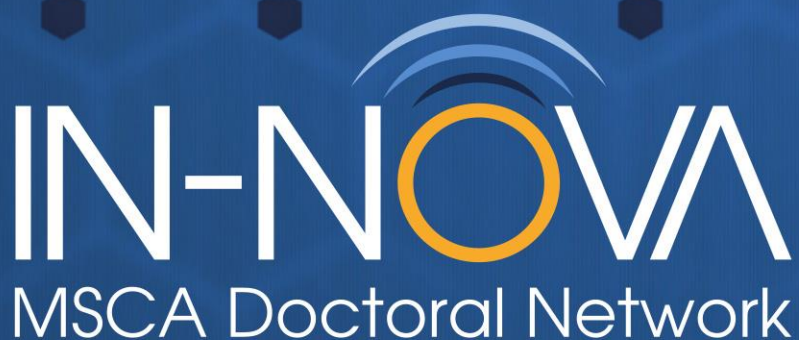




# Active reduction of noise transmitted into and from enclosures through encapsulated structures.

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## Table of Contents

|                                                     |    |
|-----------------------------------------------------|----|
| 1. Introduction .....                               | 4  |
| 2. Methodology.....                                 | 6  |
| 3. Objective Assessments.....                       | 7  |
| 3.1. Noise Levels.....                              | 8  |
| a. Sound Pressure Level .....                       | 8  |
| b. The equivalent continuous noise level.....       | 9  |
| c. Speech Sound Levels at a 4-Meter Distance .....  | 11 |
| d. Background Noise Level (Lp) .....                | 13 |
| e. Statistical noise descriptor .....               | 14 |
| f. Noise Criteria.....                              | 16 |
| 3.2. Reverberation Time.....                        | 17 |
| 3.3. Spatial Decay Rate of Speech .....             | 19 |
| 3.4. Distraction Distance and Privacy Distance..... | 20 |
| 3.5. Clarity.....                                   | 22 |
| 3.6. Psychoacoustics.....                           | 23 |
| 4. Subjective Assessments .....                     | 25 |
| 4.1. Individual Characteristics.....                | 26 |
| 4.2. Perceived Acoustic Conditions .....            | 27 |
| 4.3. Noise Interference and Preference .....        | 30 |
| 4.4. Noise Interference and Preference .....        | 32 |
| 4.5. Sound Quality .....                            | 35 |
| 4.6. Noise Sensitivity .....                        | 36 |
| 4.7. Acoustic Satisfaction .....                    | 37 |
| 4.8. Space Usage.....                               | 39 |
| 4.9. Personal Control .....                         | 41 |
| 4.10. Work Performance.....                         | 42 |
| 4.11. Subjective Workload .....                     | 45 |
| 4.12. Cognitive.....                                | 47 |
| 4.13. Psychological and Well-being.....             | 48 |

Horizon Europe MSCA Doctoral Network  
IN-NOVA – Project no. 101073037

|       |                        |    |
|-------|------------------------|----|
| 4.14. | Physiological .....    | 51 |
| 4.15. | Speech Privacy .....   | 52 |
| 4.16. | Coping Strategies..... | 54 |
| 5.    | Conclusion .....       | 55 |
| 6.    | References.....        | 58 |

## 1. Introduction

Soundscapes, defined as the acoustic environment as perceived or experienced and/or understood by a person or people in context ("ISO 12913-1:2014 Acoustics — Soundscape. Part 1— Definition and Conceptual Framework" 2014), play a crucial role in shaping the overall experience and well-being of individuals in various settings. Recent studies have shown a growing interest in exploring the soundscape within indoor settings. While the initial focus of soundscape research was on urban and outdoor environments, there has been a notable shift towards investigating how buildings influence the indoor auditory experience (Acun and Yilmazer 2019). This shift emphasises the importance of understanding how indoor soundscapes can impact the well-being and activities of occupants (Torresin et al. 2020). Researchers have highlighted the significance of adopting a perception-based approach to indoor soundscape research to create built environments that align with occupants' preferences and needs (Torresin et al. 2021).

Furthermore, the evolution of soundscape research has led to the development of new methodologies for assessing and understanding indoor sound environments, including the use of grounded theory and structural equation modelling (Acun and Yilmazer 2018a). This interdisciplinary approach has enabled researchers to delve into the complexities of indoor soundscapes in diverse settings, such as historical spaces and open-plan offices (Acun and Yilmazer 2018a; Torresin et al. 2023). By combining insights from architecture, acoustics, and psychology, researchers aim to create indoor environments that are not only acoustically pleasant but also supportive of various activities and functions (Torresin et al. 2019).

Despite the growing interest in indoor soundscapes, current research and assessment methods have been limited to certain building types, such as residential spaces, educational institutions, and healthcare facilities. The COVID-19 pandemic has highlighted the urgent need to develop soundscape assessments specifically for cognitive-function-based spaces. During

the pandemic, many individuals experienced prolonged working or learning from home, adapting to the unique acoustic conditions of their residential spaces. As the world returns to a sense of normalcy and people transition back to normal activities, they face the challenge of readjusting to the acoustic environment of their spaces.

In the context of cognitive-function-based spaces, such as offices, educational institutions, and libraries, the soundscape is critical in supporting concentration, productivity, and overall psychological well-being. Assessing the soundscape in these spaces requires a comprehensive understanding of the protocols, acoustic parameters, subjective assessment questions, and assessment tools commonly employed. By investigating these aspects, researchers can develop targeted strategies to optimise the acoustic environment in cognitive function-based spaces, ultimately enhancing occupants' well-being and performance.

This research aims to address the following questions:

- What protocols are currently employed to assess soundscapes in cognitive function-based spaces?
- How do various acoustic parameters contribute to assessing soundscapes in cognitive function-based spaces?
- What subjective assessment questions are commonly asked to evaluate the perceived quality of soundscapes in these spaces?
- What assessment tools are commonly used to investigate the correlation between soundscapes and psychological well-being?

By answering these questions, this review will provide a comprehensive understanding of the current practices in soundscape assessment in cognitive function-based spaces and identify areas for future research and development.

## 2. Methodology

A systematic literature search was conducted to identify studies addressing the assessment of soundscapes in cognitive function-based spaces. The search was performed using the Scopus database on March 4, 2024. The search strategy included combinations of key terms related to soundscapes, cognitive function, and assessment methods. The search was limited to studies published in English using the following search string:

( "acoustic" OR "sound" OR "noise" ) AND ( "soundscape" OR "percept\*" ) AND ( "Office" OR "library" OR "classroom" )

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were used as a reference for conducting the literature review. However, given the exploratory nature of this review, a predefined protocol was not registered. Studies were included if they met the following criteria:

- a. Focus on indoor environments, such as offices, libraries, or classrooms.
- b. Investigate perceptual aspects or the perception of soundscapes.
- c. Be within the field of acoustics, soundscapes, or noise.
- d. Involve participants with normal hearing.
- e. Collect primary data (i.e., not be a review article).
- f. Include adult participants aged 18 years or older.

The titles and abstracts of the 1,554 studies initially retrieved from the Scopus database on March 4, 2024, were screened based on the inclusion criteria. Full texts of potentially eligible studies were reviewed for final inclusion. After applying the inclusion criteria, 60 studies were found to be suitable for inclusion in the systematic review.

From the 60 selected studies, only aspects relevant to the review objectives were extracted and discussed according to the inclusion criteria. Data were extracted using a standardised data extraction form. The extracted data included: (1) study characteristics (e.g., authors, year, study

design); (2) cognitive function-based space type; (3) acoustic parameters investigated; (4) subjective assessment questions and tools used; (5) key findings regarding the relationship between soundscapes and cognitive performance or perception. The extracted data were summarised in tables and narratively synthesised to answer the research questions.

### **3. Objective Assessments**

Cognitive function-based spaces, such as offices, libraries, and classrooms, play a crucial role in facilitating learning, productivity, and well-being. The acoustic environment in these spaces significantly influences occupants' ability to concentrate, communicate effectively, and perform cognitive tasks. To create optimal conditions that support these activities, researchers and designers employ a range of objective assessments to evaluate and enhance the acoustic quality of these environments. These assessments include acoustic parameters, such as sound pressure levels, reverberation times, and speech intelligibility, as well as psychoacoustic indices that capture the subjective human response to sound. By measuring and analysing these factors, researchers gain valuable insights into the complex interplay between the acoustic environment and human perception, enabling them to identify potential sources of distraction, discomfort, or reduced productivity. This knowledge forms the basis for developing targeted interventions, such as acoustic treatments, noise management strategies, and evidence-based design solutions that aim to create spaces that are conducive to learning, focused work, and effective communication. In the following discussion, we will explore the various objective assessments used in cognitive function-based spaces, their significance, and their potential implications for designing and managing acoustically optimised environments that support the diverse needs of occupants in offices, libraries, and classrooms.

### 3. 1. Noise Levels

#### a. Sound Pressure Level

The studies included in this review demonstrate the importance of measuring and evaluating acoustic environments in various settings, such as classrooms, libraries, and environments with multiple conversations. The primary measurement metrics used across these studies were Sound Pressure Level (SPL) and noise levels, which provide insights into the immediate loudness, peak noise, and overall noise exposure in the respective environments. Sound Pressure Level (SPL) is a basic measure of sound pressure used to evaluate noise levels in various settings. By understanding the application of SPL in diverse research contexts, we can better comprehend how sound affects performance, health, and human comfort.

(W. Yang and Jeon 2023) and (Chan et al. 2021) focused on classroom settings, measuring sound levels under different conditions to understand how noise affects students. (W. Yang and Jeon 2023) set up various sound conditions, including ambient sound, music, and traffic at different dBA levels, using loudspeakers to create a consistent sound field. Similarly, (Chan et al. 2021) measured SPL to capture immediate loudness and peak noise moments in the classroom. (Leeniva 2019) measured background noise levels (SPL) in classrooms without main sound sources to assess the noisiness of the environment and its potential impact on student learning.

In the context of libraries, (Xiao and Aletta 2016) and (Lange, Miller-Nesbitt, and Severson 2016) employed different approaches to evaluate the acoustic environment. (Xiao and Aletta 2016) conducted a sound walk to measure sound levels in different parts of the library, assessing the suitability of noise levels for specific activities like reading and studying. (Lange, Miller-Nesbitt, and Severson 2016) used a Sound Level Meter (SLM) and a noise-monitoring device called NoiseSign to measure noise levels and investigate the potential of NoiseSign to encourage quieter behaviour.

Several studies focused on office environments and the effects of background noise on cognitive performance, satisfaction, and productivity. (Lee et al. 2020) measured noise levels in a simulated open-plan office to study how different types of background sounds affect cognitive performance, satisfaction, and physiological responses in a controlled lab environment. (A. Haapakangas et al. 2011) measured octave band spectra for different sound conditions (SPL) to characterise the acoustic properties of masking sounds used in their study, which was conducted in a laboratory designed to resemble a neutral clerical office. (J. Yang and Hermann 2017) measured office sound to create a realistic office environment for assessing the effectiveness of the SoZen system in improving productivity and mood in a noisy office scenario. (Liang et al. 2014) measured noise levels in offices to understand the quietness and loudness of office spaces, recognising that excessively loud offices can negatively impact occupant comfort and work satisfaction.

(Renz, Leistner, and Liebl 2018) and (Yadav et al. 2017) explored the effects of background noise and sound masking techniques on cognitive performance and distraction. (Renz, Leistner, and Liebl 2018) controlled SPL to compare the effects of different sound conditions on working memory and subjective annoyance while (Yadav et al. 2017) evaluated the efficacy of sound masking in reducing distractions caused by simultaneous conversations, aiming to identify the optimal SPL balance.

