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Indicators and methods for assessing acoustical preferences and needs of students in educational buildings: A review

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ABSTRACT

Sounds (e.g., human activity, nature, building systems) are one of the indoor environmental stimuli that may have positive and/or negative effects on students' well-being and performance in educational buildings. Students in educational buildings have individual acoustical preferences and needs as portrayed by occupant-related indicators, for example perception. Acoustical guidelines for educational buildings are generally focused on acoustical performance in terms of dose-related (e.g., sound pressure level) and building-related indicators (e.g., sound absorbing walls), while occupant-related indicators (e.g., heart rate) are rarely mentioned. In contrast, previous studies such as indoor soundscape studies, do take into consideration occupant-related indicators, including physiological and psychological. Therefore, this study aimed at summarizing these indicators in a comprehensive overview that is essential for investigating the students' acoustical preferences and needs in educational buildings. A literature review of relevant studies in the domain of indoor acoustics and soundscape was carried out. A number of key indicators (occupant-related, dose-related, building-related) and methods that are fundamental to be considered were identified. Only in a few studies, students' acoustical preferences and needs were investigated by considering occupant-related indicators (both physiological and psychological). In addition, dose-related indicators of other indoor environmental quality (IEQ) factors and building-related indicators were rarely taken into account in previous studies.

1. Introduction

People spend most of their time (around 90 %) in indoor environments where they are exposed to various environmental stressors that have the potential to affect individuals' health [1]. To promote individuals' well-being in indoor environments, it is therefore important to pay attention to the indoor environmental quality (IEQ) factors, comprising of thermal quality, lighting quality, acoustical quality, and air quality [2,3]. Occupants are exposed to a large number of physical stressors in indoor environments, all of which can cause annoyance and adverse effects on health [4]. It was indicated that both lighting and acoustical factors are perceived by students as factors that influence their academic performance [5]. These factors can cause annoyance and adverse effects on health, and noise was found to be the most annoying factor in schools buildings [6]. Noise, being one of these stressors, stimulates both the sympathetic nervous system and the endocrine system [7]. On the contrary, appropriate acoustical conditions in indoor environments can play a significant role in improving individuals' well-being in a positive manner [8]. The soundscape approach has been developed to consider the relationship between soundscape and individuals' well-being; individuals' sound perceptions and experience are studied [9]. According to the International Organization for Standardization (ISO) 12913-1, the term soundscape is defined as: "*acoustic environment as perceived or experienced and/or understood by a person or people, in context*" [10]. In educational buildings, previous studies showed that noise affected students' well-being (health and comfort) as well as performance [11–18]. In a field study, 38 % of students reported to be bothered by noise, especially by speech, while performing a complex cognitive task [19]. In another study, 87 % of primary school children were found to be annoyed with noise in classrooms [6]. On the contrary, positive sounds that have restorative effects

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Abbreviations: ECG, electrodes and electrocardiograms; EDA, electrodermal activity; EDT, early decay time; EEC, electroencephalogram; EEG, electroencephalograms; HF HRV, high frequency heart rate variability; HR, heartrate; IEQ, indoor environmental quality; PMV, predicted mean vote; PPD, predicted percentage of dissatisfaction; RR, respiration rate; RT, reverberation time; SCL, skin conductance level; SPL, sound pressure level; STI, speech transmission index; VOCs, volatile organic compounds.

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(e.g., water fountain) have shown to enhance students' self-rated health as well as improve the students' short-term memory and cognitive performance [20,21]. Moreover, students can have different preferences and needs with regards to the different IEQ factors [11]. Hence, while optimizing indoor acoustics of an educational building, it is fundamental to consider students' acoustical preferences and needs in their educational buildings.

When studying the quality of an indoor environment, three categories of indicators can be used: occupant-related indicators (e.g., noise annoyance), dose-related/environmental-related indicators (e.g., sound pressure level), and building-related indicators (e.g., presence of sound absorbing ceiling) [4,22]. There are various standards and requirements available for assessing acoustical quality in educational buildings. For example, Building Bulletin 93 (BB93) [23,24] is an acoustical guideline for schools that provides the standards and requirements for sound performance in schools. It includes the maximum background noise level of different types of rooms, such as typical classrooms, lecture rooms (small and large), and quiet study areas (e.g., libraries and study rooms). Additionally, it sets the requirements of the noise generated from building systems, the airborne sound insulation between spaces, and the impact sound insulation of floors. According to the ANSI/ASA S12.60 (American National Standards Institute, 2010) [25], the typical classroom (in elementary and secondary schools) volume ranges between 283 and 566 m^3, while the volume of the other larger learning spaces (e.g., lecture rooms) is larger than 566 m^3. In the Netherlands, a program of requirements for fresh schools "*Frisse Scholen 2021*" can be applied. It covers the acoustical requirements in terms of soundproofing of the façade, building system noise, room acoustics, airborne noise insulation, and impact sound insulation [26]. Nevertheless, these acoustical guidelines for educational buildings are mainly focused on dose-related and some building-related indicators, while occupant-related indicators are lacking. However, the ISO 28802 standard includes occupant-related indicators that could be assessed to examine the impact of the acoustical environment on individuals [27]. While these indicators are limited to psychological indicators (e.g., annoyance, preferences satisfaction, and acceptability), physiological indicators are not included. Therefore, identifying comprehensive indicators is essential for understanding students' acoustical preferences and needs (e.g., preference for a certain sound type and need for a quiet or pleasant sounds in a study place) for promoting their well-being and performance in their educational buildings. As part of that, occupant-related indicators (physiological and psychological), dose-related indicators, and building-related indicators are essential to be considered. Thus, this review aims at summarizing the indicators and methods that have been used in previous studies for understanding students' acoustical preferences and needs in educational buildings, and developing an overview that illustrates the related results. Accordingly, the main research questions of this study are:

1. What are the indicators that have to be considered to evaluate the acoustical quality taking into account students' acoustical preferences and needs?
2. What are the methods that are used for measuring and assessing these indicators?

2. Materials and methods

An overview was established by summarizing main occupant-related, dose-related, and building-related indicators as well as the methods that are required for investigating the students' acoustical preferences and needs. These three main indicators are important to understand the IEQ taking into account both human and environmental levels [28]. In a recent study [29], it was observed that previous studies on indoor acoustics can be divided into studies focusing mainly on the dose-related indicators and some building-related indicators, and studies focusing on indoor soundscapes, including all three categories of indicators. Accordingly, in Table 1, the first concept (related to human level such as health) was defined to find the studies that considered occupant-related indicators, while the second concept was introduced to find both dose-related and building-related indicators linked to the acoustical environment. The third concept was included to specify the context and building occupants of the previous studies. The fourth concept focuses on the cross-modal perception was included to explore dose-related indicators of other IEQ-factors that have interaction with the acoustics. The soundscape concept was introduced during the recent review [29]. This concept was used to search for a number of relevant studies in the domain of educational buildings and other contexts (e.g., offices, hospitals) since there are limitations on indoor soundscape studies within the educational buildings context.

These five concepts with their keywords (Table 1) were expanded to find relevant studies for this scoping review: human level, acoustical environment, occupants, cross-modal perception, and soundscape were used to find the relevant studies. This table was used to find the relevant studies by creating different search queries. The concepts were combined with and/or, and the synonym of each concept was combined with another concept by using and/or. There are some terms under concept 3 that were used to find relevant studies in the domain of indoor soundscapes since it is an emerging topic. An example of search queries was ("performance" OR "perception" OR "psychological" OR "physiological") AND ("noise" OR "acoustic" OR "sound level") AND ("pupils" OR "students" OR "school children") AND ("interaction effect" OR "cross-modal perception" OR "thermal" OR "lighting") AND ("soundscape" OR "sound preference" OR "sounds").

Three scientific databases were used to search the state-of-art studies, which are Scopus, Web of Science, and Google Scholar. These keywords were used to find the relevant studies in the scientific databases by different search strings of the combinations of

Table 1
Keywords for the literature review.

	Combined with AND				
	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Combined with OR	Physiological	Acoustical environment	University students	Cross-modal perception	Soundscape
	Human level	Background noise	Pupils	Interaction effect	Indoor soundscape
	Psychological	Noise	Students	Combined effect	Soundscape preference
	Preferences	Sound level	School children	Lighting	Sound preference
	Performance	Sound sources	Office workers*	Thermal	Sounds
	Health		Patients*		
	Well-being	Sound environment	Nurses*		
	Perception	Acoustic			

*Keywords used for finding studies in indoor soundscapes due to the limited studies in the indoor soundscapes and students.

these keywords. 916 articles were found in the databases. It can be noted that there was no time limitation for the resources set during the searching process, since this review aims at summarizing all possible indicators and methods that are used by previous studies. The resources that are considered for this review include peer-reviewed journal papers and book series. In addition, two conference proceedings were also included because they were focused on the effects of indoor soundscapes on students in educational buildings. The inclusion criteria of this scoping review were set to include studies in the domain of soundscape and acoustical environment considering occupant-related indicators in an indoor environment, acoustical environment with one or more effects (positive and/or negative) on individuals' (and students') physiological health, psychological health, performance, and preferences, and cross-modal perception of acoustics with other IEQ-factors. In contrast, this review excluded the studies focused on only the urban soundscape without considering indoor soundscape, or conducted only objective measurements of acoustical environment and other IEQ-factors without taking into account occupant-related indicators, or focused on the impact of acoustical environment/ indoor soundscape on subjects with hearing impairment. After screening the titles and abstracts of the resources, 44 articles (out of which 25 focused on students) were regarded as eligible and have been reviewed.

3. Results

The synthesis of the results section is based on presenting a) the previous studies on indoor acoustics in relation to students' physiological needs, psychological needs, performance, and the cross-modal effects of the interaction between acoustics and other IEQ factors (Sub-section 3.1); and b) an overview of indoor soundscape studies (Sub-section 3.2).

3.1. Previous studies on indoor acoustics

An acoustical environment of a place, known as sound or sonic environment, refers to all sounds generated from different sound sources that an individual is able to perceive in that place [30]. Indoor acoustics in relation to students has been examined through several dimensions with relation to concept 1 and 4 in Table 1 in terms of physiological needs, psychological needs, performance, and cross-modal perception. Cross-modal perception refers to the perception of the interaction between two or more environmental stimuli such as between noise and temperature. Furthermore, several studies examined the acoustical environment within the field of indoor soundscape.

