positive states can lead to an increased skin temperature [53].

Floorplan and Observational Analysis

Recent studies have highlighted the relationship between office design and employee satisfaction, employing various methodologies to analyse how spatial and acoustic factors influence workplace experiences. The studies reviewed provide a comprehensive view of how office layout, design, and daily activities influence employee satisfaction, particularly in terms of privacy, collaboration, and soundscape perception.

Forooraghi et al. (2023) emphasised the importance of floorplan analysis in understanding the impact of office design on employee satisfaction [41]. By examining architectural drawings and comparing them with on-site photographs, the authors identify the types and diversity of work zones, such as quiet areas, semi-quiet spaces, and collaboration zones. Similarly, Indrani et al. (2023) focused on spatial and architectural analysis, examining in particular how cubicle design and the placement of office elements like corridors and windows impact visual and sound privacy [29].

In addition, Acun et al. (2018) employed observational methods to contextualise participants' responses and gain deeper insights into the physical and acoustic environments of offices. By observing the layout, employee behaviour, and sound levels, the study revealed how employees adapt their actions to mitigate noise disruptions, highlighting the dynamic interaction between office design and employee behaviour. The researchers also utilised field notes, categorised into descriptive, reflective, and analytical types, to document observations and interviews in detail. Descriptive notes captured the physical and acoustic aspects of the offices, reflective notes provided insights into researchers' interpretations and employees' emotional responses, and analytical notes identified emerging patterns, such as recurring noise-related issues affecting concentration [22].

4. Discussion

4.1. First Research Question: Which Methods Are Currently Employed to Assess Soundscapes in Office Environments?

The assessment of soundscapes in office environments involves a combination of subjective and objective methodologies. Subjectively, questionnaires are the most commonly used tools to capture participants' perceptions of the acoustic environment [11,14,29,31,33–48,50–66,68,69]. These questionnaires often use various scales, such as 5-point or 7-point scales, to standardise responses and enable thorough statistical analysis. In addition to questionnaires, interviews and discussions are used to provide deeper insights into individual experiences and perceptions, offering nuanced insights that complement the quantitative data [22,47,48,64].

In terms of objective assessment, direct acoustic measurements are typically conducted to assess physical acoustic parameters, providing a concrete basis for evaluating soundscapes [11,22,29,31,33,34,37,38,40,42–48,50–57,60,61,63,65–69]. In some cases, acoustic simulation software is used to model and predict the acoustic characteristics of environments, particularly in virtual experiments or when assessing potential modifications to existing spaces [11,22,47,50]. Cognitive tasks are also designed to evaluate aspects of cognitive function, such as memory, attention, and information processing, under different acoustic conditions [11,43–45,47,48,50,52–54,63,66,68,69]. These tasks help to understand the impact of soundscapes on cognitive performance.

4.2. Second Research Question: Which Factors Are Typically Included in Subjective Assessments to Evaluate the Perceived Quality of Soundscapes in Office Environments?

Subjective assessments of soundscapes in office environments consider a variety of factors, which are broadly categorised into acoustic and non-acoustic factors. Acoustic factors are directly related to the characteristics of sound and how it influences individual perception and comfort, while non-acoustic factors pertain to elements beyond the sound itself that affect how individuals perceive and respond to the soundscape.

Acoustic factors involve the identification of sound sources, including the categorisation of noise sources such as machinery, equipment, human activities, and environmental noise [11,29,33–36,42,49,52,55,56,58,62]. Perceived noise disturbance is a critical factor, with studies assessing how various noise sources impact work performance, concentration, and overall satisfaction [22,29,33–54,64]. The condition of the sound environment is evaluated through general assessments of the soundscape, sudden changes in acoustic conditions, and perceived sound quality across different contexts. Acoustic comfort and satisfaction are measured using direct questioning or semantic scales, often focusing on specific activities or situations that might influence how comfortable individuals feel in their acoustic environment [29,39,42,46,47,50,56,67,69].