In conclusion, this systematic review emphasises the importance of measuring and evaluating acoustic environments using metrics such as SPL, noise levels, and octave band spectra. The findings contribute to our understanding of the impact of noise on occupants in various settings, including classrooms, libraries, offices, and simulated open-plan offices. The results guide designing and managing spaces to promote acoustic comfort, minimise distractions, enhance cognitive performance, and improve occupant satisfaction.

b. The equivalent continuous noise level

The Equivalent Continuous Sound Level (Leq) is an essential acoustic measure used to describe the average sound level over time, often used to assess environmental and occupational noise exposure. Its application spans various settings, from office environments to classrooms and open-plan offices, providing valuable insights into the acoustic impact on productivity, learning, and overall well-being.

The majority of the studies (Latini et al. 2023; Mitterska and Kompała 2023a; Jo and Jeon 2022b; Jeon et al. 2022; Bourikas et al. 2021; Park et al. 2020; Lenne, Chevret, and Marchand 2020; Galindo-Romero, Fong, and Chevez 2019; Acun and Yilmazer 2018a; Vellenga, Bouwhuis, and Höngens 2017; Abdalrahman and Galbrun 2017; Hongisto et al. 2017; Ali 2011; A. Haapakangas et al. 2011; Wang and Novak 2010) focused on office environments, highlighting the importance of understanding and managing noise levels in these spaces. Researchers employed LAeq measurements to assess background noise levels, evaluate the effectiveness of sound masking systems, and explore the impact of noise on employee comfort, productivity, and well-being.

In educational settings, such as classrooms and libraries, LAeq measurements were used to examine the relationship between noise levels and students' learning experiences (Chan et al. 2021; Ricciardi and Buratti 2018; Ikhwanuddin et al. 2017). These studies emphasised the importance of maintaining appropriate noise levels to facilitate comfortable learning and teaching environments.

Several studies utilised LAeq measurements in conjunction with other metrics or evaluation methods. For example, Jo and Jeon (2022) used LAeq to control background noise levels in one experiment and characterise various noise sources in another. Haka et al. (2009) controlled Sound Pressure Level (SPL) to isolate the effects of Speech Transmission Index (STI) variations on cognitive performance. Wang, L.M. (2009) measured both A-weighted (LAeq) and C-weighted (LCeq) sound levels to assess the impact of low-frequency sounds on human comfort and performance.

The duration of LAeq measurements varied across studies, with some focusing on short-term measurements (Latini et al. 2023; Jo and Jeon 2022b; Jeon et al. 2022) and others examining noise levels over extended periods, such as an 8-hour workday (Mitterska and Kompala 2023a; Park et al. 2020; Ali 2011) or a 7-hour period with measurements taken every 15 minutes (Mediastika and Binarti 2013). These differences in measurement duration highlight the various approaches researchers have taken to understand noise exposure in different contexts.

Some studies employed innovative techniques to evaluate noise levels and their impact on occupants. (Latini et al. 2023) designed a virtual audio stimulus based on measured LAeq to create a realistic office noise setting for experiments. (Jeon et al. 2022) used LAeq measurements to ensure that a virtual reality simulation closely mimicked the background noise of a real office environment. (W. Yang and Moon 2018) measured background noise levels using LAeq to understand the normal noise environment of a room without any additional sounds, ensuring that changes in noise perception were due to introduced water sounds and not other variables. This approach is crucial for accurately comparing the effects of water sounds on different types of noise and speech recognition.

In conclusion, this systematic review demonstrates the widespread use of LAeq measurements in assessing noise levels and their impact on occupants across various building types, particularly in office spaces, classrooms, and libraries. The included studies provide valuable insights into the relationship between noise exposure and factors such as comfort, productivity, learning, and the effects of introduced sounds like water features.

#### c. Speech Sound Levels at a 4-Meter Distance

This systematic review examined various studies that measured acoustic parameters in office environments to evaluate speech intelligibility, privacy, and the impact of noise on worker comfort and productivity. The most commonly measured metric across the reviewed studies was the A-weighted Sound Pressure Level at a distance of 4 meters ( $L_{p,A,S,4m}$  or  $LA, S, 4m$ ),

which provides valuable insights into speech propagation and its potential for causing distractions.

(Bergefurt, Appel-Meulenbroek, and Arentze 2024) and (Jo and Jeon 2022b) emphasised the importance of measuring  $L_{p,A,S,4m}$  to understand how far speech can travel in an office setting and its impact on worker concentration and comfort. This metric is crucial for determining the effectiveness of office layouts and acoustic treatments in minimising distractions caused by conversations.

(Kang et al. 2023) focused on the overall noise level in the office environment by measuring the A-weighted Sound Pressure Level at 4 meters. This measurement helps assess the acoustic comfort of workers and the potential for noise to affect their productivity. Similarly, (Hongisto et al. 2017) used  $L_A, S, 4m$  measurements to evaluate the effectiveness of sound masking systems in creating a comfortable and productive office environment.

(Jeon et al. 2022) compared  $L_{p,A,S,4m}$  values obtained from field measurements with those derived from computer simulations. This comparison is essential for gauging the accuracy of simulation models in replicating real-world acoustic conditions. Close alignment between measured and simulated values indicates the fidelity of the simulation, facilitating the refinement of acoustic designs for improved office environments.

(Park et al. 2020) expanded on the importance of  $L_{p,A,S,4m}$  measurements by considering the relationship between speech intelligibility, privacy, and distraction distance ( $rD$ ). By measuring both  $L_{p,A,S,4m}$  and  $L_{p,A,B}$  (background noise level), researchers can calculate the distraction distance, which is critical for designing office layouts that minimise distractions and enhance productivity.

The studies reviewed in this systematic review highlight the significance of measuring acoustic parameters, particularly the A-weighted Sound Pressure Level at 4 meters, in evaluating and optimising office environments. These measurements provide valuable insights into speech intelligibility, privacy, and the impact of noise on worker comfort and productivity.

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By understanding the propagation of speech and the potential for distractions, designers and managers can create more effective office layouts and implement appropriate acoustic treatments to foster a comfortable and productive work environment.

#### d. Background Noise Level ( $L_p$ )

This systematic review highlights the importance of measuring and evaluating background noise levels in various environments, including offices and classrooms. Several studies have emphasised the significance of the Background sound level ( $L_{p,A,B}$ ) in assessing the general noise level in a space without specific speech (Bergefurt, Appel-Meulenbroek, and Arentze 2024). This measurement is crucial for determining the natural noisiness or quietness of an environment, which in turn informs decisions regarding the required level of sound masking or other acoustic interventions to create a comfortable atmosphere for occupants.

(Peng et al. 2023) introduced a novel approach to evaluate the acoustic environment experienced by indoor occupants. By using loudspeakers to simulate traffic noise from outside the facade, they ensured an accurate representation of real-world conditions. This method allowed for a precise assessment of noise levels within the indoor environment, providing valuable insights into occupants' comfort and annoyance levels.

The importance of background noise evaluation is further emphasised by (Park et al. 2020), who states that excessive background noise can interfere with communication, concentration, and overall well-being. Measuring background noise levels enables researchers to determine whether the environment meets recommended standards for comfort and productivity.

In addition to background noise levels, A-weighted sound levels ( $L_{S,A}$ ) were measured by (Annu Haapakangas et al. 2014) to understand the loudness of background speech from different distances in the office environment. This measurement helps in assessing the acoustic conditions that participants were exposed to during the study.

(Kennedy et al. 2006) focused on the acoustic environment in classrooms, measuring the A-weighted Background Noise levels in empty classrooms and using empirical formulas to predict the conditions when occupied. This approach aimed to ensure that the classroom was quiet enough for students to hear the teacher clearly, without the teacher's voice being drowned out by other noises such as air conditioning or people moving around.

Previous discussions in this systematic review have also touched upon the use of LAeq (equivalent continuous sound level) and SPL (sound pressure level) in evaluating background noise. These metrics provide a comprehensive understanding of the acoustic environment and its potential impact on occupants.

In conclusion, the studies included in this systematic review underscore the significance of measuring and assessing background noise levels, as well as other acoustic parameters such as LAeq, SPL, and A-weighted sound levels, in various environments, including offices and classrooms. Thus, researchers and practitioners can gain valuable insights into the comfort, productivity, and well-being of occupants and make informed decisions regarding implementing sound masking and other acoustic interventions to create optimal working and learning conditions.

#### e. Statistical noise descriptor

While the equivalent continuous sound level provides a comprehensive representation of average noise levels, several studies have recognized the importance of examining statistical noise descriptors that offer insights into the variability and extremes of sound levels within an environment. These metrics, such as L90, L10, L1-L99, LA90, Lr, LAF10%, LAF90%, LA5, minimum SPL (LAfmin), and maximum SPL (LAfmax), provide valuable information for understanding the acoustic landscape and tailoring noise mitigation strategies.

The measurement of L90, also known as the background noise level, has been particularly relevant in studies focused on evaluating the effectiveness of sound masking systems in open-plan offices (Lenne, Chevret, and Marchand 2020). By accurately quantifying

the quieter acoustic conditions (L90,occ), researchers can ensure that the sound masking system is calibrated to enhance the overall soundscape without becoming obtrusive, thereby improving acoustic comfort and worker satisfaction.

Similarly, studies in library settings (Ikhwanuddin et al. 2017) have employed metrics like L10, L50, and L90 to assess the range of sound levels and identify the most favorable acoustic conditions for studying. By understanding the distribution of sound levels, from louder to quieter moments, researchers can develop strategies to create optimal study environments that cater to students' needs.

While some studies (Bourikas et al. 2021) may not provide detailed information on specific metrics like L10, others have explored complementary parameters to capture a more comprehensive picture of the acoustic environment. For instance, (Galindo-Romero, Fong, and Chevez 2019) and (Renz, Leistner, and Liebl 2019) utilized LA90 and LAF90%, respectively, to evaluate the background noise level and its potential impact on tasks requiring concentration.

Furthermore, metrics like Lr (Renz, Leistner, and Liebl 2019) and L1-L99 (Wang and Novak 2010) offer insights into overall noise exposure and the variability of sound levels over time. By considering factors such as low-frequency noise characteristics and the presence of rumbling or vibrations, these measurements can help assess the potential annoyance and health risks associated with noise exposure in office environments.

In addition to examining background noise levels, studies have recognised the importance of quantifying peak sound levels and their potential disruptive effects. (Vellenga, Bouwhuis, and Höngens 2017) employed the LA5 metric, representing the sound level exceeded only 5% of the time, to capture the variability and potential disruptiveness of the sound environment in open-plan offices.

Similarly, studies like (Haka et al. 2009) and (Ali 2011) have focused on measuring minimum SPL (LAfmin) and maximum SPL (LAfmax) to understand the loudness range in office environments. By identifying the quietest and loudest sounds people might experience,

researchers can better design office spaces that maintain noise levels within comfortable and safe limits, minimising potential hearing damage or concentration disruptions.

In summary, the incorporation of statistical noise descriptors like L90, L10, L1-L99, LA90, Lr, LAF10%, LAF90%, LA5, minimum SPL (LAfmin), and maximum SPL (LAfmax) provides a more comprehensive understanding of the acoustic landscape. These metrics offer insights into background noise levels, sound level variability, peak sound levels, and potentially disruptive or annoying noise characteristics. By considering these complementary measurements, researchers can develop tailored strategies for optimising acoustic environments, ensuring occupant comfort and productivity while mitigating potential health risks associated with excessive noise exposure.