3.1.1. Indoor acoustics and students' physiological needs

According to Maslow, the five human needs are 1) physiological needs, 2) safety, 3) love/belonging, 4) esteem, and 5) self-actualization (in descending order of importance) [31]. To ensure the well-being in any indoor environment, it is important to ensure firstly the physiological needs, which are basic needs before moving upward [32]. As concept 1 in Table 1 includes physiological and health terms, this review found that the effects of indoor acoustics on students' physiological health have been tested by various researchers [33–38]. For example, Alvarsson et al. [33] tested the effect of four sound types on stress recovery by measuring two physiological indicators of students; skin conductance level (SCL) and high-frequency heart rate variability (HF HRV). It was concluded that SCL recovery was fast during the exposure to natural sound. Furthermore, Park and Lee [39] examined the effects of floor impact sounds on individuals' physiological health by monitoring three occupant-related indicators; heart rate (HR), electrodermal activity (EDA), and respiration rate (RR). The results showed that sound pressure level (SPL) had a negative impact on both EDA and RR, while HR was not influenced by the SPL. Conversely, Abbasi et al. [36] had investigated the impacts of low-frequency sound exposure on students' physiological health, such as brain activity, by measuring electroencephalography and electrooculography. Also, mental fatigue, which is known as a mental impairment that leads to an unwillingness to perform any mental effort, was assessed by a subjective questionnaire. This questionnaire was based on the visual analogue scale of fatigue (F-VAS), which students filled out after the sound exposure. The outcomes showed that a high amount of SPL (65–75 dBA) could cause mental fatigue of students, which significantly affected their HR and working memory.

3.1.2. Indoor acoustics and students' psychological needs

Environmental stressors such as noise play a vital role in affecting an individual's comfort, and it is strongly dependent on the individual's psychological state [40]. The psychological responses to sound are associated with an individual's emotions, which arise from hearing a certain sound source. Individuals perceive, interpret, and prefer sounds differently with regards to sound features such as quiet, friendly, safe, calm, and distinctively clear [41]. The psychological process starts with expectations followed by the perception and may result in outcome (e.g., emotions, feelings, and thoughts) and/or behaviour-oriented action [42]. Calmness and vibrancy are two resultant emotions that could be evoked by exposure to a specific sound source [43]. Also, pleasantness (valence) and eventfulness (arousal) are the two emotional reactions that are considered valid metrics for evaluating the soundscape quality [44]. Previous studies examined the influence of indoor acoustical conditions on students' psychological needs and responses. For instance, Scannell [13] indicated that some spaces with lower background noise levels (such as airflow through ventilation systems) were perceived by students as suitable sound in informal learning spaces. These are spaces where students (usually in higher education) can perform their informal learning activities (study-related activities) such as collaborative or individual learning. These activities are usually performed outside the classroom, which could be at home or in an educational building [45]. Whereas, results from a study conducted by Wålinder et al. [46] proved that noise affected primary school children (fourth grade) negatively by increasing their stress which caused health issues such as fatigue and headache (physiological indicators). Additionally, it was found that their psychological responses in terms of emotional responses (e.g., anxiety, insecurity, and aggressiveness) were not associated with SPL.

3.1.3. Indoor acoustics and students' performance

Generally, indoor acoustics can influence an individuals' performance and productivity in indoor environments. For example, the effect of low-frequencies noise on individuals' cognitive performance was examined in a laboratory study [47]. It was concluded that participants had a shorter time response while they were exposed to noise, which was related to a higher stress level based on the arousal theory. Another study testified that acoustical indicators sound types such as speech noise had a significant negative effect on participants' performance and the effects were stronger by increasing the speech transmission index (STI) of the noise [48]. The impacts of indoor acoustics on students' performance were investigated in previous studies. For instance, a field study, conducted by Braat-eggen et al. [19], in an open-plan study environment in a university measured the effects of dose-related indicators, such as reverberation time (RT), a-weighted SPL, spatial decay rate, and distraction distance, on university students' performance and disturbance. It was found that 38 % of students were bothered by noise while they were performing a complex cognitive task (e.g., studying for an exam, reading, and writing). Additionally, Tristan-Hernandez et al. [15] observed the negative effect of the background noise generated inside six university facilities on changes in students' attentional processes. Furthermore, a lab study was carried out by Zhang et al. [49] with 335 primary school children (age 9 to 13) who were exposed to a series of listening tests in two test chambers (acoustically treated and untreated) with one of seven types of background sounds. The outcomes showed that there were significant interactions between the effect of the acoustical indicators; sound type and SPL on the children's performance. Whilst, the performance of students in a quiet environment was found to be not significantly better than in the other environmental scenarios which include background speech noise [12]. Prodi and Visentin [17] examined the effects of conditions in two classrooms with different RT, one quiet and one noisy (RT from 0.57 to 0.69 s), on the performance of school children (age 11 to 13 years old). They concluded that a longer RT affected the children's accuracy while performing a perception task.

3.1.4. Cross-modal effects of interactions between acoustics and other IEQ-factors

The cross-modal effects of interactions between the acoustics and other IEQ-factors had been covered by previous studies [29]. In general, Hasegawa and Lau [50] indicated in their review article that sound sources influenced the various perceptual responses such as audio, visual, cognitive, as well as emotional perceptions. Also, the visual indicators such as greenery elements and water features proved to reduce the noise annoyance perceived by individuals in an indoor environment. With regards to students' context, Chung et al. [51] found that the participants (undergraduate students) preferred sea views more than road views, since sea views attenuated the noise annoyance, while road views aggravated it. Liebl et al. [52] tested the combined effects of acoustical and visual indicators, which are speech intelligibility and lighting type, on individuals' cognitive performance and well-being. It was found that individuals perform better with the combination of low intelligibility background speech and static lighting. The speech intelligibility refers to the possibility of hearing the speaker (e.g., teacher speech) clearly in an indoor environment, which depends on the built environment characteristics in terms of RT and signal-to-noise ratio. Speech transmission index (STI) is an objective measurement for the speech intelligibility that ranges between 1.0 (perfect intelligibility) and 0.0 (no intelligibility) [53]. Furthermore, the perception of the indoor acoustical environment could be influenced by thermal conditions. Pellerin and Candas [54] mentioned that the perception of indoor acoustics might be affected by exposure to short-term and long-term thermal strains. In addition, the exposure to high noise levels contributed to thermal discomfort.

Students' perception of indoor acoustics seems to be influenced by the multisensory interactions with other IEQ-factors. For example, sound types may have an impact on the smell assessment. Bluyssen et al. [55] found that listening to the sound of primary school children talking could negatively affect the evaluation of smell. Likewise, Choi et al. [34] tested the combined effects of IEQ-factors indicators; temperature, odour, and sound type on students' stress levels. The stress level was measured by using both the paper-based test (stress examination sheet) and an electroencephalogram (EEG) to measure brain waves. The outcome indicated that individuals' stress levels increased by the exposure to the combined environment of 30 °C temperature, odour irritants volatile organic compounds (VOCs), and road traffic noises. In terms of the cross-modal perception between noise level and temperature, Yang et al. [56] examined the interaction effects of room temperature and background noise on students' perception of floor impact noises in a room. A bipolar visual analogue scale subjective questionnaire was used to capture the perceptions including loudness (which is a psychological term that refers to the magnitude of the auditory sensation) and noisiness (which expressed in the sound quality). It was found that the loudness and noisiness of the floor impact noise were affected by the room temperature, background noise level, and floor impact noise levels. Dehghan et al. [35] found that both physiological indicators; systolic and diastolic pressures of students increased after exposure to different levels of noise (70, 85, and 95 dB), and the changes in both blood pressures after exposure to the combination of high temperature (40 °C) and noise were subtle. These SPL are considered as high values, in which they were played in a climatic chamber by using a loudspeaker. The exposure duration was 40 min. Contrarily, Abbasi et al. [37] evaluated the combined effects of two dose-related indicators; noise level and air temperature on students' neurophysiological responses; HR and RR. It was proved that high noise levels as well as high air temperature (30 °C) could increase the mean value of neurophysiological responses of students. With regards to the cross-modal perception between the acoustics and other two or three IEQ-factors, Sun et al. [38] investigated the students' perceptions and physiological reactions to the combined environment of dose-related indicators of three IEQ-factors, which are; temperature, illuminance, and sound level. It was revealed that the physiological indicators; blood pressure, HR, and skin temperature were influenced by all the three indicators of the IEQ-factors.

3.2. Previous studies on indoor soundscape

3.2.1. Soundscape

The concept of 'soundscape' was introduced by the Canadian composer R. Murray Schafer in the 1960s [57]. The soundscape is an individual's perceptual construct of an acoustical environment [30]. The main seven perceptual construct elements of soundscapes are context, sound source, acoustical environment, auditory sensation, interpretation of auditory sensation, and human responses, as presented in Fig. 1 [10]. The auditory sensation is one function of the neurological process that begins with receiving auditory stimuli that can be sensed by the ear receptors [10,58]. The three pillars to be considered in soundscape studies are: people, acoustical environment, and context [58,59]. The context refers to the interconnection between person, activity, and place [10,60]. Hence, the difference between the acoustical environment and soundscape is that the acoustical environment is a physical phenomenon that can be assessed by measuring dose-related indicators in terms of indoor acoustics such as SPL. On the contrary, the soundscape take into account occupant-related indicators by considering individuals' perceptual constructs (e.g., sensation, interpretation, emotional responses) of this physical phenomenon (dose-related indicators) as is illustrated in Fig. 2.

3.2.2. Urban soundscape vs Indoor soundscape

Urban soundscape has been studied over decades, while indoor soundscape is an emerging topic [61]. Soundscape has been recently applied to the indoor environment to explore how individuals perceive, experience, and understand indoor acoustics in different contexts, such as working and relaxing environments [62].

