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# METHODS, ACOUSTIC MEASURES AND SOUND SOURCES IN HOSPITAL SOUNDSCAPE RESEARCH: A SCOPING REVIEW

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## Abstract

The present study aims to systematically review existing research on hospital soundscapes with a specific focus on studies incorporating user-based assessments. The objective is to identify methodological approaches, acoustic indicators, and dominant sound sources, in order to highlight current gaps and inform future research directions.

The research method involved a preliminary search in Scopus and Web of Science databases using a combination of keywords related to the acoustic environment (e.g., noise), hospital setting and user perception. All retrieved records were imported into Covidence for screening and management of the review process. The studies were reported in accordance with PRISMA 2020 guidelines. From an initial corpus of 148 studies, 16 met the eligibility criteria and were included for detailed analysis. The selected studies were evaluated according to research design, acoustic indicators, and reported sound source types and the extracted data were synthesized thematically. Four main methodological categories emerged: experimental, mixed-method, perception-based, and computational. Across these studies, acoustic characterization was predominantly based on sound level metrics, with 13 out of 16 reporting indicators such as LAeq, Lmax, Lden, L10,90 followed by the event/frequency-based metrics, psychoacoustic, speech related, composite or index based, and room acoustic parameters as less frequently reported. Regarding sound sources, human-related sounds were reported in 13 out of 16 studies making them the most frequently identified sound source. Medical equipment and alarms were reported in 10 studies, followed by mechanical systems, while natural and environmental sounds were rarely represented.

The review provides a structured overview of current research practices, identifies methodological gaps in user-based hospital soundscape research, and offers directions for future methodological development.

**Keywords**: *hospital soundscape, hospital soundscape methods, acoustic measures, sound sources, user's input*

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## 1. Introduction

Hospital soundscapes are complex and difficult to predict, shaped by multiple dynamic sources, including communication, alarms, medical procedures, and mechanical systems [1,2] While hospital acoustic environments have been widely investigated due to their impact on patients, staff, and healthcare processes, research approaches vary considerably across studies [2–4]. Recent work increasingly adopts a soundscape perspective [2,4–8]; however, there is still no structured overview integrating the methodological approaches, objective acoustic measures, and reported sound sources used in hospital soundscape research. Consequently, it remains difficult to compare findings across studies or to identify methodological trends and research gaps. This study addresses this gap by presenting a focused synthesis from a broader scoping

review of hospital soundscape research involving user-based assessments. Specifically, it examines the research methods employed, the objective acoustic measures used to characterize hospital acoustic environments, and the dominant sound sources reported across the literature. By mapping these elements, the study aims to clarify current research practices and support the development of a more structured framework for assessing hospital acoustic environments.

## 2. Material and Methods

The appropriate review to address this work's research question was a scoping review. This approach was selected to systematically map the methods used to assess hospital acoustic environments, the objective acoustic measures reported, and the sound sources identified in previous studies, rather than to evaluate intervention effects or user outcomes. The present analysis represents one component of a broader scoping review that also examines users' direct input (i.e., perceptual data) to identify common themes in hospital soundscape research. Accordingly, this section describes the search strategy, study screening and data management, and data extraction procedures.

### 2.1 Search Strategy

The search strategy consists of systematic searches of WoS (2008-2025), Scopus (2008-2027) and PubMed (2008-2026), limited to peer-reviewed English language articles. The search targeted studies examining hospital soundscapes from users' perspectives, using subjective or self-reported assessment methods. Studies focusing primarily on clinical interventions and/or patient-level treatments were excluded; consequently, the PubMed-retrieved articles were later not included in the final review.

The search strategy combined three conceptual domains: (1) acoustic environment, (2) hospital setting, and (3) user perception. For example, the Web of Science string was: ("acoustic environment" OR "noise" OR "soundscape" OR "acoustics") AND ("hospital" OR "hospital environment" OR "hospital facility") AND ("user perception" OR "patient experience" OR "self-report" OR "subjective assessment" OR "feedback" OR "interview" OR "survey") NOT ("nursing home*" OR "dental" OR "pediatric" OR "dementia" OR "hearing loss" OR "tinnitus" OR "noise-induced hearing loss" OR "hearing disorder").