#### f. Noise Criteria

The studies included in this systematic review highlight the importance of assessing and managing internal noise levels in buildings to ensure occupant comfort, productivity, and well-being. The application of various noise rating systems, such as Noise Criteria (NC), Room Noise Criteria (RNC), Room Criteria (RC), Quality Assessment Indicator (QAI), Preferred Noise Criterion (PNC), and Balanced Noise Criterion (NCB), has been crucial in evaluating the acoustic performance of indoor environments (Hongisto, Oliva, and Rekola 2015; Kim et al. 2020; Gatland et al. 2018; Wang and Novak 2010; Yadav et al. 2017).

(Kim et al. 2020) emphasised the significance of measuring internally generated noise in the post-retrofit phase of a building to ensure compliance with the WELL Building Standard and create a healthy and productive environment. Similarly, (Gatland et al. 2018) assessed background noise levels in a LEED-certified building, demonstrating the effectiveness of sound masking systems in achieving desirable noise levels and enhancing speech privacy between workstations.

(Hongisto, Oliva, and Rekola 2015) provided an overview of various noise rating systems, including NC, RNC, RC, QAI, NR, PNC, and NCB, and their role in designing spaces that minimise

disturbance due to continuous background noise and maintain comfortable and non-intrusive noise levels. (Wang and Novak 2010) further investigated the alignment of these noise rating systems with people's actual perceptions of noise, aiming to refine the assessment of indoor noise and ensure that measurements accurately reflect the true impact of noise on comfort and annoyance.

(Yadav et al. 2017) applied the Room Noise Criterion (RNC) in a simulated open-plan office environment, demonstrating its effectiveness in detecting low-frequency fluctuations and surges within specific frequency bands. This approach provided a nuanced understanding of the acoustic environment's impact, identifying and quantifying random fluctuations and other specific acoustic phenomena that traditional noise measurement methods might overlook.

In conclusion, the review emphasises the crucial role of noise rating systems in assessing and managing internal noise levels in buildings. The application of these systems, coupled with continuous monitoring and evaluation, can lead to the creation of healthy, comfortable, and productive indoor environments that promote occupant well-being and satisfaction.

### 3. 2. Reverberation Time

Reverberation time, a crucial acoustic parameter, has been widely studied to assess the acoustic quality and performance of various indoor environments, including open-plan offices, classrooms, libraries, and experimental settings. This metric, often denoted as RT, RT60, T20, or T30, measures the time it takes for sound energy to decay by a certain level (e.g., 60 dB for RT60 or 30 dB for T30) after the sound source has stopped. In addition to reverberation time, Early Decay Time (EDT) has also been employed to provide further insights into the perceived reverberance and clarity of sound in these environments.

T30 was the most commonly used metric, with several studies (Kang et al. 2023; Caniato et al. 2022; Jeon et al. 2022; Lenne, Chevret, and Marchand 2020; Utami et al. 2018; Acun and Yilmazer 2015; Bourikas et al. 2021) employing it to assess acoustic properties in open-plan offices, classrooms, and libraries. (Kang et al. 2023) used T30 to validate and refine computer-

generated acoustic models, exploring how different acoustic environments influence work performance and perceptions. (Caniato et al. 2022) and (Utami et al. 2018) measured T30 to compare the effectiveness of acoustic treatments in reducing reverberation in classrooms and libraries, respectively.

T20 was used by (Ricciardi and Buratti 2018) and (Park et al. 2020) to evaluate speech clarity and sound quality in classrooms and offices. (Ricciardi and Buratti 2018) found that shorter T20 times led to better conditions for speech intelligibility, while (Park et al. 2020) used T20 to assess the effectiveness of sound absorption in different office environments.

RT60 was employed by (Kim et al. 2020) and (W. Yang and Moon 2018) to assess the acoustic performance of retrofitted workspaces and ensure sound clarity in auditory tests, respectively. Kim et al. (2020) evaluated RT60 to determine if the spaces met the acoustic criteria set by the WELL Building Standard.

EDT was used by (Ricciardi and Buratti 2018) and (Kennedy et al. 2006) to evaluate the perceived reverberance and clarity of sound in classrooms. A lower EDT is generally preferred in educational settings to avoid the sensation of echo and improve speech intelligibility.

Several studies (Kang et al. 2023; Utami et al. 2018; Latini et al. 2023) utilised a combination of in-situ measurements and simulations to assess RT. This approach allows for a comparative analysis between real and simulated data, helping researchers understand how changes in room design or materials might influence RT.

The relationship between RT and building standards, such as the WELL Building Standard and LEED certification, was investigated by (Kim et al. 2020), (Bourikas et al. 2021), and (Gatland et al. 2018). These studies highlight the importance of considering acoustic performance in designing healthy and sustainable buildings.

(Leeniva 2019) measured RT to analyse its impact on the auditory perception of students with different educational backgrounds, aiming to design acoustically effective educational environments that cater to the specific needs of different learner groups.

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In conclusion, the various RT metrics used in the studies included in this systematic review provide valuable insights into the acoustic properties of different built environments. T20, T30, RT60, and EDT each contribute to a better understanding of speech clarity, overall sound quality, and perceived reverberance. The use of both in-situ measurements and simulations allows for a more comprehensive assessment of acoustic conditions and the potential impact of design interventions. Future research should continue to explore the relationships between different RT metrics, occupant experiences, and building standards to develop more targeted strategies for creating acoustically optimal spaces.

### 3. 3. Spatial Decay Rate of Speech

The spatial decay rate of speech (D2,S) is a critical parameter for assessing the acoustic performance of office environments, particularly in relation to speech privacy and intelligibility. The studies reviewed in this systematic analysis consistently highlight the importance of measuring D2,S to evaluate the effectiveness of various office design elements, such as layout, architectural features, and noise control measures, in managing the propagation of speech sound.

(Kang et al. 2023) validated the accuracy of acoustic simulations by comparing D2,S measurements in an actual office setting with those obtained from a simulated model. This comparison ensures the reliability of the findings and their applicability to real-world scenarios. By accurately modelling the acoustic behaviour of the space, researchers can optimise office designs and layouts to enhance speech privacy and minimise distractions.

(Bergefurt, Appel-Meulenbroek, and Arentze 2024; Lenne, Chevret, and Marchand 2020) investigated the effectiveness of acoustic screens and adaptive sound masking systems in controlling speech noise propagation. By quantifying D2,S, these studies aimed to determine the achievable level of speech privacy across different workstation setups and background noise conditions. The findings contribute to the optimisation of office layouts and noise control measures, ultimately enhancing acoustic comfort and privacy in the workplace.

(Jo and Jeon 2022b) and (Park et al. 2020) emphasised the importance of D2,S in evaluating the acoustic performance of office spaces, particularly in terms of speech containment and privacy. These studies aligned their measurements with the ISO 3382-3 standard, ensuring the reliability and comparability of their findings. By analysing D2,S values, researchers can provide insights into how effectively an office space can contain speech within a limited area, minimising unwanted sound travel and enhancing overall speech privacy.

(Jo and Jeon 2022b) and (Hongisto et al. 2017) focused on the role of D2,S in designing office spaces that effectively manage speech intelligibility and privacy across different distances. A higher D2,S value indicates stronger attenuation of speech sound levels as the distance from the source doubles, contributing to better speech privacy by reducing the audibility of conversations across the workspace. These studies highlight the importance of considering D2,S when assessing the acoustic comfort and effectiveness of spatial configurations and materials used in office environments.

In conclusion, the measurement of the spatial decay rate of speech (D2,S) is crucial for understanding and optimising the acoustic performance of office environments. The studies reviewed in this systematic analysis demonstrate the significance of D2,S in evaluating the effectiveness of office design elements, noise control measures, and sound masking systems in enhancing speech privacy and minimising distractions. By quantifying and analysing D2,S, researchers can provide valuable insights for designing office spaces that promote acoustic comfort, productivity, and well-being for employees.

### 3. 4. Distraction Distance and Privacy Distance

In open-plan offices, the acoustic environment plays a crucial role in determining the comfort, productivity, and overall well-being of employees. Two key parameters that have been widely studied to assess the acoustic performance of these spaces are the distraction distance (rD) and the privacy distance (rP).

The studies included in this review highlight the importance of measuring and understanding the distraction distance ( $rD$ ) and privacy distance ( $rP$ ) in open-plan office environments. These acoustic parameters are crucial for designing workspaces that minimise speech intelligibility beyond a certain distance, thereby reducing distractions and enhancing privacy.

The measurement of  $rD$  helps determine the radius within which speech remains fully intelligible and potentially disruptive to others (Jo and Jeon 2022b; Hongisto et al. 2017). By quantifying this distance, researchers can assess the effectiveness of acoustic design and sound masking systems in limiting the area of speech intelligibility (Hongisto et al. 2017). A smaller  $rD$  value indicates better speech privacy, as it suggests that speech does not travel far from the speaker, thus minimising potential distractions (Hongisto et al. 2017). This aligns with the objectives of creating a more focused and less disruptive work environment, as prescribed by acoustic standards like those in ISO 3382-3 (Jo and Jeon 2022b).

The insights gained from measuring  $rD$  and  $rP$  can inform the acoustic design and arrangement of office environments, ensuring that they support concentration and confidentiality (Jeon et al. 2022). By understanding these parameters, designers can create workspaces that minimise unintentional eavesdropping and enhance overall acoustic comfort (Jeon et al. 2022). This, in turn, contributes to the development of office spaces that promote productivity and privacy, as employees can work without being distracted by surrounding conversations or concerned about the confidentiality of their own discussions (Park et al. 2020).

In conclusion, the measurement of distraction distance ( $rD$ ) and privacy distance ( $rP$ ) is crucial for evaluating and optimising the acoustic performance of open-plan offices. By quantifying these parameters, researchers and designers can gain valuable insights into how to create workspaces that minimise speech intelligibility beyond a certain distance, thereby reducing distractions and enhancing privacy. The studies included in this systematic review

underscore the importance of considering rD and rP when designing acoustically comfortable and productive office environments.

### 3. 5. Clarity

The studies included in this systematic review provide valuable insights into the application of various acoustic parameters related to clarity across different environments. The findings highlight the importance of understanding and optimising acoustic conditions to support effective communication and occupant satisfaction in open-plan offices, classrooms, and simulated settings.

In open-plan offices, the challenge of balancing speech intelligibility and privacy is a recurring theme. The studies by (Acun and Yilmazer 2015; 2018a), (Annu Haapakangas et al. 2014), and (Gatland et al. 2018) demonstrate the impact of room acoustics, masking sounds, and speaker proximity on speech privacy and employee perception. These findings emphasise the need for a holistic approach to office design, considering factors such as absorption materials, sound masking systems, and the spatial distribution of workstations to create an environment that supports collaboration and concentration.

The importance of acoustic clarity in educational settings is another key aspect highlighted in this review. Studies by (Chan et al. 2021; Leeniva 2019; Kennedy et al. 2006; Ricciardi and Buratti 2018) investigate the relationship between classroom acoustics and speech intelligibility using various parameters, including STI, %ALcons, C50, C80, and D50. These studies underscore the need for optimising classroom acoustics to accommodate diverse student needs and enhance learning outcomes. By improving speech clarity and reducing background noise, educators can create an environment that promotes effective communication and student engagement.

The use of simulation and modelling techniques in acoustic research is another notable aspect of this review. Studies by (Kang et al. 2023; Yadav et al. 2017) showcase the potential of acoustic simulations and advanced models like the multi-resolution envelope-power spectrum

model (mr-sEPSM) in predicting speech intelligibility and privacy under various conditions. These approaches offer a cost-effective and efficient way to explore the effectiveness of different acoustic treatments and guide the design of optimal sound environments.