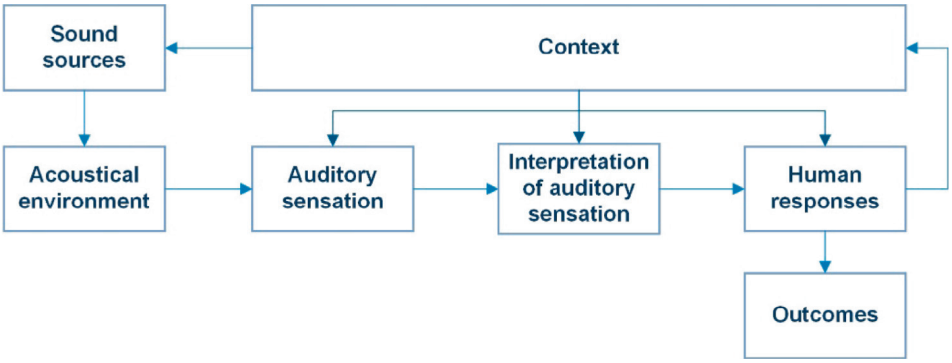

Fig. 1. Perceptual construct elements in a soundscape. Source: redrawn and adapted from [10].

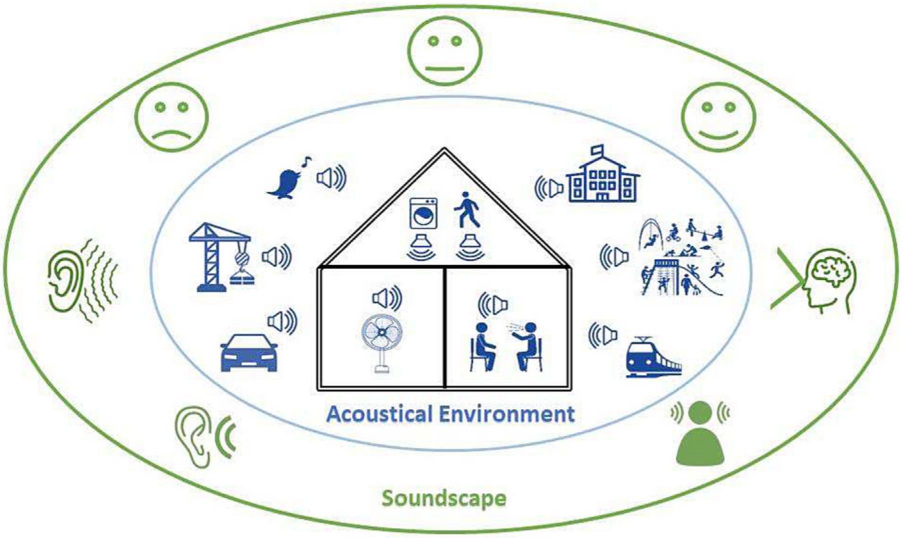

Fig. 2. Illustration of the difference between the acoustical environment and soundscape.

However, indoor soundscapes are more complex than urban soundscapes due to the complexity of the indoor acoustical environment [63]. The major factors of the indoor soundscape are classified as acoustical factors, architectural factors, and contextual factors. Among them, architectural factors, including function, architectural properties (building-related indicators), and physical environment (dose-related indicators), are the most remarkable and unique factors to the indoor soundscape. This is due to the role of the architectural factors in the way how sound propagates through the indoor environment [60]. Indoor soundscape studies have taken into account the individuals' perception of indoor acoustics by considering the human-centered approaches. Torresin et al. [62] indicated that human-centred approaches are essential to achieve positively perceived indoor acoustics. Also, Torresin et al. [64] mentioned that sound can be utilized as a biophilic design approach. The main two appraisal dimensions of the soundscape are pleasantness and eventfulness as illustrated in the soundscape circumplex model (Fig. 3). Individuals can evaluate a particular soundscape with a combination of more than one attribute [65]. For example, Yang and Moon [66] pointed out that water sounds enhanced the participants' perceptions with regards to calmness and pleasantness. Therefore this circumplex model can be considered for investigating occupant-related indicators with regard to students' preferences and needs for certain indoor acoustics.

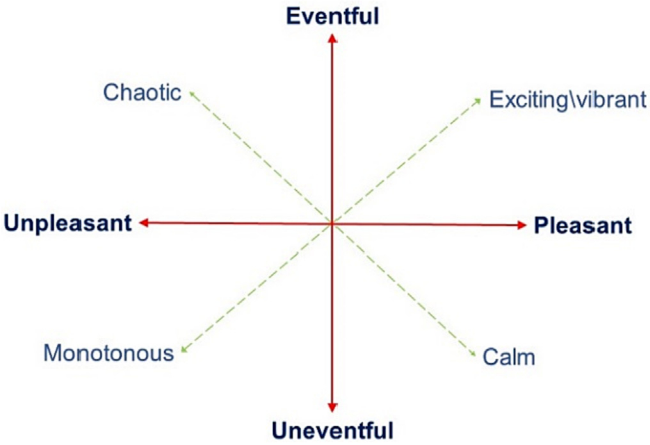

Fig. 3. Soundscape appraisal dimensions. Source: redrawn and adapted from [65].

3.2.3. Indoor soundscape studies

Only a few studies about the indoor soundscape in educational buildings (e.g., schools and university buildings) have been published. Most of them indicated that there are limited studies on indoor soundscape within context. These studies were eight and were conducted in university libraries [67–69], classrooms in higher education institutions [70], high school classrooms and computer laboratories [71,72], open study spaces in a university [73], students at home [21], and children in a classroom [20]. On the other hand, there are other studies that investigated the indoor soundscape in different contexts, in which 13 studies were found. Therefore, this study reviewed the investigations of indoor soundscapes in other types of buildings (e.g., healthcare facilities, residential buildings, offices) since the methods used in these studies and the related findings can still be seen as references.

A study conducted in healthcare facilities by Mackrill et al. [74] was one of the first studies on indoor soundscape, made use of semi-structured interviews with patients and nurses to understand the subjective responses to soundscapes in a hospital ward. The results show that patients and nurses adopted coping methods for habituating to the soundscape. Moreover, Mackrill et al. [75] carried out a lab study with participants who evaluated their emotional and cognitive responses to different hospital ward soundscapes clips. It was found that the rated emotional response as a relaxation was significantly influenced by the natural sound. Furthermore, Aletta et al. [76] examined the soundscape of the nursing homes' living rooms and found that there was a relationship between the SPL and the number of people inside the room. Indoor soundscapes have also been studied in offices. For example, the grounded theory (GT) approach was performed to investigate sound perception in an open-plan office. A user-focused soundscape survey and semi-structured interviews were used to assess the employees' sound perception. The study concluded that employees adopted strategies, such as putting on headphones, to cope with the unexpected soundscape or the sounds that were interfered with their concentration [63]. Abdalrahman and Galbrun [77] have done laboratory experiments on the potential of using water elements as sound-masking in an open-plan office. Results from these experiments proved that the water elements improved sound perception. With regards to the residential sector, Torresin, et al. [78] conducted a listening test in a laboratory to develop a soundscape model in residential buildings. The results pointed out that 1) comfort was negatively linked to loudness, 2) the content was positively connected with sound level variability, and 3) familiarity was negatively associated with sharpness. Additionally, Mohamed and Dokmeci Yorukoglu [79] indicated that cross-cultural differences and social factors affected sound perceptions. Furthermore, several previous studies carried out indoor soundscape studies in historical buildings which focused on capturing individuals' perception and/or interpretation and/or expectations towards the acoustical environment [61,80,81]. Besides a study examined the soundscapes in a shopping mall which took into account individuals' shopping habit and their expectations towards the acoustical environment [82].

In educational buildings within the context of university buildings, Dokmeci Yorukoglu and Kang [67,68] carried out an indoor soundscape study in three university libraries by recording the sounds in three timeslots. SPL and psychoacoustic parameters (loudness, roughness, and sharpness) were measured. In addition, a subjective assessment questionnaire was used for evaluating soundscape in terms of noise annoyance and sound preferences. The questionnaire's results indicated that sounds induced by mobile phones, personal music players, and construction sites were rated as the most annoying sounds; while footsteps and page-turning sounds were the least annoying. In addition, a significant relationship was found between the objective parameters such as SPL and loudness with the subjective assessment. Xiao and Aletta [69] also conducted a soundscape study in a university library where soundwalk -a technique involving walking inside a space to listen to the surrounding environment- was performed for identifying the sound types. Also, a questionnaire survey was carried out for subjective assessments as to the frequency of hearing the sound, sounds quality, and appropriateness of sound. It was found that the soundscape quality was influenced by the space activity and the acoustical perception. Additionally, it was mentioned that space layout is a factor that can influence acoustical comfort. Furthermore, Chan et al. [70] investigated the indoor soundscape in nine classrooms of higher education institutions. This study conducted acoustical measurements including SPL. Within the context of schools, Cankaya and Yilmazer [71] developed a conceptual indoor soundscape framework of high-school environments using the GT approach to investigate the effects of soundscape on students' perception in two educational spaces: classrooms and computer laboratories. The conceptual framework demonstrated the relationships between students' expectations and sound preferences. Additionally, a series of semi-structured interviews with students were conducted to evaluate their soundscape perception. Based on their expectations, students might be annoyed by speech sounds in the classroom and by fan sounds in computer laboratories. However, speech sound was perceived as the most annoying sound source in both spaces. Cankaya Topak and Yilmazer [72] proposed guidelines for designing facilities for educational buildings (classrooms, and computer laboratories) with respect to students' perception of the acoustical environment. This was done through conducting a mixed methods approach including a questionnaire, interview, and acoustical measurements at the environmental level (including SPL, RT, and STI). The proposed design guidelines were developed using GT as an analysis method. The authors concluded that the auditory perception was linked to the space context (e.g., lecture) rather than the SPL, so it is significant to consider these perceptions while designing educational buildings.

Acun and Yilmazer [73] examined the soundscape of four open study spaces in a university through a questionnaire survey. The results showed that the sounds generated by human activities were the most disturbing and negatively affected students' concentration. During the COVID-19, Dzhambov et al. [21] carried out a study to investigate the effect of indoor soundscape on the self-rated health of university students during the pandemic. An online questionnaire was used to explore the frequency of hearing sound sources and the pleasantness of these sounds perceived by students. The outcomes of this study indicated that exposure to mechanical sounds resulted in worse self-rated health which reduced restorative quality. It was shown that positive indoor soundscapes, such as nature sounds (e.g., birdsong and flowing water), have a significant impact in improving self-rated health during social distancing times. Similarly, Puglisi et al [83] conducted an online survey during COVID-19 to capture the soundscape perception in terms of the annoyance of workers (e.g., university staff) working from home. They concluded that 25 % of these workers found sounds generated by other people (e.g., walking, talking) as the most annoying sound sources. This annoyance resulted in the loss of concentration and inability to relax.