Another important aspect is the affective quality of the sound environment, which considers how sounds influence emotions, mood, and overall feelings. This aspect is often described using terms like calmness, tranquillity, comfort, distraction, and stress [29,37,50,56,58,63–65]. Office acoustic metrics are evaluated through assessments of noise levels, acoustic privacy, and speech clarity, all of which help to determine how well individuals can communicate and feel comfortable in their environment [29,33,38,39,41,45–47,50,51,56,57,59,60,62,64]. Noise control strategies, both passive and active, are also examined to understand the effectiveness of noise management and its impact on occupant satisfaction [29,33,37,43–46,51,56,58,62,69].

Non-acoustic factors play a crucial role in shaping how individuals perceive and interact with their acoustic environment. Individual characteristics, such as personality traits measured by tools like the Big Five Inventory, help to understand how different personalities may influence perceptions of noise and acoustic comfort [29,33,35,37,45,55,58,62]. Sensitivity to noise is another key factor, with various tools assessing how noise sensitivity affects daily activities and overall well-being [29,33,37,44,45,50,55,60,62,68,69].

Coping strategies are commonly developed by individuals to adapt to disruptive environments. These include the use of headphones, leaving the workspace, interacting with colleagues, and managing noise levels. Acoustic adaptability, or the ability to adjust to and tolerate noise, is also essential for maintaining productivity and well-being. The cognitive workload is evaluated to understand how noise affects mental capacity and efficiency, often using tools like the NASA Task Load Index [11,43–45,47,48,50,52–54,63,66,68,69].

Work performance is assessed through measures of productivity, concentration, motivation, and job satisfaction, highlighting the influence of the acoustic environment on these outcomes [11,37,43,45,46,49,50,52,54,58,60,64]. Spatial dynamics, including workstation layout, density, privacy, and separation, are also considered, as these factors significantly impact how individuals use and experience space [29,33,36,39–41,49,51,52,59,64]. Work habits, such as attendance patterns and movement within the workspace, are evaluated to understand how these behaviours interact with the acoustic environment [29,36,39,64]. Social behaviour is examined to explore its dynamics of interaction with noise and how noise affects communication and relational conflicts in the workplace [22,41].

Finally, suggestions for space improvement are often solicited to enhance the acoustic quality, with respondents offering ideas on how to better manage sound and improve comfort in office environments [31,34,39,57,64].

Collectively, these factors provide a comprehensive understanding of the elements considered in subjective assessments of soundscapes in office environments, encompassing both direct acoustic impacts and broader contextual influences that shape individual experiences.

4.3. Third Research Question: Which Assessment Tools Are Commonly Used to Evaluate the Physical and Psychological Well-Being of Office Workers in Relation to Their Perception of the Sound Environment?

Various assessment tools have been employed by researchers to comprehensively examine both the physical and psychological responses to auditory environments. Questionnaires on work-related stress and anxiety are frequently used to measure the general perception of stress, including its frequency and intensity, as well as the specific impact of soundscapes on psychological states [11,14,29,31,33–48,50–66,68,69]. Tools like the Four-Item Patient Health Questionnaire for Anxiety and Depression (PHQ-4) [95] assess symptoms such as nervousness, worry, sadness, and loss of interest, which can be influenced by the sound environment [37].

Additionally, the Multidimensional Fatigue Inventory (MFI-20) is used to assess mental fatigue and motivation, providing insights into how soundscapes contribute to fatigue and decreased motivation [55]. Furthermore, the UWIST Mood Adjective Checklist evaluates emotional states by assessing mood and arousal, helping to understand the impact of soundscapes on emotional well-being [96].

The Karolinska Sleepiness Scale measures sleep difficulties and alertness, which are often affected by environmental noise, indicating how soundscapes influence sleep quality and overall mental well-being [94]. Similarly, the Oldenburg Burnout Inventory-Based Questionnaire focuses on work-related fatigue and engagement, examining aspects like exhaustion and disengagement to understand the role of soundscapes in burnout [97].