The relationship between speech intelligibility and cognitive performance is also explored in studies by (A. Haapakangas et al. 2011) and (Haka et al. 2009). Their findings suggest that higher speech intelligibility can lead to increased noise perception and reduced task performance in office settings. This highlights the importance of striking a balance between communication clarity and acoustic privacy to support employee well-being and productivity.

(Hongisto, Oliva, and Rekola 2015) and (Zhang, Ou, and Kang 2021) delve into the effects of different masking sounds and speech-to-noise ratios on speech intelligibility. Their findings contribute to our understanding of how noise spectra and background sounds can be optimised to facilitate clear communication or effectively mask distracting conversations in various environments.

In conclusion, this systematic review showcases the diverse applications of acoustic parameters, particularly STI, in assessing speech intelligibility and privacy across different settings. The findings emphasise the need for a comprehensive approach to acoustic design, considering factors such as room acoustics, masking sounds, and occupant needs. By applying these insights to real-world environments, designers and managers can create spaces that support effective communication, collaboration, and individual focus, ultimately enhancing occupant well-being and productivity.

### 3. 6. Psychoacoustics

Psychoacoustic indices, such as loudness, sharpness, roughness, and fluctuation strength, play a crucial role in evaluating how humans perceive and respond to sound in various environments. These measures go beyond traditional acoustic parameters, like sound pressure levels, to provide insights into the subjective experience of sound, including aspects such as comfort, annoyance, and distraction. By understanding and managing these psychoacoustic

factors, researchers and designers can create acoustic environments that optimise human well-being and performance.

Loudness emerges as a crucial factor across all studies, as it directly impacts the perceived intensity of sound and its potential to cause discomfort or decreased productivity. (Chan et al. 2021) emphasise the importance of managing loudness in classrooms to enhance student comfort and engagement while (Wang and Novak 2010) investigates how varying degrees of noise from building mechanical systems influence subjective annoyance and distraction in office-like settings. These findings underscore the need for developing effective noise control strategies that prioritise human experiences of sound intensity.

Sharpness and roughness are also identified as significant psychoacoustic indices, particularly in the context of minimising auditory discomfort. (Latini et al. 2023) discuss how sharp, piercing sounds can be disruptive in workplaces, leading to increased stress and reduced concentration. Similarly, (Hongisto, Oliva, and Rekola 2015) explore how metamaterials can be used to reduce the sharpness and roughness of sounds, thereby improving comfort in noise-sensitive environments.

Fluctuation strength is another important factor considered in these studies, as variations in sound intensity can cause significant distractions, especially in tasks requiring high concentration. Both (Latini et al. 2023) and (Hongisto, Oliva, and Rekola 2015) highlight the relevance of measuring fluctuation strength to develop acoustic conditions that support sustained attention and efficiency in workplaces and to assess the effectiveness of metamaterials in handling sounds with varying intensities.

The comprehensive approach adopted by these studies, which involves measuring multiple psychoacoustic indices, provides a holistic understanding of how sound is perceived by humans. This knowledge is essential for creating acoustically optimised environments that cater to the specific needs of different settings, such as classrooms, offices, and residential areas.

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In conclusion, the findings of this systematic review emphasise the importance of considering psychoacoustic indices beyond just sound pressure level when evaluating and designing acoustic environments. By understanding how loudness, sharpness, roughness, and fluctuation strength affect human perception and performance, researchers and practitioners can develop more effective strategies for noise control and sound quality improvement.

#### 4. Subjective Assessments

In conducting soundscape assessments in indoor environments such as offices, classrooms, and libraries, subjective evaluation is important in understanding individual perceptions, preferences, and responses to the acoustic environment. This subjective evaluation involves collecting data from space users through various methods such as questionnaires, interviews, and other survey methods, which aim to capture their subjective experiences related to the acoustic quality of the space.

Subjective evaluation in soundscape assessment includes various aspects that can influence an individual's perception and response to the acoustic environment. These aspects include individual characteristics, perception of acoustic conditions, satisfaction with the environment, noise identification and annoyance, sensitivity to noise, personal control, sound quality, use of space, work performance, psychological well-being, cognitive function, physiological responses, coping strategies, privacy in conversation, as well as positive and negative affective scales.

By considering these factors, subjective evaluations provide important information regarding how individuals interact with their acoustic environment and how it may affect their experience, performance, and overall well-being. A comprehensive understanding of these subjective perceptions is critical to designing and managing optimal acoustic environments in workplaces, classrooms, and libraries.

Horizon Europe MSCA Doctoral Network  
IN-NOVA – Project no. 101073037

In the next section, we will discuss in more detail the aforementioned subjective evaluation items, each of which uniquely contributes to understanding individual perception and response to soundscapes in indoor environments.

#### 4.1. Individual Characteristics

The review in this section aims to highlight the importance of considering individual differences, particularly personality traits, when assessing the impact of office acoustic conditions on employee well-being, satisfaction and performance. These findings suggest that personality traits such as extraversion, neuroticism, and sensitivity to noise can significantly influence how individuals perceive and cope with noise in various office environments.

(Bergefurt, Appel-Meulenbroek, and Arentze 2024) conducted their research in a real office environment, using the 10-item Big Five Inventory to assess personality traits on a scale of 1 – 5 strongly disagree -strongly agree. This approach allows for a more realistic evaluation of how sound masking affects noise annoyance, coping strategies, and mental health over time while accounting for individual personality differences.

(Forooraghi et al. 2023) used a mixed methods approach, combining an AFO-specific questionnaire with floor plan analysis. Their study focused on social interactions, including cooperation within the teams, work atmosphere, and sense of belonging, on a scale of 1-7 (1 = Very poor, 7 = Very good) to evaluate the impact of AFO design on workplace dynamics.

(Indrani, Ekasiwi, and Arifianto 2023) developed the Indoor Soundscape Questionnaire to assess contextual factors and subjective experiences of office workers in open offices on university campuses on a scale of 1 – 5 (1 = strongly disagree, 5 = strongly agree). The questionnaire covers personal and demographic factors, sociocultural characteristics, psychological factors, expectancy factors, and perception factors, providing a comprehensive understanding of how these elements influence employees' perceptions and satisfaction with their acoustic environment.

(Appel-Meulenbroek et al. 2020) assessed extraversion and neuroticism using two statements, with ratings combined into an overall score and respondents categorised into “medium” and “high” groups for each trait. This allowed them to analyse the influence of levels of extraversion and neuroticism on perceived productivity, preferences for coping strategies, and the expected effectiveness of selected strategies in open offices.

(Oseland and Hodsman 2018) used an online survey with 44 sub-questions based on the Big Five Inventory (BFI) to measure openness, conscientiousness, extroversion, agreeableness, and neuroticism. Respondents rated their agreement with various statements on a scale aimed at validating previous findings showing that extroverts are better able to cope with noise than introverts, while neurotic individuals may be more adversely affected.

(Haka et al. 2009) conducted a laboratory experiment in a controlled office environment, assessing mental health, psychological well-being, and subjective distress using questionnaires. They measured introversion using 5 statements rated on a 1-5 scale, locus of control through 4 statements rated on a 1-5 scale, trait anxiety using 4 items rated on a 1-5 scale, and state anxiety at multiple points using 6 items rated on a 1-4 scale. Their study explains how individual differences in these properties can influence subjective experience and performance under various acoustic conditions.

The findings from these studies collectively emphasise the need for a personalised approach when designing office spaces, assessing office acoustic conditions and implementing noise management strategies. By considering individual personality traits and using appropriate scales to measure those differences, organisations can create more effective and tailored solutions to reduce the negative impact of noise on employee well-being and productivity.

#### 4.2. Perceived Acoustic Conditions

The studies included in this systematic review utilised various methods to assess the subjective perception of soundscapes in different indoor environments, such as university

classrooms, open-plan offices, and libraries. The most common approach was using questionnaires and interviews, which allowed researchers to gather detailed information on participants' experiences, preferences, and reactions to the acoustic environment.

Several studies employed semantic differential scales to measure soundscape perception (Utami et al. 2018; Ikhwanuddin et al. 2017). These scales required respondents to rate their experiences on a spectrum between opposing adjectives, such as "unpleasant - pleasant" or "agitating - calming." This approach provided a nuanced understanding of how individuals perceived and responded to different soundscape aspects.

Other studies used Likert scales to evaluate participants' agreement with statements about the acoustic environment (W. Yang and Jeon 2023; Latini et al. 2023). These scales allowed researchers to assess the overall perception of the soundscape, including factors such as pleasantness, disturbance, and the ability to concentrate in the given environment.

Semi-structured interviews were also employed in some studies (Acun and Yilmazer 2018b; 2015) to capture qualitative feedback and gain deeper insights into employees' perceptions of their work environment. These interviews provided valuable information on the common sound sources and their impact on the overall experience and satisfaction of the occupants.

In addition to the general perception of soundscapes, some studies focused on specific aspects, such as the impact on learning attitudes (Chan et al. 2021), the appropriateness of acoustic conditions in libraries (Xiao and Aletta 2016), and the effect of soundscapes on task performance (J. Yang and Hermann 2017).

The Indoor Soundscape Questionnaire (Dokmeci Yorukoglu and Kang 2017; Indrani, Ekasiwi, and Arifianto 2023) was a comprehensive tool that assessed various factors, including expectations and reactions to acoustic and spatial factors. This questionnaire provided valuable insights into what users considered important and how they rated the quality of these factors in their environment.

Horizon Europe MSCA Doctoral Network  
IN-NOVA – Project no. 101073037

The studies by Ayoko et al. (2023) and Hongisto et al. (2015) provide valuable insights into the subjective evaluation of noise in open-plan offices. Both studies employed questionnaires to assess employees' perceptions and attitudes towards different aspects of noise in their working environments.

Ayoko et al. (2023) focused on the immediate emotional responses of employees to noise, adapting the PANAS scale to measure negative affect, such as feelings of frustration and anger. This approach highlights the importance of considering the affective impact of noise on employees, as negative emotions can mediate the relationship between noise and various behavioural outcomes. By understanding how noise influences employees' emotional states, organisations can better address the challenges associated with open-plan office environments.

On the other hand, Hongisto et al. (2015) conducted their study in a real-world setting at Plantronics Ltd. in the UK, evaluating employees' perceptions of different water-based and pseudo-random masking sounds. Their questionnaire encompassed positive and negative attitudes towards noise, including factors such as pleasure, habituation, work-related attitudes, loudness, disturbance, and concentration interference. This comprehensive approach allows for a more nuanced understanding of how different types of noise can impact employees' comfort, productivity, and overall satisfaction with their work environment.

Combining these two studies emphasises the multifaceted nature of noise perception in open-plan offices. While Ayoko et al. (2023) focused on immediate emotional responses, Hongisto et al. (2015) explored a broader range of attitudes and perceptions. Together, these studies suggest that addressing noise in open-plan offices requires a holistic approach that considers both the affective and cognitive aspects of employees' experiences.

The subjective assessments in these studies were crucial in understanding the human experience and perception of acoustic environments. The findings from these assessments can inform the design and management of indoor spaces to enhance user satisfaction, comfort,

and productivity. By considering subjective perceptions alongside objective measurements, researchers and practitioners can develop more effective strategies to create optimal soundscapes in various indoor settings.