Furthermore, indoor soundscape studies can involve lab studies as a method of collecting data [20,84,85]. For instance, Shu and Ma [20] conducted a lab study where they tested the effects of classroom soundscapes on children's cognitive performance. The study revealed that among all sounds, water and fountain sounds showed the best restorative effects on children's cognitive performance. Adding to that, exposure to both fountain and stream sounds showed a better performance in short-term memory. Another study conducted by Ma and Shu [84] considered students' physiological and psychological indicators in the context of an open-plan office. This was done by measuring students' HR and blood pressure (systolic and diastolic). In addition, students' psychological experiences (e.g., fatigue, annoyance, and tension) were evaluated. It was indicated that the soundscapes that were perceived as pleasant had positive effects on fatigue restoration and reduced the annoyance level of individuals. Similarly, Medvedev et al. [85] measured the physiological indicators, including HR and SCL, of participants (students and staff) caused by different soundscapes when the participants were performing stressful tasks and resting. This study asserted that soundscapes can influence individuals' autonomic functions during both activities. Also, subjective responses were investigated through the soundscape appraisal dimensions (e.g., pleasantness, arousal, familiarity, eventfulness, and dominance).

4. Discussion on the findings

4.1. Indicators for investigating indoor acoustics

There are a number of indicators concerning occupant-related, dose-related, and building-related indicators examined by the previous studies on indoor acoustics and soundscapes that were mentioned in the results section. Appendix A summarizes the indicators that were investigated in the 44 previous studies. The following three subsections answer the first research question: What are the indicators that have to be considered to evaluate the acoustical quality taking into account students' acoustical preferences and needs?

4.1.1. Occupant-related indicators

Occupant-related indicators are divided into physiological and psychological indicators, which were considered by the previous studies on indoor acoustics. With regards to physiological indicators, the authors measured the physiological indicators of individuals for investigating the individuals' acoustical needs. These indicators are HR [36–39,46,47,84,85] or HF HRV [33,36], RR [37,39], blood pressure (diastolic/systolic) [35,38,46,84], SCL [33,85], electroencephalogram (EEC) for capturing students' stress level [34], EDA [39], salivary cortisol [46], skin temperature [38], and cerebral behaviour [15].

Regarding psychological indicators, previous studies captured students' acoustical preferences through investigating several indicators. The psychological indicators are stress levels/state [34], emotional responses (e.g., annoyance [39,51,67,68,76,84] or assessment of disturbance [19,46], pleasantness [21,81,85], calmness [76], eventfulness [76,85], tension [84], and fatigue [84]), perception as to the acoustical environment /sound [13,55,63,71,73,74,79,81,82,86,87] or background noise [56,66] or floor impact noise [56] or cross-modal perception with other IEQ-factors (e.g., draught [55], smell [55], light [55,87], temperature/thermal sensation [55,56,87]) or perceptual dimensions (comfort, content, familiarity) [78], restorative effect [13,20,21,74], preference in terms of acoustic/sound preferences [54,61,67,68,77,79,80] or view preference [51,77] or thermal preference [54], noticeability [39], coping methods [63,71,73,74], appropriateness of sound environment [69], acoustic comfort [54,67,68], soundscape expectation [61,80,81], and interpretation of soundscape [61,80].

Based on the mentioned overview of occupant-related indicators, Fig. 4 summarizes all these indicators used to assess the effects of indoor acoustics on students preferences and needs. In the study of students' well-being in an educational building, both categories of these indicators are essential to consider. It can be noted that the HR [33,36–39,46,47,84,85] was the most used physiological indicator in previous studies, while the perception of the acoustical environment/sound/noise [13,55,56,63,66,74,79,81,82] was the most studied psychological indicator. Measurements of physiological indicators seem to be more applicable in lab studies. Apart from that, Wålinder et al. [46] carried out a field study in a real classroom that measured several physiological indicators. Psychological indicators can thus be studied in both field and lab studies.

Previous studies varied regarding the selection of occupant-related indicators. Out of the 25 studies on students' acoustical preferences and needs, 10 of them (40 %) measured the physiological indicator, while 18 (72 %) investigated the psychological indicators. A number of studies only focused on physiological indicators of students [15,33,35–38], while others were limited to the students' psychological responses [21,55,56,71,73,87]. Only four studies (16 %) on indoor acoustics examined both physiological and psychological indicators of students [34,46,84,85]. According to the results found by Medvedev et al. [85], physiological measurements of the SCL were significantly associated with soundscapes' psychological responses as to pleasantness and eventfulness. Furthermore, Rossi et al. [47] ascertained the importance of considering personal characteristics alongside the physiological indicators while examining the effects of acoustical conditions at the human level. Nevertheless, it was found that students' acoustical preferences and needs in their educational buildings were rarely asked in previous studies. Moreover, occupant-related indicators are rarely included in the acoustical performance guidelines of educational buildings. Therefore, it is recommended for further studies to investigate the occupant-related indicators in both categories: physiological and psychological.

4.1.2. Dose-related indicators

The reviewed 44 studies considered several dose-related indicators with regards to indoor acoustics or other IEQ-factors. Concerning the indicators of the indoor acoustics, a number of objective parameters related to room acoustics have been measured by the previous studies which are: SPL [13,19,20,33,35–39,46,48,49,51,54,56,61,63,66–69,71,73,75–78,80–82,85–87], RT [12,13,19,71,76,80,87], STI [48,71,77,80,87], speech intelligibility [52], clarity index (C_{50}) [87], early decay time (EDT) [87], frequency [47], and sound source [12,15,20,21,33,34,39,48,49,51,54–56,61,63,69,71,73–82,84–86]. In addition, psychoacoustic parameters like loudness [20,67,68,76,78], fluctuation strength [20,78], roughness [20,78], and sharpness [20] were investigated. Furthermore, other indicators for other IEQ-factors are also essential to be considered because they might have interaction effects with indoor acoustics. These indicators of the other IEQ-factors were examined in the previous studies. Regarding thermal comfort, temperature [34,35,37,38,54,56,66,86,87], humidity [35,56,86,87], predicted mean vote (PMV) [87], and predicted percentage of dissatisfaction (PPD) [87] were examined. In terms of visual quality, illuminance intensity [38,86,87] was considered. Also, dose-related indicators with regard to indoor air quality such as odour irritant (e.g, VOCs) [34,55], was examined by the previous studies on indoor acoustics.

Based on this summary of dose-related indicators, Fig. 5 demonstrates those that can be considered in further studies on students' acoustical preferences and needs. These indicators can be measured in an existing study environment or in a laboratory (e.g., test chamber). Also, these indicators can be predicted during the design phase of the study environment such as running simulations. Among the acoustical quality indicators, SPL [13,19,20,33,35–39,46,48,49,51,54,56,61,63,66–69,71,73,75–78,80–82,86,87], and

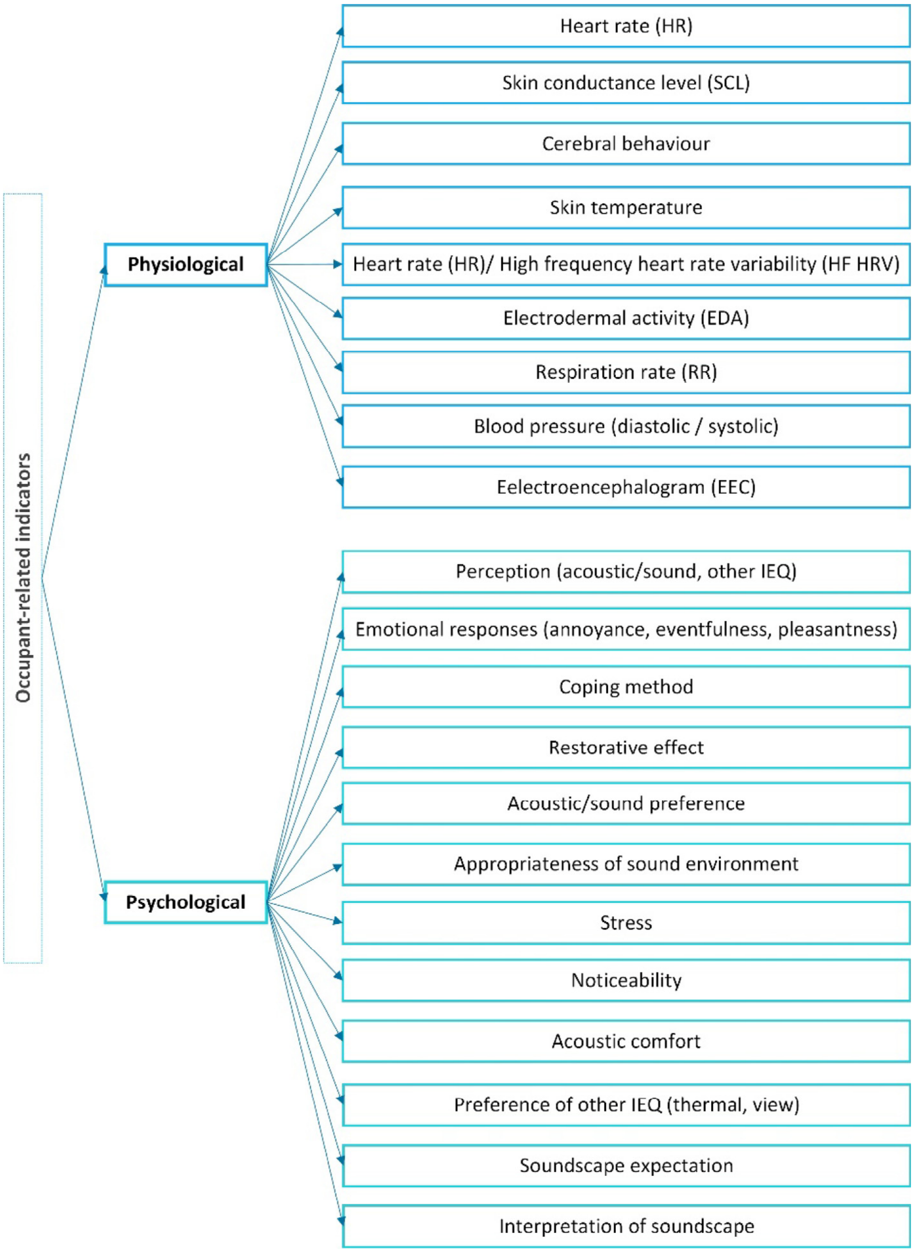

Fig. 4. Occupant-related indicators for measuring the effects of indoor acoustics on students.

sound sources [12,15,20,21,33,34,39,48,49,51,54–56,61,63,69,71,73–82,84–86] were the two most commonly investigated dose-related indicators in the previous studies. It is worth mentioning that sound sources can have both physiological and psychological effects on students [20,33,39,84,85]. In addition, the SPL can adversely affect students' physiological needs [36,39]. Furthermore, some dose-related indicators are based on the context of a study environment [13]. For instance, speech privacy as an indicator has been applied in open-plan study environments. In accordance with the guideline [23], it is also mentioned that speech privacy is used as an indicator in open plan study/teaching spaces to provide clear communication within a student group. RT in educational buildings is found to be a fundamental indicator for the acoustical performance of classrooms and open-plan study environments [12,13,17,19,55,71]. While, a higher RT proved to be important for informal learning spaces [13], a lower RT could result in a better acoustical quality. Nevertheless, the performance of students in a room with lower RT was not significantly better than in a room with a higher RT [12]. This outcome showed that improving the acoustical quality, such as reducing the RT, does not always fulfill all students' acoustical preferences and needs, in this case their performance. Thus, it is important to consider all students' preferences and needs of the acoustical environment in their educational buildings.