An equivalent search strategy was implemented in Scopus (TITLE–ABS–KEY field), applying filters for document type, language, publication year, and relevant journals (e.g., Building and Environment, Applied Acoustics, Building Acoustics, Buildings, and HERD). Initial searches retrieved 249 (WoS) and 1,039 (Scopus) records. After journal and relevance screening, 27 and 120 studies were retained, respectively.

### 2.2 Screening and Data Management

All records were imported into Covidence [9], which supports systematic and scoping reviews organized according to PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines (See figure 1). Duplicate records were removed automatically after which titles and abstracts were independently screened by both authors using predefined inclusion and exclusion criteria. Inclusion criteria required studies conducted in adult hospital settings that examined the acoustic environment and incorporated direct users-based assessment. Studies focusing on non-hospital settings, specific patient populations (e.g., Dementia) or auditory disorders were excluded. Any disagreement during the screening were resolved through discussions until consensus was reached.

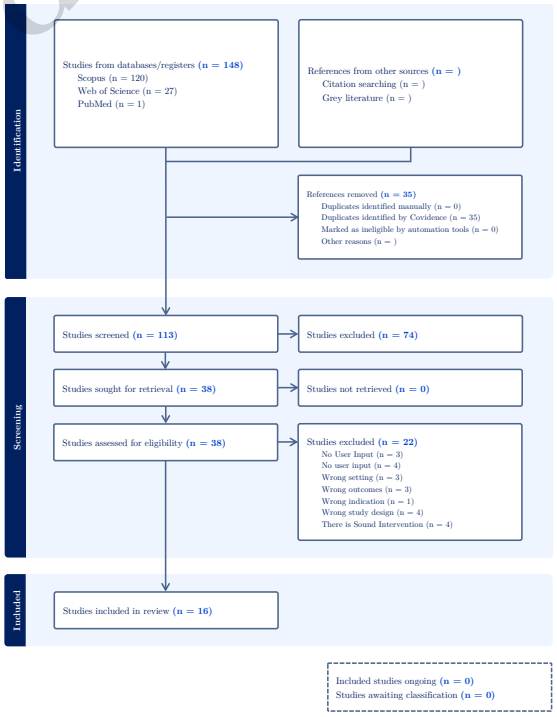


**Figure 1.** Flow diagram of screened studies included for review based on PRISMA 2020 guidelines, Covidence.

### 2.3 Data Extraction

Data extraction was performed on the 16 studies that satisfied the eligibility criteria following full-text review

of 38 articles. A structured extraction form was developed to collect information on study characteristics, research design, objective acoustic measures, user profile, sample size, time of measurements, hospital unit and location, reported sound sources, and reported outcomes. These data were subsequently synthesized to identify methodological approaches, commonly reported acoustic indicators, and dominant sound source categories in hospital soundscape research. Data extraction was finalized based on two authors' consensus until an agreement was reached.

## 3. RESULTS

The final synthesis included 16 studies that met the eligibility criteria and are provided in Appendix A of this study. The findings were organized into three complementary domains: (1) methodological approaches used to assess hospital soundscapes, (2) objective acoustic measures used to characterize hospital acoustic environments, and (3) reported hospital sound sources. This classification provides a structured overview of current research practices and highlights methodological patterns across the literature.

### 3.1 Methods employed to assess hospital soundscapes

Methods employed in hospital soundscape research are categorized across three independent dimensions: (1) evidence type (i.e., experimental, perceptual, physical, mixed, or computational), (2) study design (i.e., field-based, hybrid, or computational), and (3) methodological approach (i.e., surveys, acoustic measurements, or machine learning techniques). Although Individual studies frequently combined multiple approaches, classification was not mutually exclusive. For instance, study S03 (Please refer to the Appendix A) combines experimental design with both laboratory and field components and relies on subjective perceptual assessment including sound pressure levels, whereas study S11 represents a field-based, perception-driven survey study, along sound pressure levels. In this first synthesis of the data, four primary methodological categories are identified, experimental soundscape studies, mixed method soundscape studies, perception-based survey studies, and computational acoustic studies.