Researchers also use specific noise disturbance questionnaires to assess how particular soundscape elements contribute to stress and other negative psychological outcomes [22,29,33–54,64]. Finally, bipolar scales for affective well-being, featuring word pairs related to mood or emotional states, are used to assess the impact of soundscapes on mood and overall affective conditions [59].

These assessment tools collectively offer a comprehensive understanding of how soundscapes influence mental well-being by evaluating various psychological and physiological factors across different environments. Bergefurt, Appel-Meulenbroek, and Arentze (2024) conducted the most recent study to comprehensively examine the physical and psychological well-being of office workers in relation to their sound environment perceptions within the workplace. This study explores the impact of implementing adaptive sound masking on levels of sound disturbance, coping strategies, and mental health in open-plan offices. The aspects observed in this research include noise sensitivity, coping strategies, distraction, noise disturbance, and mental health conditions (well-being, productivity, job performance, stress, depressive symptoms, disengagement, exhaustion, concentration, fatigue, sleep quality, hedonic tone, and tense arousal) [37].

The findings indicate that installing an adaptive sound masking system in open-plan offices successfully reduced the need for employees to use personal strategies like listening to radios or wearing headphones to cope with noise disturbances. Moreover, the study concluded that the adaptive sound masking system effectively reduced disturbances from speech in open-plan offices and positively impacted employees' short-term mental health, making them feel less stressed and more at ease in their work environment [37].

However, the outcomes of evaluating office workers' physical and psychological well-being regarding their perceptions of environmental sounds in the office can vary based on the conditions of the office sound environment and other factors involved in each respective study.

4.4. Fourth Research Question: Which Objective Acoustic Parameters Are Frequently Involved in Soundscape Assessment in Office Environments?

The assessment of soundscapes in office environments often includes several objective acoustic parameters. These parameters provide quantitative measures that are crucial for evaluating the impact of the acoustic environment on comfort, productivity, and well-being.

One of the most commonly used metrics is the sound pressure level (SPL), which measures the intensity of sound in an environment. SPL is employed to evaluate baseline sound intensity in open-plan offices and other environments to understand its effects on comfort and productivity [11,33,40,51,53,54,56,69]. Another crucial parameter is the Equivalent Continuous Sound Level (LAeq), which measures average noise levels over a specified period. LAeq captures overall noise exposure and is widely used in workplaces to assess its impact on comfort, speech privacy, and productivity [11,31,33,34,38,43–46,55,57,60,63,65–68].

Statistical noise descriptors, such as Lmax (maximum noise level) Lmin (minimum noise level) [31,34], L10, L50, and L90, provide detailed insights into noise patterns and variability [11,38,55,63]. These metrics help to understand the extremes and distribution of noise levels over time, offering a comprehensive view of the acoustic environment.

Noise criterion (NC) and related metrics like room noise criterion (RNC), preferred noise criterion (PNC), and balanced noise criterion (NCB) are also employed to evaluate and optimise indoor noise levels [46,51,66,68]. These criteria ensure that noise levels meet recommended acoustic standards, contributing to the overall acoustic quality of a space.

Reverberation time (RT) is another critical parameter, particularly in office environments. RT measures how long it takes for sound to decay to an inaudible level after the source has stopped emitting it. RT60, the most commonly used measure, helps to assess the acoustic quality of spaces by evaluating how sound reflects and persists [42,51,52,55]. Shorter RT times generally indicate better speech clarity and less reverberation, which are essential for effective communication in open offices [38,47,53,60].

Speech privacy metrics, such as the A-weighted sound pressure level at a specific distance (Lp,A,S,4m), the background sound level (Lp,A,B), and the spatial decay rate of A-weighted speech level (D2,S), are crucial for assessing conversational privacy in open-plan offices. These metrics help to determine how well conversations are masked or heard at a distance, influencing the perceived acoustic comfort and privacy [11,37,46,47,50,55,60].