Regarding the indicators of other IEQ factors, temperature [34,35,37,38,54,56,66,86,87] was found to be the most measured dose-related indicator. Several studies proved that the students' physiological and psychological responses are associated with the combined effects of acoustical quality indicators (SPL and sound source) and thermal comfort indicators (temperature)

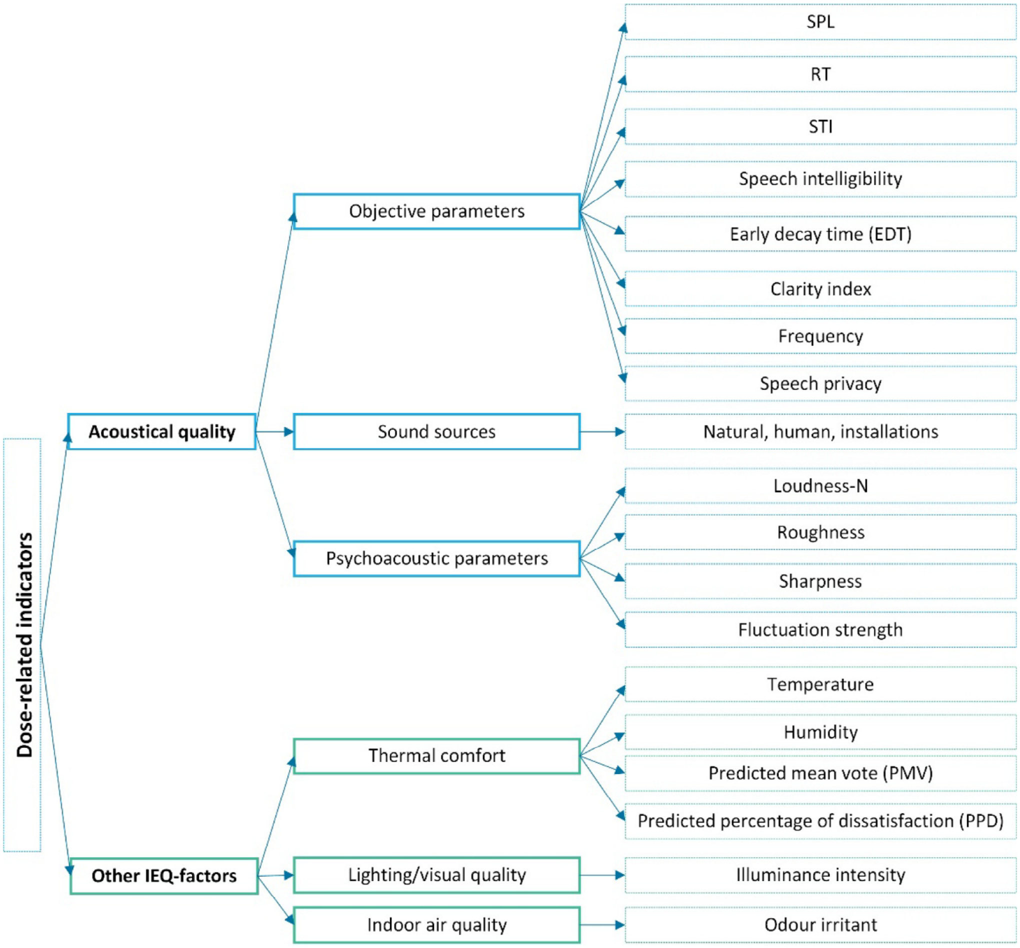

Fig. 5. Dose-related indicators to be considered in studies on students' acoustical preferences and needs.

[34,35,37,54,56]. Although the cross-modal perception between the acoustical quality and lighting/visual comfort [50–52] was not widely examined in previous studies, it was proven that they are associated with each other. In addition, natural visual scenes such as greenery, water elements, and sea view play a significant role in reducing the annoyance perception of the sound source. Hence, both categories of dose-related indicators (acoustical quality and other IEQ factors) are important to assess in studies on students' acoustical preferences and needs in educational buildings.

4.1.3. Building-related indicators

Few studies considered building-related indicators. In terms of indoor acoustics, physical environment elements, such as the presence of acoustical walls and absorbing ceiling panels, can affect the acoustical quality in an indoor environment [17,49,55]. Additionally, space layout of an educational building can play a vital role in acoustical comfort [69]. As regards visual/lighting quality, lighting type [52,55,86], visual scene [51,77], and daylight access [86] were the three building-related indicators taken into account by previous studies. Regarding indoor environmental quality, ventilation system [55] was studied.

Acoustical guidelines (BB93 [24] and fresh schools "*Frisse Scholen 2021*" [26]) for educational buildings provide a wide range of building-related indicators. These include applying a sound-absorbing ceiling, sound-absorbing wall finishing, flooring material, space layout, and room geometry that includes both room shape and room volume. The sound-absorbing walls are applied specifically between the spaces used by the students (e.g., classrooms) and the circulation spaces (e.g., corridors). However, building-related indicators have rarely been taken into account in previous studies on students' acoustical preferences and needs. It can be noted from Appendix A that only four studies considered building-related indicators [17,49,55,69]. Those showed that building-related indicators interact with occupant-related and dose-related indicators. Other building-related indicators for other IEQ factors, such as lighting quality [51,52,55,77,86] and indoor air quality [55], have been considered in previous research on indoor acoustics and soundscape. Accordingly, building-related indicators (Fig. 6) affect both occupant-related and dose-related indicators, and they need to be taken into account.

4.2. Methods for investigating acoustical quality

Several methods have been carried out to investigate the acoustical quality by measuring and assessing indicators at human level (occupant-related) and environmental-level (dose-related and building-related). The following two sub-sections answer the second research question: What are the methods that are used for measuring and assessing these indicators?

4.2.1. Investigations at the human level

Table 2 summarizes all the methods and tools that were used by previous studies to measure the occupant-related indicators.

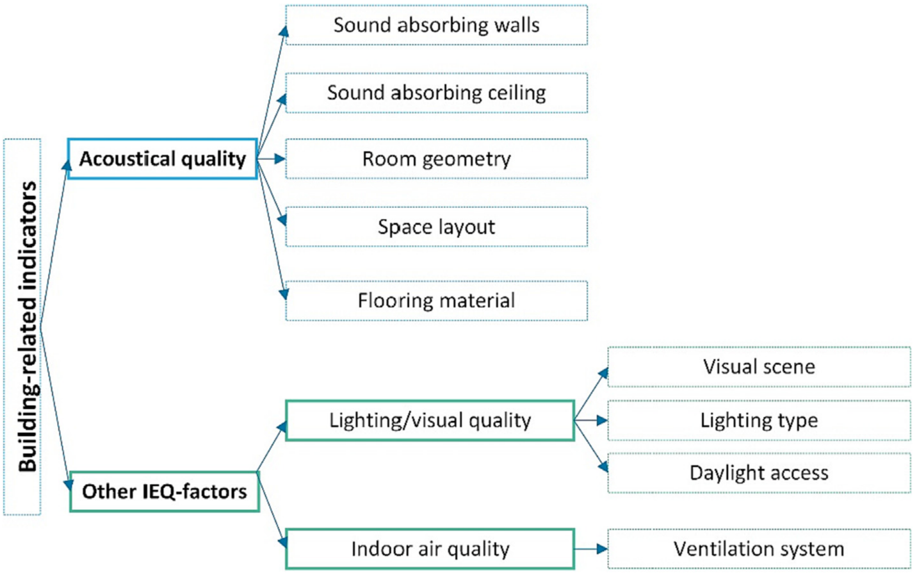

Fig. 6. Building-related indicators to be considered in studies on students' acoustical preferences and needs.

Table 2
Methods and tools for investigating the occupant-related indicators.

Reference	Method	Indicators	Tools and equipment	Context/activity
[13,21,46,47,63,67–69,72,73,75–77,79,81,82,84–87]	Questionnaire	• Demographical information • Perception (acoustic/sound, other IEQ) • Emotional response (pleasantness, calmness, eventfulness, annoyance) • Coping method • Restorative effect • Acoustic/sound preference • Appropriateness of sound environment • Stress • Noticeability • Acoustic comfort • Preference of other IEQ • Soundscape expectation • Interpretation of soundscape • Noise sensitivity • Satisfaction	• Subjective questionnaire	• Students at home • Students in an educational building (e.g., school/university classroom, informal learning spaces, open-plan study environment, computer laboratory, libraries) • Lab (e.g., test chamber)
[61,63,71,74,81,86]	Interview	• Perception • Preference • Expectation	• Structured/semi-structured questions	• Educational building (e.g., scool classroom, computer laboratory)
[15,33–39,46,47,84,85]	Objective measurements	• HR • Blood pressure (diastolic/systolic) • EEC • Electrical activity of brain	• Stethoscope and sphygmomanometer • HR sensor device • Hemomanometer • Electronic thermometer	• Lab (e.g., test chamber) • School classroom
		• SCL • EDA • RR	• Electrodes and ECG	• Lab (e.g., test chamber)
		• Cerebral behaviour (brain wave)	• Electrodes and EEG	• Lab (e.g. audiometric room)
		• Salivary cortisol	• Cotton wad	• Field study in school classroom
		• Skin temperature	• Electronic sphygmomanometer (OMRON)	• Lab (e.g., test chamber)

Investigations at the human level were conducted in both field and lab studies to measure occupant-related indicators. With regards to field studies, several data collection methods, which are soundwalks, questionnaires, objective measurements at the human level, and interviews were carried out. Soundwalk is a method of collecting perceptual data of an acoustical environment that is led by a moderator where expert participants follow a specified path in the space [58]. Various studies performed soundwalks for understanding human sensations, responses, and outcomes in specific indoor acoustics [69,86,88,89]. Generally, questionnaires are used for capturing individuals' perceptions, restorations, appraisals, preferences, and behaviours in an indoor environment [58].