#### 4.3. Noise Interference and Preference

This section explores various methods and approaches used in assessing noise annoyance, identifying noise sources, and evaluating noise preferences in open offices, classrooms, and other indoor environments. The included studies have employed a range of questionnaires, surveys, and subjective evaluation methods to measure occupants' perceptions of their acoustic environment and the impact of noise on their comfort, well-being, and productivity. Many of these studies, such as (Peng et al. 2023; Renz, Leistner, and Liebl 2019) and (W. Yang and Moon 2018), have utilised the ISO/TS 15666:2003 standard, "Acoustics - Assessment of noise annoyance by means of social and socio-acoustic surveys," which recommends the use of both descriptive and numeric scales to enhance the reliability and consistency of acoustic annoyance measurements.

(Caniato et al. 2022; Mitterska and Kompala 2023b; Jo and Jeon 2022a) and (Zhang, Ou, and Kang 2021), focused on assessing noise annoyance and identifying specific noise sources in classrooms and open offices. These studies used questionnaires to investigate the effects of background noise, assess the level of irritation caused by different sounds, and examine perceived annoyance in controlled laboratory settings designed to simulate open-plan office acoustic conditions.

Questionnaires were a common tool used in many studies, (Ricciardi and Buratti 2018; Appel-Meulenbroek et al. 2020; Oseland and Hodsman 2018; Kim et al. 2020; Acun and Yilmazer 2018b), to collect subjective assessments of the acoustic environment and identify specific noise sources. These studies evaluated various aspects, such as comfort, frequency, and perceived productivity impact of sound sources in classrooms and open offices. (Perrin Jegen and Chevret 2017; Hongisto et al. 2017) and (Haka et al. 2009) used questionnaires and

a combination of descriptive and numerical scales to assess noise annoyance caused by specific sound sources in open offices and controlled laboratory settings.

Real office environments were the focus of studies by (Ali 2011; Mediastika and Binarti 2013; Peng et al. 2023; Galindo-Romero, Fong, and Chevez 2019; Kang, Ou, and Mak 2017) and (Ayoko et al. 2023). These studies used questionnaires to evaluate the annoyance caused by various noise sources, such as conversations, office equipment, and external traffic noise, and to investigate the level of perceived disturbance in open-plan offices. (Ayoko et al. 2023) specifically measured perceived general office noise and disruption by telephone noises and office machines using a 7-point scale and specific questions. The questionnaire was adapted from (Sundstrom, Herbert, and Brown 1982).

The soundscape approach was employed by (Xiao and Aletta 2016; Latini et al. 2023) and (Dokmeci Yorukoglu and Kang 2017) to assess subjective experiences and perceptions of the acoustic environment in libraries and virtual reality settings. These studies used questionnaires and sound walks to collect data on participants' perceptions of various sound sources and their emotional responses, including preferences for certain sounds.

Occupant satisfaction with indoor environmental quality, including acoustics, in green and conventional office buildings was investigated by (Liang et al. 2014) and (Gatland et al. 2018) using questionnaires to identify sources of dissatisfaction and evaluate the impact of specific noise sources on perceived productivity. (Annu Haapakangas et al. 2014) conducted a laboratory study designed to resemble an open-plan office, assessing the impact of different acoustic conditions on cognitive performance and subjective distraction, including disturbance ratings of environmental factors such as speech from nearby and distant desks, background hum, and other office noise sources.

The assessment of specific noise control measures and their impact on perceived noise annoyance and acoustic satisfaction was investigated by (Abdalrahman and Galbrun 2017; Pierrette et al. 2015; Lee et al. 2020). These studies used questionnaires to measure changes in

occupants' perceptions of the acoustic environment before and after the implementation of noise control measures, such as water features and sound masking systems. (W. Yang and Moon 2018) evaluated the annoyance and pleasantness of 8 intrusive noise sources using an 11-point numeric scale, providing insights into the beneficial and adverse effects of indoor water sounds on intrusive noise perception.

In conclusion, this systematic review highlights the diverse methods and approaches used in assessing noise annoyance, identifying noise sources, and evaluating noise preferences in various indoor environments, with several studies employing the ISO/TS 15666:2003 standard for consistent and reliable acoustic annoyance measurements. The findings from the included studies emphasise the importance of considering the specific context, noise source characteristics, occupants' subjective experiences, and potential preferences for certain sounds when evaluating the acoustic quality of indoor spaces. The insights gained from this review can inform the design and implementation of effective acoustic interventions to create more comfortable and productive indoor environments.

#### 4.4. Noise Interference and Preference

The review in this section aims to explore the various methods and approaches used in assessing noise annoyance and identifying noise sources in open offices, classrooms and other indoor environments. The studies included in this review used a series of questionnaires, surveys and subjective evaluation methods to measure occupants' perceptions of their acoustic environment and the impact of noise on their comfort, well-being and productivity.

Several studies have focused on assessing noise annoyance and identifying specific noise sources in various indoor environments. (Caniato et al. 2022) investigated the impact of background noise distractions in classrooms, while (Mitterska and Kompała 2023b) and (Jo and Jeon 2022a) assessed the level of irritation caused by different noise sources and identified distracting sounds in open offices. Similarly, (Zhang, Ou, and Kang 2021) examined the

perceived annoyance caused by various noise sources in a controlled laboratory environment designed to recreate the acoustic conditions of an open office.

Many studies use questionnaires to collect subjective assessments of the acoustic environment and identify specific noise sources. (Chan et al. 2021) and (Ricciardi and Buratti 2018) used questionnaires to evaluate the comfort and frequency of various sound sources in classrooms. (Appel-Meulenbroek et al. 2020) and (Oseland and Hodsman 2018) used questionnaires to assess the perceived productivity impact of various noise sources and the frequency of distractions in open offices. (Kim et al. 2020) and (Acun and Yilmazer 2018b) used a questionnaire to measure environmental satisfaction and capture subjective experiences regarding the auditory environment in an open office.

Several studies, such as (Perrin Jegen and Chevret 2017) and (Hongisto et al. 2017), focused on assessing noise perceived annoyance caused by specific sound sources in open offices. These studies use questionnaires to evaluate the frequency and annoyance of various noise sources, such as machines, telephones, conversations, and ventilation systems. (Haka et al. 2009; Renz, Leistner, and Liebl 2018) and (Renz, Leistner, and Liebl 2019) used a combination of descriptive and numerical scales to measure subjective noise annoyance and annoyance in a controlled laboratory setting.

Other studies, including (Ali 2011), (Mediastika and Binarti 2013; Kennedy et al. 2006), and (Peng et al. 2023), conducted a survey in a real office environment to assess noise annoyance and identify specific noise sources. These studies use questionnaires to evaluate the annoyance caused by various noise sources, such as conversations, office equipment, and external traffic noise. (Galindo-Romero, Fong, and Chevez 2019) and (Kang, Ou, and Mak 2017) investigated the level of perceived disturbance caused by common noise sources in open-plan offices using a questionnaire.

(Ayoko et al. 2023) conducted a study in an open-plan office using a questionnaire that covered various aspects of the participants' demographics, office environment, and their

reactions to noise. The study measured perceived general office noise using five items from (Sundstrom, Herbert, and Brown 1982) on a 7-point scale. The questionnaire also included specific questions about disruption by telephone noises and office machines, such as printers, typewriters, keyboards, or computers. The study collected data through an opening survey and twice-daily momentary ESM surveys.

Several studies have used a soundscape approach to assess subjective experience and perception of the acoustic environment. (Xiao and Aletta 2016) and (Latini et al. 2023) used questionnaires and sound walks to collect data on participants' perceptions of various sound sources and their emotional responses in libraries and virtual reality environments. (Dokmeci Yorukoglu and Kang 2017) applied the Indoor Soundscape Questionnaire to evaluate users' perceptions of sound sources and their reactions to them in the library lobby area.

Some studies, such as (Liang et al. 2014) and (Gatland et al. 2018), focused on assessing occupant satisfaction with various aspects of indoor environmental quality, including acoustics, in green and conventional office buildings. These studies use questionnaires to identify sources of dissatisfaction and evaluate the impact of specific noise sources on perceived productivity.

(Annu Haapakangas et al. 2014) conducted a study in a laboratory setting designed to resemble a real open-plan office. They used questionnaires to assess the impact of different acoustic conditions on cognitive performance and subjective distraction. The study included disturbance ratings of environmental factors, such as speech from nearby and distant desks, background hum, and other office noise sources. The findings from this study provide insights into how different acoustic conditions affect perceived disturbance and distraction in open-plan offices.

Finally, (Abdallahman and Galbrun 2017), (Pierrette et al. 2015), and (Lee et al. 2020) investigated the assessment of specific noise control measures and their impact on perceived noise annoyance and acoustic satisfaction. These studies used questionnaires to measure

changes in occupants' perceptions of the acoustic environment before and after the implementation of noise control measures, such as water features and sound masking systems.

In conclusion, the review highlights the various methods and approaches used in assessing noise annoyance and identifying noise sources in various indoor environments. Findings from the included studies emphasise the importance of considering the specific context, noise source characteristics, and occupants' subjective experiences when evaluating the acoustic quality of indoor spaces. The insights gained from this study can inform the design and implementation of effective acoustic interventions to create more comfortable and productive indoor environments.

#### 4.5. Sound Quality

The studies included in this systematic review provide valuable insights into the subjective evaluation of sound quality in various settings, such as classrooms, offices, and libraries. The findings highlight the importance of assessing occupants' perceptions of sound quality attributes to create comfortable and functional acoustic environments.

Several studies employed subjective questionnaires or surveys to gather data on perceived sound quality. (W. Yang and Jeon 2023) conducted a sound perception evaluation in a university classroom, asking participants to rate sound quality and volume using semantic attributes such as softness, loudness, quietness, and noisiness. This approach allows for a comprehensive assessment of the subjective sound quality experience in the classroom setting.

(Jeon et al. 2022) investigated the effects of acoustic environments on perceived affective quality in open-plan offices. The study examined how varying physical acoustic parameters influenced subjects' ratings of acoustic attributes such as loudness, variability, and reverberation. Understanding the perception of these sound quality attributes is crucial for designing pleasant and functional open-plan office environments. (Otterbring, Bodin Danielsson, and Pareigis 2021) provides additional insights into the subjective evaluation of sound quality in office environments, focusing on real estate agents working in various offices

throughout Sweden. The study employed a single-item seven-point scale to evaluate perceived noise levels. Understanding the perception of these sound quality attributes is crucial for designing pleasant and functional open-plan office environments.

(Hongisto, Oliva, and Rekola 2015; Wang and Novak 2010) focused on specific sound quality attributes such as rumble, roar, hiss, and tones. These studies employed questionnaires with subjective measures to assess subjects' perceptions of different sound characteristics. (Hongisto, Oliva, and Rekola 2015) investigated the perception of rumble (low-frequency content), roar (mid-frequency content), and hiss (high-frequency content) in pseudorandom noise sounds. Similarly, (Wang and Novak 2010) used a questionnaire to evaluate participants' perceptions of loudness, rumble, roar, hiss, tones, changes over time, annoyance, and distraction in a simulated office environment. These studies highlight the importance of considering specific sound quality attributes when assessing the subjective experience of acoustic environments.

The findings of these studies emphasise the need for a comprehensive approach to acoustic design that considers the subjective perception of sound quality. By understanding how different sound quality attributes contribute to the overall acoustic experience, designers and researchers can develop strategies to optimise acoustic environments for occupant comfort and well-being.

#### 4.6. Noise Sensitivity

The review in this section aims to synthesise the literature on noise sensitivity evaluation methods in real-office and simulated office laboratories. The studies reviewed used a variety of questionnaires to assess noise sensitivity, with the GABO questionnaire and the Noise Sensitivity Questionnaire (NoiseQ) being the most commonly used.