Speech intelligibility metrics, including the Speech Transmission Index (STI), Clarity Index (C50, C80), and Definition Index (D50), are used to evaluate how clearly spoken words can be understood in an environment [22,42–44,63,68,69]. These metrics are crucial in office environments, where clear communication is essential for effective performance and comprehension.

Psychoacoustic metrics, such as loudness, sharpness, and fluctuation strength, assess how sounds are perceived by individuals, focusing on the subjective experience of noise [52,63,66]. These metrics are key to understanding the impact of noise on comfort and cognitive performance, as they concern the experiential aspects of sound rather than just its physical properties.

Finally, sound insulation metrics, like Sound Transmission Class (STC), measure the ability of building elements to reduce sound transmission between spaces [66]. This is particularly important in environments where noise from adjacent areas can disrupt activities, such as in offices.

Additionally, apart from evaluating room characteristics, cognitive tasks, used by 14 studies, are also frequently utilised to examine the effects of acoustic conditions on cognitive abilities. These tasks are designed to assess various cognitive aspects such as memory, attention, problem-solving, and cognitive flexibility. Tasks like the serial recall and Auditory Backward Digit Span gauge short-term memory by requiring participants to recall sequences of items or numbers in a specific order [11,43,44,50,63,68,69]. The Operation Span Task challenges participants to balance mathematical problem-solving with memory retention [44,45,52,53]. The Magnitude-Parity Test and N-back tasks measure task-switching capabilities and cognitive flexibility by prompting participants to quickly shift their mental focus or identify items from a sequence presented earlier [44,53,54]. Attention and processing tasks, such as the Flanker and Stroop Tests, evaluate the ability to concentrate and process interfering stimuli, which is essential for understanding cognitive control in noisy environments [52,54]. Proofreading and creative tasks also explore error detection and idea generation, showcasing complex cognitive activities [43,45]. Moreover, tasks like the Text Memory and Hampshire Tree Task investigate how individuals process, store, and utilise textual information and strategic planning under varying conditions, underscoring the profound impact of environmental factors, particularly noise, on cognitive functions [44,68]. These studies aim to provide various approaches by assessing diverse aspects such as memory, attention, problem-solving, and cognitive flexibility, allowing task selection to be tailored to the objectives of the research and the specific aspects being evaluated.

Collectively, these parameters provide a comprehensive assessment of the acoustic environment, enabling better design and management of office environments in order to enhance comfort, productivity, and well-being.

4.5. Limitations

In conducting this systematic review, several potential biases may have arisen. Limiting the search to a single database, Scopus, could have resulted in the exclusion of relevant studies published elsewhere, thereby compromising the comprehensiveness of the review. Selection bias is also a concern, particularly since the initial screening was based solely on titles and abstracts, which might not capture all pertinent information. Data extraction bias could occur due to the subjective interpretation of what constitutes relevant content by reviewers. Furthermore, excluding studies that were not accessible through UCL Library Services (E-resources @ UCL) could have affected the completeness and diversity of the data analysed.

5. Future Agenda

This systematic review has identified various factors influencing soundscape evaluations within office environments. Notably, the study conducted by Indrani et al. (2023) provides comprehensive insights into soundscape assessment in open-plan offices. In this study, the authors developed an indoor soundscape questionnaire based on a literature review and designed a theoretical model to assess causal relationships among spatial usage, psychological conditions, user expectations, soundscape perceptions, and work behaviour [29]. This model served as the basis for constructing the questionnaire. Furthermore, the GABO Questionnaire was used in the study to complement the assessment of the acoustic environment.

This review also reveals that the discussion of individual factors varies in depth across the studies, reflecting the distinct goals and methods employed in each. This variation highlights the diverse approaches researchers use to address complex interactions within soundscape evaluations. Additionally, this review points to factors that may have been overlooked in earlier research, identifying gaps in the current understanding of soundscape evaluation in office environments.