Questionnaires were also used to identify the appropriateness of the sound [69], coping methods [73], expectation [81], and emotional responses in terms of the pleasantness of sound [21]. For example, Ricciardi and Buratti [87] used a questionnaire that included questions about students' noise perception, consequences of this perception, evaluation of the acoustical quality, and sound intelligibility. A field study carried out by Braat-eggen et al. [19] also involved a questionnaire to obtain students' assessments of noise disturbance induced by noise sources while performing tasks. The questionnaire of this study comprised several components such as students' demographical information, noise sensitivity, and noise annoyance. Furthermore, an example of a questionnaire applied in indoor acoustical studies is the one developed by Dokmeci Yorukoglu and Kang [42], which includes psychological factors, space usage factors, and demographical factors. Demographical factors are essential in indoor acoustical studies for identifying individual characteristics of the participant group, such as gender, age, educational background, socio-cultural characteristics, and habits. Accordingly, the difference between soundwalk and the questionnaire is that soundwalk involves participants (known as experts) who might or not be the main users of the space. In addition, soundwalk requires following a certain path and listening to different acoustical environments, while it is not required in questionnaires.

Moreover, field studies could involve objective measurements of physiological indicators and students' subjective assessments. For example, Wålinder et al. [46] conducted a field study among 78 fourth-grade students for four weeks. One day of each week, a stethoscope and sphygmomanometer devices were used to measure students' blood pressure; a cotton wad was used for sampling and testing students' salivary cortisol, and a questionnaire was filled out by the students to capture their disturbance and symptoms. In addition, students were asked to draw a human figure based on Koppitz's instruction (as psychological assessments) for assessing their emotions. Often in previous studies, interviews were carried out in indoor acoustical studies [61,63,71,74,81,86,90,91]. The interview aims at in-depth understanding individuals' feelings and emotions induced by indoor acoustics [58].

Lab studies are also conducted for examining the impact of various conditions of indoor acoustics (dose-related and building-related) at the human level (occupant-related) [92,93]. Previous lab studies focused on exploring the effects of different acoustical conditions on students' physiological health [33–38,84], psychological responses [13,34,55,94], performance [12,15,48,49], and multisensory interaction/cross-modal perception [55,95]. Before conducting lab experiments, most studies screened the students based on their hearing health [33,35–37,47]. With regards to physiological measurements, several electrical devices were applied to measure physiological indicators. For instance, electrocardiograph electrodes attached to participants' right wrist and ankles were used to measure the HR. Also, a transducer belt worn around the participant's chest was applied to measure the RR [39]. Additionally, heartbeat monitoring devices were utilized to measure blood pressures (systolic and diastolic) before and after the experiment [35]. An electronic sphygmomanometer device was used for measuring the blood pressure and HR of students [38]. Furthermore, EEG, which monitor brain activity, were used to examine students' stress [34]. Also, EEG and electrodes were used to record the brain wave activity in an audiometric room [15]. On the other hand, electrodes and electrocardiograms (ECG) were applied to measure SCL, RR, and EDA [33,39,85]. In multi-sensory interaction studies, an electronic thermometer device was used to measure the participant's skin temperature [38]. In terms of psychological assessments, a designed stress examination sheet was used as a questionnaire to investigate students' stress [34]. In addition, questionnaires were also commonly used in previous lab studies. They can be used to assess students' perception of acoustical and environmental suitability [13], and cross-modal perception (acoustical, lighting, and air quality) [55]. With regards to the performance, dif-

Table 3
Methods and tools for investigating the dose-related indicators.

Reference	Method	Indicators	Tools and equipment	Additions
[12,13,19,20,33,35–39,46,48,49,51, 52,54,56,61,63,66–69,71–73, 75–78,80–82,86,87]	Objective measurements	• SPL • RT • STI • Clarity index (C_{50}) • Speech intelligibility • EDT	• Sound level meter • Omni-directional loudspeaker • Omni-directional microphone • Omni power sound source • 12-sided loudspeaker • Precision condenser microphone • DT8820 multi-function environment meter	• SPL measured for background speech • SPL measured in unoccupied spaces and/or occupied spaces • SPL measured the background noise at one or more than one positions • Standard: ISO 3382 • In classroom, loud speaker positioned at 1.5 m hight (teacher postion) to measure the STIand clarity index, while the microphone positioned in a student position (1.1 m hight)
		• Psychoacoustics parameters	• Psychoacoustic analysis software	–
		• Thermal parameters (temperature, humidity, PMV, PPD)	• Microclimatic measurement set BABUC	–
		• Illuminance intensity	• Luxmeter	• Standard: EN 12464–1
[12,20,34,36,37,49,77,84,92–94]	Playing sound stimuli	• Sound type	• Loudspeaker • Headphone	• Different sound types (e.g., speech, music, traffic, birds)
[69,86,88,89]	Soundwalk	• Sound source identification • SPL	• Sound level meter	• Standard: ISO 12913–2
[58,75]	Binaural measurements	• Sound recordings	• Calibrated binaural measurement systems	

ferent tasks have been applied in different studies. For example, Zhang et al. [49] used the phonological processing task to assess primary school children's performance in a lab study; Tristan-Hernandez et al. [15] used the Toulouse-Pieron test to assess the attention capacity and perception of university students and staff; Kang and Ou [48] used cognitive tasks such as serial recall, mental arithmetic reading comprehension, proofreading to assess the work performance of office workers.

4.2.2. Investigation at the environmental level

Table 3 summarizes all the methods and tools that were used by previous studies to measure the dose-related indicators. Investigations at the environmental level were also done in both field and lab studies by applying different methods for studying dose-related and building-related indicators. Several researchers in the field of indoor acoustics have performed field studies to assess the acoustical quality in educational buildings [19,46,72,87]. Some studies investigated the environmental level by measuring the dose-related indicators for the acoustics and other IEQ factors. For example, Ricciardi and Buratti [87] conducted a field study to evaluate three IEQ-factors (thermal, acoustical, and visual quality) in seven university classrooms. This study measured dose-related indicators with regards to indoor acoustics including the SPL of the background noise level, clarity index, STI, RT, and EDT based on the standard ISO 3382 [96]. A twelve-sided loudspeaker, as the source of the white noise, was placed at the professor's desk at a height of 1.5 m. A precision condenser microphone, as a receiver, was placed at 4 to 6 measured points at the height of 1.1 m as a seated student. The SPL of the background noise was measured for five minutes in the centre of each classroom by using the sound analyser. The STI and clarity index were measured in the situation of the speaker-to-listener position. Moreover, thermal indicators (e.g., temperature and humidity) were measured by using a microclimatic measurement system known as BABUC, and the measurements points were placed as a seated student (at a height of 1.1 m). Regarding the lighting, the illuminance (lux) of each classroom was measured by a luxmeter. Also, the measurements points were based on the space index that was calculated according to the standard EN 12464-1 [97]. Other studies had only focused on the acoustical environment. For example, Braat-eggen et al. [19] measured the acoustical indicators (such as distance disturbance, A-weighted background noise level, and RT) of five open-plan study environments according to the standard ISO 3382-3 [98]. Furthermore, Wålinder et al. [46] did a field study that included measurements of objective occupant-related indicators in three classrooms in a primary school for four weeks. SPL was measured daily (3–5 h) by a sound-level meter placed at the centre of each classroom during all schooldays of the four weeks. Moreover, several studies investigated the indoor soundscape in study environments (e.g., library, classroom, open study area) [67–69,71,73]. Binaural measurements are performed for recording the acoustical environment in a space by using calibrated binaural measurement systems such as an artificial head. This recording method can be used for reproducing the acoustics of environments in laboratory experiments [58]. For instance, a binaural recording device was used to record 32 soundscapes of a hospital. These recordings were re-produced in a further experimental procedure in which individuals were exposed to them [75]. In addition, SPL, RT, and STI were measured by using a sound level meter or multi-function environment meter and omnidirectional loudspeaker [69,71,73,86]. Additionally, a building checklist can be utilized for investigating building-related indicators in field studies such as identifying ventilation systems and finishing materials of ceilings, walls, and floors [6].