The GABO questionnaire, developed by (Pierrette et al. 2015), has been used in several studies (Perrin Jegen and Chevret 2017; Abdalrahman and Galbrun 2017; Lenne, Chevret, and Marchand 2020; Indrani, Ekasiwi, and Arifianto 2023; Bergefurt, Appel-Meulenbroek, and

Arentze 2024). This questionnaire assesses employees' perceptions of workplace noise environments and identifies factors influencing their assessments. The noise sensitivity component of the GABO questionnaire is often a simplified version of the Noise Sensitivity Questionnaire (NoiseQ), which measures respondents' agreement with noise sensitivity-related statements on a 4-point scale.

The Noise Sensitivity Questionnaire (NoiseQ) was used in various forms across the studies reviewed. (Yadav et al. 2017) and (Hölle and Bleichner 2023) used the full version of NoiseQ consisting of 35 items, while (Annu Haapakangas et al. 2014) used a 4-item version of the 'occupation' subscale. NoiseQ assesses noise sensitivity across domains, such as leisure, work, residence, communication, and sleep, using a scale ranging from 0-3 to 1-7.

Other noise sensitivity evaluation methods include the Weinstein Noise Sensitivity Scale (Zhang, Ou, and Kang 2021), the 12-item Noise Sensitivity Questionnaire (Kang et al. 2023), and the 5-item noise sensitivity questionnaire (Park et al. 2020). (Haka et al. 2009) used a 6-item measure of noise sensitivity as part of their initial questionnaire.

The findings of this review highlight the importance of considering noise sensitivity when evaluating the acoustic environment in office environments. The various questionnaires used in the studies reviewed provide a valuable tool for assessing individual differences in noise sensitivity, which may influence employee perception, performance, and well-being in such work environments.

#### 4.7. Acoustic Satisfaction

The review in this section aims to examine the methods and rationale for assessing acoustic satisfaction in various indoor environments, including open offices, classrooms, and virtual settings. The studies included in this review used a variety of approaches, including controlled laboratory experiments, field studies, and surveys, to evaluate occupants' subjective perceptions and experiences of their acoustic environments.

Several studies have focused on assessing acoustic satisfaction using questionnaires and rating scales. These questionnaires typically include questions regarding overall satisfaction with the acoustic environment, noise levels, speech privacy, and acoustic comfort. The scales used to measure acoustic satisfaction varied across the studies, ranging from 5-point (Kang et al. 2023; Zhang, Ou, and Kang 2021; Kang, Ou, and Mak 2017), 7-point (Jo and Jeon 2022a; Jeon et al. 2022; Lee et al. 2020; Castaldo et al. 2018; Bourikas et al. 2021; Liang et al. 2014; Chan et al. 2021), to 10-point scales (Ricciardi and Buratti 2018). Some studies also used semantic differential scales such as "The sound environment was pleasant" to "The sound environment was disturbing" (A. Haapakangas et al. 2011) or satisfaction scales with specific labels, such as "very dissatisfied" to "very satisfied" (Hongisto et al. 2017; Sakellaris et al. 2019). The use of questionnaires and various rating scales allows researchers to collect subjective data regarding occupants' perceptions and experiences, which is essential for understanding the acceptability and perceived quality of different acoustic environments.

In addition to questionnaires, some studies use more in-depth qualitative methods, such as semi-structured interviews and focus group discussions, to gain a deeper understanding of residents' experiences and perceptions (Acun and Yilmazer 2015; Rolfö, Eklund, and Jahncke 2018). This qualitative approach provides valuable insight into the specific problems and concerns residents face in their acoustic environments, as well as suggestions for improvement.

The reasons for assessing for assessing acoustic satisfaction vary across studies but generally focus on understanding the impact of acoustic conditions on occupants' well-being, performance, and overall satisfaction with their environment. Many studies, including Yang and Jeon (2023), emphasised the importance of acoustic satisfaction in determining the overall quality of the work or learning environment, as poor acoustic conditions can lead to increased fatigue, reduced cognitive performance, and dissatisfaction among occupants (Kang et al. 2023; Jo and Jeon 2022a; Zhang, Ou, and Kang 2021; Lee et al. 2020; Hongisto et al. 2017; A. Haapakangas et al. 2011; Ricciardi and Buratti 2018; Castaldo et al. 2018; Bourikas et al. 2021;

Liang et al. 2014; Gatland et al. 2018; Kang, Ou, and Mak 2017; Sakellaris et al. 2019; Ahmadpoor Samani, Zaleha Abdul Rasid, and Sofian 2017; Rolfö, Eklund, and Jahncke 2018; Chan et al. 2021)

Some studies also aim to evaluate the effectiveness of various acoustic interventions or design strategies in improving occupant satisfaction and well-being. For example, (Latini et al. 2023) assessed acoustic comfort in virtual office environments while (Gatland et al. 2018) compared occupant satisfaction with traditional office buildings and LEED-certified buildings. These studies provide valuable insight into the potential benefits of implementing various acoustic design strategies and technologies in indoor environments.

Overall, the studies included in this review highlight the importance of assessing acoustic satisfaction in various indoor environments, as this plays an important role in determining occupants' overall well-being, performance and satisfaction with their environment. The use of questionnaires and rating scales, as well as qualitative methods, enabled researchers to collect comprehensive data regarding residents' subjective experiences and perceptions. The findings from this research can inform the design and management of indoor spaces to create more comfortable, productive, and satisfying acoustic environments for occupants.

#### 4.8. Space Usage

In this section, the review focuses on evaluation methods used to assess occupants' perceptions of space usage in various types of buildings, such as offices and libraries. Space usage refers to how building occupants interact with and utilise different spaces within a building, including factors such as frequency of visits, time spent in various areas, and preferences for certain spaces. A review of space use is very important to be able to evaluate the effectiveness of building design and management strategies in meeting the needs and preferences of building occupants. The studies reviewed used various methods, such as interviews and questionnaires, to collect data regarding occupants' experiences and patterns of space use in their work environments.

Several studies conducted by (Ayoko et al. 2023; Kim et al. 2020) focused on open-concept offices and used a questionnaire to assess building occupants' perceptions of office space density and territorial behaviour. (Ayoko et al. 2023) used a 7-point scale to measure feelings of crowding in participants' work spaces, while (Kim et al. 2020) used a 7-point Likert scale to evaluate occupant satisfaction with various aspects of their office environment, including perceptions of office space density. These studies highlight the importance of understanding how spatial density and territorial behaviour influence occupants' experiences of open-plan offices.

(Indrani, Ekasiwi, and Arifianto 2023) developed an indoor soundscape questionnaire to assess contextual factors, including space usage, in open-plan offices. This questionnaire explores employees' preferences for different types of space in the office, as well as the frequency of use and time they spend in the various spaces. This study emphasises the need to consider how occupants use and interact with their workspaces when evaluating the acoustic environment in open offices.

Similar to (Indrani, Ekasiwi, and Arifianto 2023) the indoor soundscape questionnaire was also given to visitors to the library foyer area by (Dokmeci Yorukoglu and Kang 2017). The questionnaire asks questions on several topics which include space use patterns, frequency of use, and preferences for different spaces. This study shows the importance of understanding how occupants use and perceive specific areas within a building when evaluating the acoustic environment.

In their research, (Castaldo et al. 2018) adapted a questionnaire from ISO 1551:2019 to assess the physical environment, including the workplace. The questionnaire contains questions about space use, such as frequency of going to work, working hours, and number of work positions in the office. This study shows that standardised questionnaires can be useful in evaluating occupant perceptions and use of space in office environments.

Horizon Europe MSCA Doctoral Network  
IN-NOVA – Project no. 101073037

Two studies (Utami et al. 2018; Ikhwanuddin et al. 2017) focused on university libraries and used questionnaires to survey occupants' preferences regarding acoustic conditions, frequency of visits, and types of activities within the library. These studies demonstrate the importance of considering space use patterns and occupant activities when evaluating the acoustic environment in libraries.

(Rolfö, Eklund, and Jahncke 2018) conducted research comparing occupant experiences in open offices and activity-based workplaces. This study used pre-relocation and post-relocation questionnaires, focus group interviews, and individual in-depth interviews to assess changes in perceptions and experiences. The questionnaire covered topics such as furniture adjustments, frequency of use of the same workplace, and time spent searching for a suitable workplace. This study highlights the importance of considering how different office layouts and designs impact occupant experiences and space use patterns.

Overall, the studies reviewed in this systematic review emphasise the importance of using various evaluation methods and questionnaires to assess space use and occupant perceptions in various building types. The findings from this research can inform the design and management of workspaces to optimise occupant comfort, satisfaction and productivity.

#### 4.9. Personal Control

The studies included in this systematic review highlight the importance of personal control over various aspects of the physical work environment in office settings. The findings suggest that occupants' perceived control over their surroundings plays a crucial role in their satisfaction, comfort, and, potentially, their productivity.

(Kim et al. 2020) utilised a pre-retrofit questionnaire to assess occupants' environmental satisfaction, including their sense of control over physical conditions. The questionnaire items focused on the ability to alter physical conditions in the work area and satisfaction with the extent of control over aspects such as lighting, noise, and privacy. This approach emphasises

the significance of personal control in shaping occupants' perceptions of their work environment.

Similarly, (Castaldo et al. 2018) adapted a questionnaire from ISO 1551:2019 to gather information on how occupants interact with their workspace. The questionnaire included items related to personal control over lighting, temperature, ventilation, and window operation. By asking about occupants' usual behaviours and preferences regarding these aspects, the study aims to understand the relationship between personal control and comfort in the workplace.

The OFFICAIR study, as reported by (Sakellaris et al. 2019), employed an online questionnaire survey to collect data from office building occupants across eight European countries. One of the key components of the questionnaire was perceived personal control over indoor environment parameters, including temperature, ventilation, shading from the sun, lighting, and noise. The study used a 7-point scale to measure the extent of control occupants felt they had over these aspects. By focusing on perceived personal control, particularly over noise, the study aimed to comprehensively evaluate the impacts of acoustic environment control on overall occupant comfort, performance, and well-being in offices.

The inclusion of personal control as a variable in these studies underscores its importance in understanding occupant satisfaction and comfort in office environments. The findings suggest that when occupants perceive a higher level of control over their physical work environment, they are more likely to experience greater satisfaction and comfort. This, in turn, may have positive implications for their productivity and well-being.

#### 4.10. Work Performance

This systematic review aimed to synthesise the current literature on the impact of open-plan office acoustics on employee work performance and productivity. The studies included in this review employed a variety of methodologies, including questionnaires, interviews, and experimental designs in both laboratory and real office settings.

A primary focus of the reviewed studies was the assessment of perceived work performance and productivity. (Kang et al. 2023; Jo and Jeon 2022a; Hongisto et al. 2017) used subjective measures to evaluate how participants felt their ability to execute tasks was influenced by varying acoustic conditions. These measures often utilised Likert scales to gauge the impact of noise on specific work activities, such as reading, writing, problem-solving, and collaboration (Hongisto et al. 2017; Peng et al. 2023). The findings consistently demonstrated that noise in open-plan offices can have a detrimental effect on employees' perceived productivity and performance. (Jeon et al. 2022) also assessed work satisfaction in relation to acoustic environments, providing insights into how environmental factors contribute to overall job satisfaction.