*3.1.1 Experimental soundscape studies*

Only one study, S03, adopted a fully experimental study design combining both field and laboratory conditions. The study compared several acoustic scenarios under controlled conditions to investigate their influence on perception, whereas the acoustic environment was described in terms of SPL metrics. Therefore, such studies evidence type is based on an experimental condition including subjective data and the acoustic characterization ranges from basic to advanced acoustic measures.

*3.1.2 Mixed-method soundscape studies*

This category of studies evidence type is based on subjective perception data (i.e., satisfaction, perception, annoyance) with advanced acoustic measurements. Data collection usually includes on-site sound level measurements together with user questionnaires. Most of the studies were grouped in this category (e.g., studies S08, S09, S10, S16, S21, S22, S23, S24, S25, S32, S34, S38) as indicated in Appendix. The aim of these studies is to explore relationships between physical acoustic indicators and human perception of the sound environment. Objective acoustic measurements range from noise levels to room acoustic parameters.

*3.1.3 Perception-based survey studies*

These studies rely primarily on questionnaire-based surveys to evaluate users' perceptions of the acoustic environment in real setting (field). The evidence type is mainly subjective. They typically analyze variables such as perceived noise levels, annoyance, acoustic comfort, and satisfaction using statistical methods. Objective acoustic measurements are limited to sound pressure levels. For instance, 2 out of 16 studies employ this method such as, S11 and S29.

*3.1.4 Computational acoustics studies*

Main focus of this category of studies is on objective acoustic measures. These studies use machine learning to analyze acoustic environments including clustering for classification of sound environments based on acoustic datasets. For instance, S07 study is an example of this category.

### 3.2 Acoustic measures reported in hospital soundscape studies

The reported acoustic measures were grouped into seven categories: level-based indicators, event-based metrics, spectral descriptors, psychoacoustic parameters, index-based metrics, room acoustic parameters, and speech-related measures. This classification illustrates the diversity of acoustic characterization methods currently used in hospital soundscape research.

*3.2.1 Level based sound pressure (SPL) measures*

Level-based sound pressure descriptors were by far the most frequently reported acoustic measures, appearing in 13 of the 16 reviewed studies, S21, S22, S23, S24, S25, S32, S03, S07, S08, S09, S10, S11, S16. Some of them included only SPL such as the S03 study to describe the acoustic environment. Sound pressure level information in hospital soundscape research included mainly $L_{Aeq}$ / $L_{eq}$ / $L_{AFeq}$, $L_{min}$, $L_{max}$, $L_{AFmin}$, $L_{AFmax}$, $L_{Cpeak}$ and also the also statistical percentile levels such as $L_{10}$, $L_{50}$, $L_{90}$, $L_{95}$, $L_{99}$, $L_{5}$, $L_{33}$, $L_{A05}$, $L_{A10}$, $L_{A33}$.

*3.2.2 Event-based metrics*

Studies additionally reported also event-based metrics such as $L_{max}$–$L_{eq}$, $L_{peak}$–$L_{eq}$, occurrence rates [OR(N)], % high-level events. In this review 4 out of 16 studies have included these data to assess the acoustic environment. For instance, studies S22, S08, S11 and S32.

*3.2.3 Spectral- based metrics*

Studies on hospital soundscape research have also included spectrogram analysis along with octave band and 1/3 octave band acoustic information which we have grouped as spectral sound descriptors. In this category 4 out of 16 studies provide spectral based information, for example, S22, S24, S07, S03

*3.2.4 Psychoacoustic descriptors*

Based on the review studies have also included psychoacoustic measures such as Loudness, sharpness, roughness, fluctuation strength and also NACF (τe). Only 2 of 16 studies have included these descriptors, for instance S10 and S22.

*3.2.5 Index-based acoustic metrics*

Metrics such as Rating Level (LAr), Harmonica Index (HRM), Room Criteria (RC/NCB), Quality Assessment Index (QAI), where also included in some studies which we grouped as index-based metrics. 3 out of 16 studies, S21, S09, S10, have included these data information.