Generally, lab studies can be designed with various acoustical conditions with different levels of SPL and sound recordings stimuli [92,93]. The time duration for exposing participants to acoustical stimuli was different in the previous studies due to the difference in each lab study's protocol. For instance, Choi et al. [34] exposed students to combined environmental stimuli: the sound source, temperature, and odour irritants for 15 min; Shu and Ma [13] exposed students to four rounds of experiments, in

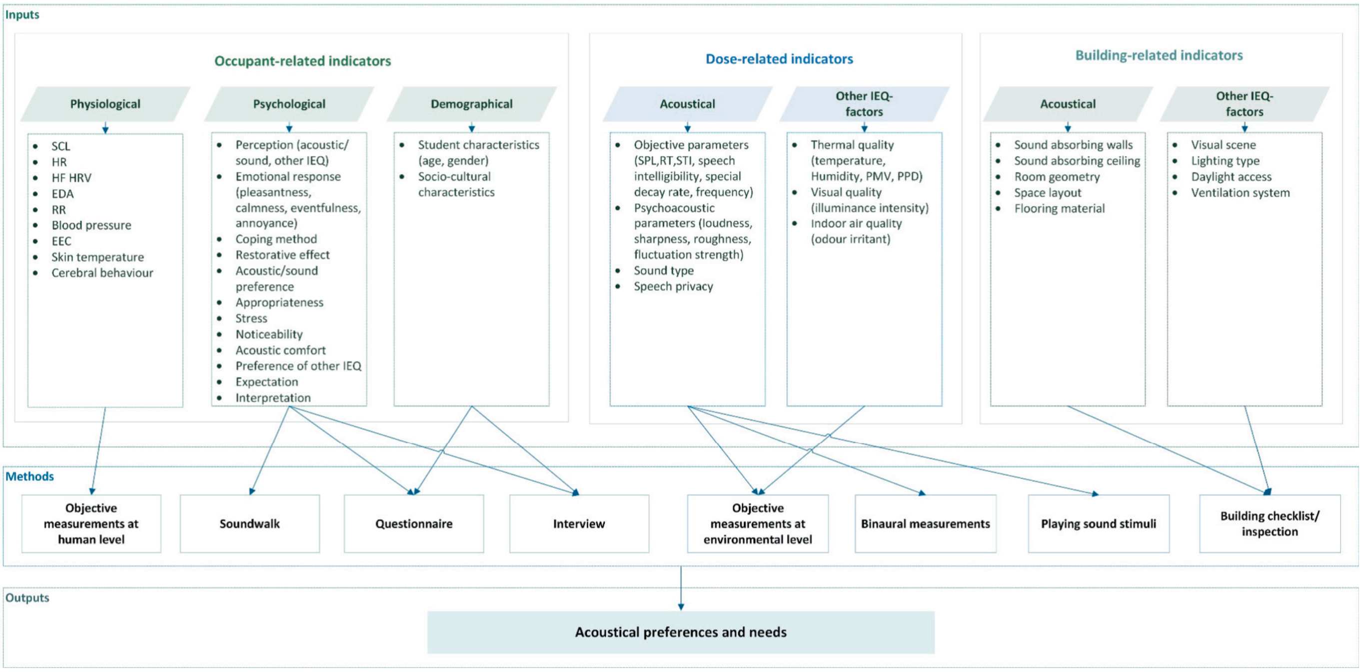

Fig. 7. An overview of indicators and methods that could be used for investigating students' acoustical preferences and needs in educational buildings.

each round, the audio-visual soundscape was played for 3 min; Abbasi et al. [36] exposed students to sound stimuli for 5 min, including 10 min for adaptation before running the experiment as well as 5 min for rest between playing the sound stimuli. Ba and Kang [94], exposed students to a series of 9 audio stimuli continuously by playing each audio for 40 s, including a 10-second interval between each audio. Some studies used the loudspeakers for playing the sound stimuli [36,37,49], while others used headphones to play the sound stimuli [12,77,84].

Appendix B is a matrix that includes all the methods that were used by the selected studies in indoor acoustics. These methods are divided into methods used for investigations at the human level, and methods for investigations at the environmental level.

5. Conclusions and limitations

The acoustical quality can influence (positive and/or negative) students' preferences and needs, and it can affect the well-being of students in an educational building. Different students have different acoustical preferences and needs. Thus, it is important to take account of occupant-related indicators while optimizing the acoustical quality of educational buildings to understand in-depth what do students prefer and need in their educational buildings. Nonetheless, guidelines for acoustical performance of educational buildings are generally focused on dose-related and building-related indicators, while occupant-related indicators are missing. However, previous studies in indoor acoustics and soundscape proved that dose-related indicators can significantly affect occupant-related indicators in terms of physiological and psychological effects.

In this study, a narrative synthesis was employed to develop an overview of indicators and methods that can be adopted in future studies for examining students' acoustical preferences and needs in educational buildings. Fig. 7 illustrates an overview of the indicators and methods which includes three main processes in sequential order: inputs, methods, and outputs. In the inputs' part, three groups of indicators are included: occupant-related, dose-related, and building-related indicators. Occupant-related indicators consist of three subgroups: physiological, psychological, and demographical. Under each of these subgroups, there are a set occupant-related indicators which are essential to be considered for investigating students' acoustical preferences and needs. Dose-related indicators are divided into two subgroups that are acoustical indicators, and indicators for other IEQ-factors. The acoustical indicators are significant to be taken into account for ensuring the indoor acoustical quality, while the indicators of the other IEQs are important for studying the cross-modal perception of the interactions between the acoustics and other IEQ-factors. Building-related indicators consist of the physical environment elements and building systems in terms of acoustical and other IEQ factors. These indicators can be observed and inspected of an existing educational building, or modified in a lab study.

In the methods part, several of them can be applied after determining the intended indicators to be examined at both human and environmental levels. These methods can be conducted in lab studies or field studies. Objective measurements at the human level, soundwalk, questionnaire, and interview are methods that were used in previous studies for assessing occupant-related indicators. Besides, objective measurements at the environmental level, binaural measurements, and playing sound stimuli were the main methods for studying dose-related indicators. In addition, a building checklist or inspection can be used for identifying the building-related indicators. As it was indicated by previous studies [4,22], it is important to take into account all the three categories of indicators (occupant, environmental, and building) in order to assess the health and comfort of indoor environments. Accordingly, students' acoustical preferences and needs will be identified by determining a comprehensive set of indicators (considering the three types of indicators) as well as by selecting the appropriate methods.

The indicators and methods that are summarized in this review article (which are represented in an overview Fig. 7) are limited to the 44 selected studies that are illustrated in Appendix A and Appendix B. This review is limited to studies on indoor acoustics and soundscape with regard to students in both schools and universities (undergraduate and graduate). It can be noted that the minimum age of the students in these studies was 8 years old, while the maximum age was 34 years old. It can also be indicated that soundwalk was only applied in one study on a study environment, which was conducted by Xiao and Aletta [69] in a public library. This library includes study areas (e.g., group study areas, and quiet study areas) that can be used by students. Almost none of these studies considered neither students' acoustical preferences nor needs in educational buildings. Thus, this review recommends examining the three main indicators to study the students' acoustical preferences and needs in future studies.

Data availability

No data was used for the research described in the article.

Declaration of Competing Interest

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

Appendix

Appendix A. Summary of indicators used in indoor acoustics studies.

Ref.	Context/ Activity	Occupant-related indicators			Dose-related indicators						Building-related indicators		
		Physiological	Psychological	Performance	Indoor acoustics			Other IEQ-factors			Indoor acoustics	Lighting/ visual quality	Indoor air quality
					Objective parameters	Sound sources	Psychoacoustic parameters	Thermal comfort	Lighting/ visual quality	Indoor air quality			
[12]	Writing task in open-plan study environment	–	–	Writing task	SPL, RT	People talking	–	–	–	–	–	–	–
[13]	Students in informal learning spaces	–	Perception	–	SPL, RT	–	–	–	–	–	–	–	–
[15]	Students performed attention task in university facilities (lab experiment in an audiometric room)	Cerebral behaviour	–	Attention task	–	Classroom in exam, normal classroom, libraries, computer labs, hallways, adapted study hall	–	–	–	–	–	–	–
[19]	Students in open-plan study environment	–	Perception, assessment of disturbance	–	SPL, RT	–	–	–	–	–	–	–	–
[33	Students performed stressful mental task	HF HRV, SCL	–	Mental arithmetic stress task	SPL	Nature sound, traffic, quiet backyard	–	–	–	–	–	–	–
[34]	Students were exposed to different environmental stimuli and completed a stressful task in a test chamber	Stress level (EEC)	–	Stress examination sheet	–	Nature sounds, traffic sounds	–	Temperature	–	With odour irritants, without odour irrians (VOCs)	–	–	–
[35]	Students were exposed to different environmental stimuli in a test chamber	Blood pressure	–	–	SPL	–	–	Temperature	–	–	–	–	–
[36]	Students were exposed to different environmental stimuli in a test chamber	HR, HF HRV	–	–	SPL	–	–	–	–	–	–	–	–
[37]	Students performed mental task (*N*-back task) and were exposed to sound stimuli in a test chamber	HR, RR	–	–	SPL	–	–	Temperature	–	–	–	–	–
[38]	Students were exposed to different environmental stimuli in a test chamber	HR, blood pressure, skin temperature	Perception	–	SPL	–	–	Temperature, relative humidity	Illuminance intensity	–	–	–	–

* [39]	Participants were exposed to different sound stimuli in a test chamber	HR, RR, EDA	Emotional responses, noticeability	–	SPL	Floor impact sounds	–	–	–	–	–	–	–
* [66]	Participants were exposed to different environmental stimuli in a laboratory	–	Perception	–	SPL	Water sounds, traffic sound	–	Temperature	–	–	–	–	–
[46]	Primary school children in classrooms	HR, blood pressure, salivary cortisol	Emotional responses	–	SPL	–	–	–	–	–	–	–	–
* [47]	Participants were exposed to different sound stimuli in a hemi-anechoic room, and were asked to complete a cognitive task	HR	–	Cognitive test (stroop effect)	Frequency	–	–	–	–	–	–	–	–
[48]	Students were exposed to different sound stimuli in a laboratory, and were asked to complete cognitive tasks	–	–	Cognitive tasks (serial recall, mental arithmetic, reading comprehension, proofreading)	SPL, STI	Background noise (speech), masking sound (pink noise)	–	–	–	–	–	–	–
[49]	Students were exposed to different sound stimuli in a test chamber, and were asked to complete a listening test	–	–	Listening test	SPL, RT	Traffic noise, children talking, music, no sound	–	–	–	–	Acoustically treated wall, acoustically untreated wall	–	–
[51]	Students were exposed to different environmental stimuli in a laboratory	–	Emotional responses, view preferences	–	SPL	Sea sounds, road traffic sounds	–	–	–	–	–	Visual scene	–
[52]	Students were exposed to different environmental stimuli in mock-up offices, and performed cognitive tests	–	–	Four cognitive tests (concentration performance test, grammatical reasoning test, serial recall task, text comprehension task)	SPL, speech intelligibility	–	–	–	Illuminance	–	–	Lighting type	–
* [54]	Participants were exposed to different environmental stimuli in a climate chamber	–	Acoustic comfort, thermal preference	–	SPL	Quiet place, human speech, noisy workplace	–	Temperature	–	–	–	–	–
[55]	Primary school children exposed to different	–	Acoustical perception, cross-modal	–	SPL, RT	No sound, traffic, children talking	–	–	–	VOCs emitted from	All acoustical panels,	Direct ligt, indirect	Mixing ventilation, displacement