Several studies, including (Lee et al. 2020; Peng et al. 2023; Indrani, Ekasiwi, and Arifianto 2023), investigated the impact of noise on concentration and cognitive performance. These studies highlighted the importance of designing acoustic environments that support focused work and minimise distractions, as noise can significantly impair employees' ability to concentrate and perform cognitive tasks effectively. (Oseland and Hodsman 2018) further explored the relationship between noise distraction and performance impact, ability to work, and concentration issues, providing a detailed understanding of how noise affects cognitive processes and work efficiency.

(Bergefurt, Appel-Meulenbroek, and Arentze 2024; Appel-Meulenbroek et al. 2020) explored the effectiveness of various coping strategies and acoustic interventions in mitigating the negative effects of noise on work performance in open-plan offices. These studies provided valuable insights into how employees perceive and adapt to different acoustic conditions and how organisations can implement strategies to improve the acoustic environment and support productivity.

The impact of open-plan office acoustics on creativity and collaboration was also investigated in some studies. (Ahmadpoor Samani, Zaleha Abdul Rasid, and Sofian 2017)

specifically focused on the link between open-plan workplaces and creativity in creative industries, highlighting the importance of considering the specific needs and requirements of different industries and job roles when designing acoustic environments.

Individual factors and job characteristics were also considered in relation to the perception of open-plan office acoustics and work performance. (Sakellaris et al. 2019; Rolfö, Eklund, and Jahncke 2018) investigated how personal preferences, environmental control, and job demands interacted with the acoustic environment to shape employee experiences and productivity outcomes. (Park et al. 2020) examined the relationship between acoustic factors, job characteristics, and job satisfaction in open-plan offices, providing a more comprehensive understanding of the interplay between these variables.

(Acun and Yilmazer 2018b; 2015) used qualitative methods like interviews to gather detailed insights into employees' subjective perceptions of the soundscape and its impact on their work performance and concentration. These studies provided a more nuanced understanding of the complex ways in which acoustic factors can influence productivity in open-plan offices.

(Ali 2011) and (Latini et al. 2023) further contributed to the understanding of the impact of open-plan office acoustics on work performance by examining specific noise sources and their perceived influence on productivity. These studies emphasised the need to identify and manage the most disruptive noise sources to optimise the acoustic environment for work performance.

(Galindo-Romero, Fong, and Chevez 2019) assessed staff perceptions of various noise sources and their impact on focus work and general work, providing a detailed analysis of how different sounds can be beneficial, neutral, or disruptive to productivity.

In conclusion, this systematic review demonstrates the significant impact of open-plan office acoustics on employee work performance and productivity. The findings underscore the importance of designing acoustic environments that support focused work, minimise

distractions, and cater to the specific needs of different industries and job roles. Future research should focus on developing and evaluating targeted interventions and strategies to optimise the acoustic environment in open-plan offices, with the ultimate goal of enhancing employee productivity and performance.

#### 4.11. Subjective Workload

The studies reviewed in this section provide information on the impact of the acoustic environment on mental workload in the office. Using various assessment tools, such as the NASA Task Load Index (NASA-TLX) and the Individual–Workload–Activity (IWA) model, these studies offer a comprehensive understanding of how different acoustic conditions influence the cognitive demands placed on employees.

NASA-TLX, a well-established tool for evaluating mental workload, was used in several studies (Kang et al. 2023; Zhang, Ou, and Kang 2021; Yadav et al. 2017; Annu Haapakangas et al. 2014) to assess how different acoustic conditions affected cognitive load in participants performing tasks in an open office or laboratory simulation environment. This multidimensional approach allows a comprehensive understanding of the cognitive and emotional demands placed on individuals in different acoustic environments.

In addition to NASA-TLX, several studies used other questionnaires to capture the complexity of mental workload and subjective experience. (Lenne, Chevret, and Marchand 2020) used a comprehensive mental workload questionnaire based on the IWA (Individual - Workload - Activity) model, which assesses intrinsic cognitive load, extraneous cognitive load, germane cognitive load, and available cognitive resources. This approach highlights the importance of considering both task-related and environmental factors when evaluating the impact of office acoustics on employee well-being and performance.

Subjective workload assessment was also carried out in the research of (A. Haapakangas et al. 2011) to measure participants' perceptions of the mental effort and cognitive resources required to perform tasks under different sound conditions. This assessment provides valuable

insight into the cognitive impact and mental resource demands caused by different acoustic environments, thereby contributing to a more comprehensive understanding of the psychological strain associated with various acoustic conditions.

Furthermore, (Park et al. 2020) broadened the scope of the investigation by examining the interactions between acoustic factors, job characteristics, and employee satisfaction in real open offices. By incorporating the Job Diagnostic Survey (JDS), this research emphasises the importance of considering non-acoustic factors, such as skill diversity, task identity, task significance, and autonomy, when evaluating the impact of office acoustics on employee well-being and satisfaction.

In conclusion, the studies included in this systematic review used various questionnaires, especially the NASA-TLX, to assess the impact of acoustic conditions on mental workload and subjective experience in open offices. A multidimensional approach to evaluating mental workload, combined with consideration of acoustic and non-acoustic factors, provides a comprehensive framework for understanding the cognitive and emotional demands placed on individuals in different office environments. The diverse methodologies used in these studies, ranging from laboratory simulations to field studies, contribute to a robust understanding of the relationship between office acoustics, employee well-being, and performance.

Apart from that, it is also important to note the difference between mental workload and work performance. Studies investigating mental workload primarily use the NASA Task Load Index (NASA-TLX) and other similar questionnaires to assess participants' perceptions of mental demands, physical demands, time demands, performance, effort, and frustration in different acoustic environments. These studies aim to understand the cognitive and emotional demands placed on individuals in various office environments, providing a more comprehensive picture of the psychological strain associated with adverse acoustic conditions. On the other hand, research examining job performance focuses on the direct impact of acoustic conditions on employees' ability to perform tasks effectively, their willingness to work,

and their overall job satisfaction. These studies investigate the impact of noise and distractions on daily work activities, creative performance, and challenges associated with office redesign, such as the transition to activity-based workplaces (ABW).

#### 4.12. Cognitive

The review in this section aims to summarise the cognitive assessments conducted in studies evaluating the impact of the acoustic environment on cognitive performance and subjective perception in open offices or simulated office environments. The studies reviewed used a variety of cognitive tests to assess various aspects of cognitive function, such as working memory, attention, cognitive flexibility, and task performance.

The most commonly used cognitive tests in this research are variations of the serial recall task (Kang et al. 2023; Renz, Leistner, and Liebl 2018; 2019; Annu Haapakangas et al. 2014), which assesses the ability of participants to remember the sequence of numbers, letters, or words in the correct order. This task primarily evaluates short-term memory and working memory, which are important for office work performance. Other tests, such as the N-back task (Peng et al. 2023; Annu Haapakangas et al. 2014; Lee et al. 2020), Stroop task (Peng et al. 2023; Latini et al. 2023; Lee et al. 2020), and digit span tasks (W. Yang and Jeon 2023; Jo and Jeon 2022a; Yadav et al. 2017), are also frequently used to assess working memory, cognitive control, and attention.

Some studies use more applied tasks to evaluate cognitive performance in simulated office environments. For example, (J. Yang and Hermann 2017) used a spreadsheet input task to measure productivity in terms of the number of inputs and number of errors while (Wang and Novak 2010) used tests of typing, grammatical reasoning, and mathematics to assess performance in a simulated office environment. (Yadav et al. 2017) used a comprehensive battery of tests, including the Hampshire Tree Task and Spatial Slider, to capture the broad spectrum of cognitive skills required in office tasks.

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IN-NOVA – Project no. 101073037

(Hölle and Bleichner 2023) used a unique approach to assess cognitive performance and sound processing in controlled laboratory conditions and a more naturalistic beyond-the-lab (BTL) setting. In the controlled laboratory, participants performed four tasks (task-free, reading, listening, and counting) while listening to click tones in a quiet room. This served as a reference for interpreting the data collected in the BTL condition.

The majority of studies were conducted in controlled laboratory environments designed to simulate open office environments (Kang et al. 2023; Peng et al. 2023; Renz, Leistner, and Liebl 2019; Zhang, Ou, and Kang 2021; Lee et al. 2020; Annu Haapakangas et al. 2014; Wang and Novak 2010). These simulated environments allow researchers to manipulate acoustic conditions and evaluate their impact on cognitive performance while minimising potential confounding variables. However, some studies, such as (Hölle and Bleichner 2023) included assessments in real office environments or conditions outside the laboratory to provide insight into cognitive performance in more real environments.

In conclusion, this systematic review highlights the diverse cognitive tests and assessment methods used to evaluate the impact of the acoustic environment on cognitive performance in open offices. These findings underscore the importance of considering objective measures of cognitive performance and subjective perceptions when designing office spaces to optimise employee well-being and productivity.

#### 4.13. Psychological and Well-being

The studies included in this systematic review provide valuable insights into the psychological, mental health, and well-being impacts of noise in open-plan offices. The findings highlight the complex interplay between acoustic conditions, employee perceptions, and various dimensions of well-being.

Several studies focused on assessing specific mental health indicators, such as stress, depressive symptoms, exhaustion, disengagement, concentration, fatigue, and sleep quality (Bergefurt, Appel-Meulenbroek, and Arentze 2024; Lenne, Chevret, and Marchand 2020; Haka

et al. 2009). These studies employed validated questionnaires and scales, such as the Patient Health Questionnaire-4 (PHQ-4), Oldenburg Burnout Inventory (OLBI), and Checklist Individual Strength (CIS), to evaluate the short-term and long-term mental health aspects of employees in open-plan offices. The results suggest that noise levels and acoustic conditions can significantly influence employees' mental well-being, with higher noise levels often associated with increased stress, fatigue, and reduced concentration.

The emotional response to noise was another important aspect explored in several studies (Zhang, Ou, and Kang 2021; Yadav et al. 2017; Annu Haapakangas et al. 2014). The NASA Task Load Index (NASA-TLX) was commonly used to assess frustration levels and mental workload in response to different acoustic environments. Although the studies did not provide detailed results on frustration specifically, the inclusion of this measure highlights the potential emotional impact of noise on employees' well-being and work performance.

Subjective well-being and psychological factors were also investigated in relation to office type, perceived noise levels, and acoustic satisfaction (Otterbring, Bodin Danielsson, and Pareigis 2021; Indrani, Ekasiwi, and Arifianto 2023; Oseland and Hodsman 2018). These studies utilised surveys and questionnaires to assess cognitive and affective well-being, auditory sensations, concentration, past experiences, mood, and perceived impacts on peace of mind, motivation, and job satisfaction. The findings emphasise the subjective nature of noise perception and its influence on employees' overall well-being and productivity.

The physiological aspects of noise-induced stress were addressed in some studies (Haka et al. 2009; Sakellaris et al. 2019). These studies examined physiological stress responses and their potential long-term effects on performance when individuals are consistently exposed to the same noise conditions. The Personal Symptom Index-5 (PSI-5) was used to evaluate symptoms associated with sick building syndrome, while effort-reward imbalance (ERI) and negative life events were considered psycho-social factors influencing occupants' perceptions and well-being.

The studies conducted in controlled laboratory settings (Kang et al. 2023; Zhang, Ou, and Kang 2021; A. Haapakangas et al. 2011; Yadav et al. 2017; A. Haapakangas et al. 2011) allowed for the manipulation of acoustic conditions and the assessment of their impact on various well-being measures. These studies provide valuable insights into the causal relationships between noise, mental health, and well-being. However, it is important to note that laboratory settings may not fully capture the complexity and dynamics of real open-plan office environments.