As a result, this review underscores the necessity for a comprehensive and standardised soundscape assessment protocol for open-plan offices that integrates all relevant factors. Future research should focus on refining existing protocols and developing a unified assessment framework adaptable to various settings, thus ensuring a detailed evaluation of the acoustic environment. The proposed protocol should undergo rigorous validation through pilot studies in diverse real-world environments to ensure its robustness and effectiveness.

The importance of the soundscape has been widely recognised, yet a unified standard or protocol for its assessment and implementation is still lacking. This underscores the need for the development of such a standard. To establish a comprehensive and validated protocol, empirical data use and rigorous studies are essential. The next research phase will focus on gathering and analysing the necessary data to support the validation process. Similar approaches were undertaken in urban soundscape studies, where standardised protocols were developed through empirical validation, providing a precedent for this endeavour.

The application of the soundscape concept has increased steadily, particularly in research focused on urban environments [16,17]. The establishment of ISO 12913 marks a significant milestone in formalising and standardising soundscape concepts, especially within urban contexts. This set of standards provides a comprehensive framework for understanding, assessing, and managing soundscapes in various settings, including urban areas. ISO 12913 is divided into several parts, each addressing different aspects of soundscape research and application, enabling a systematic approach to soundscape management.

Moreover, the integration of advanced acoustic modelling and physiological monitoring technologies could enhance the precision of soundscape assessments. Longitudinal studies are also critical for assessing the long-term effects of soundscapes on well-being and productivity, offering insights into temporal dynamics and delayed impacts.

6. Conclusions

This review aimed to explore existing soundscape assessment protocols in open-plan offices to identify the methods and factors used to evaluate soundscape perception in office environments. A total of 41 publications were included in this qualitative review after passing the screening process based on predetermined inclusion criteria. The entire review process was conducted following PRISMA guidelines.

Regarding the first research question on the protocols employed to assess soundscapes, this review found that both subjective and objective methodologies are widely used. For subjective assessments, questionnaires are the most common tools; they are often complemented by interviews and discussions in order to capture in-depth perceptions. For objective assessments, direct acoustic measurements and cognitive tasks are employed to understand the acoustic environment's impact on cognitive performance.

For the second research question on the factors included in subjective assessments, this review identified a range of acoustic and non-acoustic factors. Acoustic factors include sound source identification, noise disturbance, sound environment perception, acoustic comfort and satisfaction, the affective quality of sound environment, office acoustic metrics, and noise control. Non-acoustic factors encompass individual characteristics, sensitivity to noise, coping strategies, adaptability, cognitive workload, work performance, space dynamics, working habits, and social behaviours.

Regarding the third research question on the tools used to investigate the physical and psychological well-being of workers, this review highlighted the use of questionnaires assessing stress, anxiety, mental fatigue, mood, sleep quality, and burnout. These tools provide a comprehensive understanding of how sound environments affect physical and psychological conditions.

Lastly, addressing the fourth research question on objective acoustic parameters, this review revealed the frequent use of metrics such as sound pressure level (SPL), Equivalent Continuous Sound Level (LAeq), statistical noise descriptors, reverberation time, and speech privacy and intelligibility metrics. These parameters are crucial for quantitatively assessing the impact of the acoustic environment on comfort, productivity, and well-being. Additionally, cognitive tasks are frequently utilised to examine the effects of acoustic conditions on cognitive abilities, assessing various aspects such as memory, attention, problem-solving, and cognitive flexibility.

Overall, this review successfully identifies acoustic and non-acoustic factors in evaluating soundscapes in office environments. The results of this review can be beneficial for researchers and/or professionals in indoor office soundscapes, providing insights into the existing factors involved in soundscape evaluations in such settings. Furthermore, the results of this review may serve as a valuable reference for future research stages, especially for researchers and/or professionals aiming to develop a comprehensive and unified method for assessing soundscapes in office environments.

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