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Ref.	Context/ Activity	Occupant-related indicators			Dose-related indicators						Building-related indicators		
		Physiological	Psychological	Performance	Indoor acoustics			Other IEQ-factors			Indoor acoustics	Lighting/ visual quality	Indoor air quality
					Objective parameters	Sound sources	Psychoacoustic parameters	Thermal comfort	Lighting/ visual quality	Indoor air quality			
	environmental conditions in a lab study of a classroom set-up		perception (draught, smell, light)							acoustical panels	fewer panels	light, soft light	ventilation,
[56]	Students were exposed to different environmental stimuli in a test chamber	–	Perception of floor impact noise, cross-modal perception (thermal conditions)	–	SPL	Background sounds, floor impact sounds	–	Temperature	–	–	–	–	–
[87]	University classrooms (field study)	–	Acoustical perception, lighting perception, thermal sensation	–	SPL, RT, STI, clarity index, EDT	–	–	Temperature, humidity, PMV, PPD	Illuminance intensity	–	–	–	–
[20]	Children performed a mental task after they were exposed to sound stimuli in a simulated classroom setting	–	Restorative effect	Arithmetic task, sustained attention to response test, digit span test	SPL	Music, birdsong, fountain sound, bell rings, stream sound, ambient noise	Loudness, fluctuation strength, sharpness, roughness	–	–	–	–	–	–
[21]	University students at home during COVID-19	–	Emotional response (pleasantness), restorative effect	–	–	Traffic, indoor mechanical, outdoor mechanical, music, human, nature	–	–	–	–	–	–	–
* [63]	Employee working in open-plan office	–	Acoustical perception, coping methods	–	SPL	Sounds generated by people, mechanical sounds, outdoor sounds, music	–	–	–	–	–	–	–
[67,68]	University libraries	–	Emotional response (annoyance), sound preference, acoustic comfort	–	SPL	–	Loudness, roughness, sharpness	–	–	–	–	–	–
* [74]	Hospital wards	–	Acoustical perception, coping methods	–	–	–	–	–	–	–	–	–	–
* [75]	Hospital wards	–	Emotional response	–	SPL	Natural sound, hospital wards sounds	–	–	–	–	–	–	–
* [76]	Living rooms in nursing homes	–	Emotional response (calmness, eventfulness, annoyance)	–	SPL, RT	Installation sounds, indoor activity sounds, electronic sounds, outdoor sounds	Loudness	–	–	–	–	–	–
[84]	Students performed mental tasks in simulated open-plan office	HR, blood pressure	Emotional response (annoyance, tension, fatigue)	Calculation task	–	Water sound, birdsong, footsteps, traffic noise, air conditioner sound	–	–	–	–	–	–	–

* [77]	Participants exposed to environmental stimuli in open-plan office	–	Sound preference, view preference	–	SPL, STI	Background noise (speech), sound masking (water)	–	–	–	–	–	Visual scene	–
* [78]	Residential buildings	–	Perceptual dimension (comfort, content, familiarity)	–	SPL	No sound, traffic (heavy, light), pedestrian area, garden, fan sound, music, TV	Loudness, strength, roughness	–	–	–	–	–	–
[69]	Public library	–	Appropriateness of sound environment	–	SPL	Verbal individual sound, non-verbal individual sound, mechanical sound, traffic noise, loud music, crowds of people	–	–	–	–	Space layout	–	–
[71]	High school students in two contexts: classroom and computer laboratory	–	Acoustical perception, coping methods	–	SPL, RT	Speech, footsteps, outside traffic, birdsong, electrical equipment, installation sounds, keyboard/key clicking mouse sounds	–	–	–	–	–	–	–
[73]	Students in open study areas in a university campus	–	Sound environment perception, coping methods	–	SPL	Computer sound, water sound, music, unintelligible speech, intelligible speech, footsteps, people laughing, installations	–	–	–	–	–	–	–
[86]	University office spaces	–	Soundscape perception	–	SPL	Outdoor sounds, sounds from corridors, sounds people sounds	–	Temperature, humidity	Illuminance intensity	–	–	Lighting type, daylight access	–
* [79]	Residential space with two different cultural background	–	Acoustical perception, sound preference	–	–	Outdoor sounds, people talking, installations	–	–	–	–	–	–	–
* [80]	Historic worship space	–	Soundscape expectation, interpretation of soundscape, sound preference	–	SPL, RT, STI	–	–	–	–	–	–	–	–
* [61]	Historical spaces	–	Soundscape expectation, interpretation of soundscape, sound preference	–	SPL	–	–	–	–	–	–	–	–
* [81]	Museum	–	Perception of sound environment, soundscape expectation, emotional response (pleasantness)	–	SPL	Outdoor sounds, people sounds, installations and equipment sounds, music	–	–	–	–	–	–	–
* [82]	Public shopping malls	–	Perception of sound environment	–	SPL	No music, background music, foreground music	–	–	–	–	–	–	–

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Ref.	Context/ Activity	Occupant-related indicators			Dose-related indicators						Building-related indicators		
		Physiological	Psychological	Performance	Indoor acoustics			Other IEQ-factors			Indoor acoustics	Lighting/ visual quality	Indoor air quality
					Objective parameters	Sound sources	Psychoacoustic parameters	Thermal comfort	Lighting/ visual quality	Indoor air quality			
[85]	Students were exposed to different sound stimuli in a laboratory after they performed a stressful task	HR, SCL	Emotional responses (pleasantness, eventfulness,	Stressful task	SPL	Ocean sound traffic sound, silence, birdsong, construction sound	–	–	–	–	–	–	–
[17]	Students (302 school children) performing tasks in classroom	–	–	Speech perception, mental calculation, and sentence comprehension	RT	Classroom sounds (scraping chairs, turning pages, pencils falling). Continuous speech phrases	–	–	–	–	Sound absorbing ceiling or applying sound-absorbing polyester fiber blankets	–	–
[72]	Questionnaire: 117 students (59 in classrooms, 58 in computer laboratory) Semi-structured interview: 50 students	–	Auditory perception	–	SPL, RT	Classroom: speech, footsteps, outside traffic, birds, rain, installations, paper sound. Computer laboratory: Installations, computer sounds, chair wheel sounds, speech, footsteps	–	–	–	–	–	–	–

* Participants/context: not students/studying context

Appendix B. Methods used in indoor acoustics studies.

Ref.	Participants	Occupant-related Indicators					Dose-related indicators			
		Questionnaire	Interview	Objective measurements	Soundwalk	Performance task	Indoor acoustics			Other IEQ-factors
							Objective measurements	Playing a sound stimuli	Binaural measurements	Objective measurements
[12]	47 students (F: 18, M: 29), age 16–27	–	–	–	–				–	–
[13]	850 university students		–	–	–	–		–	–	–
[15]	33 participants of university students, teachers, and other staff, (F: 16, M: 17), age 19–34	–	–		–				–	–
[19]	496 university students in different five open-plan study environments	–	–	–	–			–	–	–
[33]	40 university students (F: 24, M: 18), average age 27	–	–		–	–			–	–
[34]	12 students (undergraduate and graduate students, F:6, M:6)		–		–	–			–	• –
[35]	12 university students	–	–		–	–		–	–	
[36]	35 university students, age 20 to 30	–	–		–	–		–	–	–
[37]	35 university students, age 20 to 30 years	–	–		–	–		–	–	–
[38]	35 university students (F: 8, M: 27)	–	–		–	–		–	–	
* [39]	21 participants (F: 13, M: 8), age 18 to 42		–		–	–			–	–
* [66]	54 participants (F: 29, M: 25), mean age 22		–	–	–	–			–	
[46]	78 fourth grade children (age 10)		–					–	–	–
* [47]	25 participants (F: 12, M: 13), age 19–29		–		–				–	–
[48]	38 postgraduate students at university (F:20, M: 18), age 22–27	–	–	–	–				–	–
[49]	335 primary school children, age 9–13		–	–	–				–	–
* [51]	Experiment 1: 85 participants Experiment 2: 60 participants		–	–	–	–			–	
* [52]	32 participants (F: 17, M: 15), age 19–31		–	–	–				–	
* [54]	18 participants (F: 9, M: 9), mean age 23		–	–	–	–			–	
[55]	250 primary school children, mean age 10.5		–	–	–	–			–	
[56]	32 undergraduate and graduate students (F: 14, M: 18), age: 19–30		–	–	–	–			–	
[87]	928 university students		–	–	–	–		–	–	
[20]	Experiment 1: 46 children (aged 8–12) Experiment 2: 45 children	–	–	–	–					
[21]	323 students in two universities		–	–	–	–	–	–	–	–
* [63]	49 employees		–	–	–	–		–	–	–
* [67,68]	30 participants in each library		–	–	–	–		–	–	–
* [74]	27 participants (patients and nurses)	–		–	–	–		–	–	–
* [75]	24 participants		–	–	–	–				–
* [76]	Nursing homes		–	–	–	–		–	–	–
[84]	75 graduate student		–		–	–	–		–	–
* [77]	Experiment 1: 28 participants (F:13, M:15)Experiment 2: 31 participants (F:16, M:15)		–	–	–	–			–	
* [78]	35 participants (F:17, M:18)		–	–	–	–			–	–
[69]	12 undergraduate students participated in sound walks		–	–		–		–	–	–
[71]	30 high school students in total (16 in classroom and 14 in computer laboratory)	–		–	–	–		–	–	–
[73]	120 university students, age 18–26		–	–	–	–		–	–	–
* [86]	Observation of 38 offices Interviews with 20 offices			–				–	–	
* [79]	405 (two different cultural background groups)		–	–	–	–	–	–	–	–
* [80]	15 participants	–		–	–	–		–	–	–
* [61]	15 participants (F: 10, M: 5), age: 24–64	–		–	–	–		–	–	–
* [81]	60 participants (30 in each museum)			–	–	–		–	–	–
* [82]	70 participants (F: 30, M: 40)		–	–	–	–			–	
[85]	Study 1: 45 postgraduate students, member, and staff Study 2: 30 university students and staff		–		–				–	–
[72]	Questionnaire: 117 high school students Semi-structured interview: 50 high school students, age 14–18			–	–	–		–	–	–
[17]	Experimental study in three classrooms with 302 school children, age 11–13, grade 6 to 8	–	–	–	–				–	–

*Participants are not students

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