On the other hand, field studies conducted in actual open-plan offices (Lenne, Chevret, and Marchand 2020; Acun and Yilmazer 2018b; Hongisto et al. 2017; Indrani, Ekasiwi, and Arifianto 2023; Ali 2011; Sakellaris et al. 2019) offer ecological validity and provide a more comprehensive understanding of the real-world impacts of noise on employee well-being. These studies highlight the importance of considering contextual factors, such as office layout, cultural differences, and individual preferences, when assessing the psychological and well-being outcomes of noise exposure.

In conclusion, this review demonstrates the multifaceted nature of the psychological, mental health, and well-being impacts of noise in open-plan offices. The included studies employ a range of methodologies, assessment tools, and settings to investigate various dimensions of well-being, including stress, emotional responses, subjective perceptions, and physiological reactions. While the specific findings may vary across studies, the overall evidence suggests that noise in open-plan offices can have significant negative impacts on employees' mental health, well-being, and productivity. Future research should continue to explore the complex relationships between acoustic conditions, individual differences, and well-being outcomes to inform the design and management of open-plan office environments that promote employee well-being and satisfaction.

#### 4.14. Physiological

The studies included in this review section investigated the physiological effects of noise in open offices and controlled laboratory environments simulating open offices. Evaluation methods used in these studies range from advanced physiological assessments using ear EEG, pulse oximetry, and EDA to social surveys assessing the impact of noise on physiological conditions.

(Hölle and Bleichner 2023) performed a comprehensive physiological assessment using ear EEG, pulse oximetry, and EDA in a controlled laboratory and office environment. Their research used advanced equipment such as cEEGrids for EEG, smartphones for data recording and stimulus control, nEEGlace for auditory presentation, and ear microphones for environmental sound recording. This multi-modal approach allowed for detailed analysis of participants' auditory processing and physiological responses to noise in an open office setting.

Similarly, (Lee et al. 2020) investigated physiological responses to different types of background noise in a controlled laboratory environment simulating an open office. They used pulse oximetry using the MightySat Masimo SET® to measure heart rate, oxygen saturation, respiratory rate, maximal variability index, and perfusion index. Additionally, they used an EDA sensor (E4 bracelet from Empatica) to measure skin conductance, along with additional sensors for heart rate, temperature, and movement. This comprehensive approach allowed the researchers to compare physiological responses to various background sounds typically encountered in open offices.

In contrast to the advanced physiological assessment used by previous studies, (Ali 2011) conducted a social survey in 10 different open-air office locations in Egypt to assess the impact of noise on physiological conditions. The survey included questions about the physiological impact of open office noise on respondents, such as fatigue, mental fatigue, headaches and hearing loss. Although this approach relies on self-reported data, it provides

valuable insight into the subjective experiences of individuals working in open offices and the impact of noise on their physical health.

The studies included in this review demonstrate the variety of methods used to evaluate the physiological impacts of noise in open offices, ranging from advanced technology assessments to self-reported surveys. The findings from this study contribute to our understanding of the potential health implications of noise exposure in open office environments and highlight the importance of considering objective physiological measurements and subjective experiences when assessing the impact of noise on worker well-being.

#### 4.15. Speech Privacy

This systematic review examined the content of the assessments used to evaluate acoustic privacy in various building types, with a focus on open-plan offices. The reviewed studies employed a range of questionnaires and rating scales to capture occupants' perceptions of acoustic privacy in their work environments.

The content of the assessments varied across the studies, but several common themes emerged. Many studies focused on evaluating occupants' satisfaction with the level of acoustic privacy in their workspaces (Ayoko et al. 2023; Forooraghi et al. 2023; Kim et al. 2020; Sakellaris et al. 2019; Sundstrom, Herbert, and Brown 1982). This included questions about the ability to have private conversations without being overheard (Ayoko et al. 2023; Ali 2011; Rolfö, Eklund, and Jahncke 2018), the degree of privacy provided by physical barriers such as walls, screens, or furniture (Kim et al. 2020; Rolfö, Eklund, and Jahncke 2018), and the level of background noise and speech intelligibility (Kim et al. 2020; Park et al. 2020).

Several studies used the GABO questionnaire (French acronym for Acoustic Annoyance in Open-Plan Offices) or similar instruments that assessed the Control/Privacy dimension of the physical working environment (Perrin Jegen and Chevret 2017; Abdalrahman and Galbrun 2017;

Pierrette et al. 2015). This dimension included ambient sound, the ability to hold private conversations, noise management, and the ability to personalise the workspace.

Some studies focused on more specific aspects of acoustic privacy, such as speech privacy (Jeon et al. 2022; Park et al. 2020) and the impact of noise on work activities (Ali 2011; Hongisto et al. 2017). These assessments aimed to capture the extent to which occupants could hear and understand the content of conversations around them and how this affected their work performance and satisfaction.

In addition to quantitative assessments, (Acun and Yilmazer 2018b) employed semi-structured interviews to explore employees' perceptions of acoustic privacy in open-plan offices. This qualitative approach allowed for a more in-depth understanding of the specific concerns and coping strategies related to speech privacy in these work environments. The interviews revealed that employees expressed discomfort about the lack of background noise, which heightened their concerns about speech privacy. They also discussed how they used earphones to mitigate these issues.

In addition to the content of the assessments, the rating scales used to measure occupants' perceptions of acoustic privacy varied across the studies. The most common scales were Likert-type scales, ranging from 5 to 7 points, with anchors such as "Strongly disagree" to "Strongly agree" or "Very dissatisfied" to "Very satisfied" (Ayoko et al. 2023; Forooraghi et al. 2023; Jeon et al. 2022; Kim et al. 2020; Sakellaris et al. 2019; Rolfö, Eklund, and Jahncke 2018; Sundstrom, Herbert, and Brown 1982). Some studies used semantic differential scales, such as the "Communal-Private" scale, to assess acoustic privacy in specific settings like campus libraries (Utami et al. 2018; Ikhwanuddin et al. 2017).

The content of the assessments used in the reviewed studies demonstrates the efforts to capture a wide range of aspects related to acoustic privacy in various building types. The findings suggest that a comprehensive evaluation of acoustic privacy should consider factors such as the ability to have private conversations, the impact of background noise and speech

intelligibility, the role of physical barriers in providing privacy, and the overall satisfaction with the level of acoustic privacy in the workspace.

#### 4.16. Coping Strategies

The review in this section aims to synthesise information from related studies regarding the coping strategies used by employees in offices to face acoustic challenges. The studies included in this review used a variety of methodologies, including questionnaires, semi-structured interviews, and online surveys, to investigate the coping mechanisms employed by employees in different office environments.

A recent study conducted by (Bergefurt, Appel-Meulenbroek, and Arentze 2024) conducted in an office environment found that employees used various coping strategies, such as discussing noise problems with coworkers, exerting greater effort, delaying work, changing the pace of work, using personal audio devices, being calmer, and even proposing management improvements. This is similar to previous studies by (Appel-Meulenbroek et al. 2020), who used similar strategies but categorised them into approach and avoidance strategies in their study of open offices with noise problems.

(Oseland and Hodsman 2018) investigated coping mechanisms through an online survey, revealing that employees often get away from noise sources by working outside the office, in a quiet place within the office, or at a different desk. They also found that some employees changed their work hours, used headphones, or made behavioural adjustments to deal with noise disturbances.

The studies conducted by (Acun and Yilmazer 2018b; 2015) used semi-structured interviews to understand employees' subjective responses to open office landscapes. These studies aim to identify factors influencing employees' perceptions and explore how they deal with voices in their work environment.

(Rolfö, Eklund, and Jahncke 2018) tested employee perceptions before and after relocating to an activity-based office using a combination of pre-relocation questionnaires and

post-relocation in-depth interviews. They assess aspects such as furniture customisation, frequency of using the same workplace, time spent searching for a suitable workplace, and frequency of changing workplaces.

Finally, (Ali 2011) investigated noise levels, disturbances, and precautions in open-plan offices in Egypt using a questionnaire. The study found that employees reacted to noise by considering moving to a quieter work environment, improving office acoustics, filing a complaint with the responsible authority, or a combination of these actions.

Findings from this review highlight various coping strategies used by employees in open-plan and activity-based offices to manage acoustic challenges. These strategies range from individual actions, such as using headphones or changing work habits, to collective efforts, such as discussing problems with coworkers or proposing improvements to management. The various coping mechanisms identified in this study underscore the importance of considering employee perspectives and experiences when designing and managing office environments to improve well-being and productivity.

## 5. Conclusion

Protocols for assessing soundscapes in cognitive function-based spaces involve both objective measurements and subjective evaluations. Objective assessments include measuring acoustic parameters such as sound pressure levels, reverberation times, speech intelligibility, and background noise levels. These assessments are conducted using sound level meters and other acoustic measurement tools to ensure precise evaluations of the acoustic environment. Subjective assessments are equally important and involve gathering data on individual perceptions and experiences related to the acoustic environment. This can be done through questionnaires, interviews, and surveys that focus on various aspects such as noise annoyance, satisfaction with the acoustic conditions, and the perceived impact on cognitive functions and well-being. These methods provide a comprehensive understanding of how soundscapes affect occupants in cognitive function-based spaces.

Sound Pressure Level (SPL) measures the intensity of sound in an environment, providing insights into immediate loudness and peak noise moments. It helps in evaluating noise exposure and its impact on cognitive functions and comfort. The Equivalent Continuous Sound Level (Leq) represents the average sound level over a period, useful for assessing long-term noise exposure and its effects on productivity and well-being. Reverberation Time (RT60, T20, T30) indicates how long it takes for sound to decay in a space, crucial for understanding speech clarity and overall sound quality. Speech intelligibility is assessed through metrics like the Speech Transmission Index (STI) and signal-to-noise ratio (SNR), which measure how clearly speech can be heard and understood, important for communication and concentration. Background Noise Level (Lp) assesses the ambient noise in a space, which can affect concentration and comfort. Lower background noise levels are generally preferred in cognitive function-based spaces. Frequency Response evaluates how different frequencies are reproduced in a space, affecting the overall acoustic quality and the clarity of sounds. Early Decay Time (EDT) measures the initial rate of sound decay, providing insights into perceived reverberance and clarity of sound.

Common questions in subjective assessments focus on various aspects of the acoustic environment and its impact on occupants. Typical questions include: How would you rate the overall acoustic quality of this space? How often are you disturbed by noise in this environment? To what extent does the noise affect your ability to concentrate? How satisfied are you with the current noise levels? Can you identify the most common sources of noise disturbance? How would you describe the loudness and pleasantness of the soundscape? How does the acoustic environment impact your productivity and well-being? How effective do you find any noise-masking solutions implemented in this space?

Various tools are used to comprehensively investigate the correlation between soundscapes and mental well-being. Questionnaires and surveys, such as the Indoor Soundscape Questionnaire, collect subjective data on individual perceptions, satisfaction, and preferences

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IN-NOVA – Project no. 101073037

related to the acoustic environment. Sound Level Meters (SLMs) are used for objective measurements of sound pressure levels, background noise, and other acoustic parameters. Psychoacoustic indices, which measure loudness, sharpness, roughness, and fluctuation strength, help in understanding human responses to sound. The NASA Task Load Index (NASA-TLX) evaluates mental workload and cognitive demands under different acoustic conditions. Cognitive tests, such as serial recall tasks, N-back tasks, and Stroop tasks, assess working memory, attention, cognitive flexibility, and overall task performance. Standardized questionnaires, like the Noise Sensitivity Questionnaire (NoiseQ) and the Weinstein Noise Sensitivity Scale, assess individual differences in noise sensitivity and personal control over the environment. These protocols and tools are essential for creating and managing acoustically optimized environments that support cognitive functions, well-being, and productivity in various indoor spaces.

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