*3.2.6 Spatial acoustics measures (room acoustics indicators)*

Reverberation time (RT, Tmid) were included in 2 out of 16 studies. S08 and S21 studies included Reverberation time among many other measures to describe the acoustic environment.

*3.2.7 Specialized acoustic metrics*

Specialized acoustic metrics such as Impulsiveness coefficient (KI) and tonality coefficient (KT) are included hospital soundscape research. 2 studies out of 16 include in characterizing the acoustic environment, S21, S32.

*3.2.8 Speech and communication metrics*

Based on the review metrics such as Speech Interference Level (SIL) and Speech Intelligibility Index (SII) were included in 3 out of 16 studies S10, S16 and S22 grouped in this category of acoustic measures.

**3.3 Reported Hospital Sound Sources**

Reported sound sources were synthesized into six principal categories comprising human sounds, medical equipment and alarms, operational activities, building services, electronic and communication devices, and external/environmental sounds. This classification distinguishes generic indoor sound sources from hospital-specific operational sounds.

*3.3.1 Vocal and non-vocal human sounds*

Human-generated sounds were the most frequently reported sound source category, appearing in 13 of the 16 reviewed studies, S21, S22, S23, S24, S29, S32, S03, S07, S08, S09, S10, S11, S16. Human or anthropogenic sounds are consistently reported and are divided into vocal (e.g., conversations, consultations, laughter) and non-vocal (e.g., footsteps, coughing, movement) subcategories. These sources are associated with routine interactions among patients, staff, and visitors and are widely present across hospital settings.

*3.3.2 Medical equipment and alarm-related sounds*

These sound sources form a prominent category, including alarm signals (e.g., beeping and monitoring alerts) and equipment-generated sounds (e.g., ventilators, MRI systems, suction devices). These sources are often emphasized due to their functional importance and distinct acoustic characteristics, particularly in critical care environments. 11 out of 16 studies have reported them, S21, S22, S23, S24, S32, S07, S08, S09, S10, S11, S16

*3.3.3 Operational activity sounds*

Operational and handling sounds arise from interactions with the built environment and hospital infrastructure, including door movements, cart handling, and tool usage. These are typically intermittent and reflect routine operational activities. 7 out of 16 studies have reported them S23, S24, S29, S09, S10, S11, S16.

*3.3.4 Building Services/ mechanical systems sound*
Mechanical systems, primarily associated with building services, are described as continuous background sources, including heating, ventilation, and air conditioning (HVAC) systems. These contribute to baseline acoustic conditions and are frequently measured, although not always explicitly differentiated. 9 out of 16 studies have reported them, S22, S24, S25, S03, S07, S09, S10, S11, S16

*3.3.5 Electronic and communication devices*
Electronic and communication devices include sounds from phones, televisions, and paging systems, associated with communication and information exchange within hospital environments. These are typically intermittent and reflect routine operational activities. 5 out of 16 studies reported these sounds. S22, S29, S09, S11, S16.

*3.3.6 External and environmental sounds*
External and environmental sources include both urban noise (e.g., traffic, construction) and natural sounds (e.g., birds, rain), indicating the influence of external conditions on indoor acoustic environments. 3 out of 16 studies have reported these sounds. S32, S09, S11.

## 4. Conclusion

This review provides a structured overview of current hospital soundscape research by synthesizing the methodological approaches, objective acoustic measures, and reported sound sources identified across the literature. The findings demonstrate considerable methodological diversity while highlighting several common patterns in the way hospital soundscapes are currently investigated.
Mixed-method approaches, integrating objective acoustic measurements with users' perceptual evaluations, emerged as the predominant methodological strategy and were primarily conducted under real hospital conditions. Acoustic characterization relied predominantly on conventional sound pressure level descriptors, particularly $L_{Aeq}$, $L_{den}$, and statistical percentile metrics, which do pass the standard recommended limits by World Health Organization (e.g., $L_{Aeq}$= 35dbA, $L_{Amax}$= 40dbA). Psychoacoustic, speech-related, and room acoustic parameters were reported far less frequently.

Regarding sound source characterization, most studies followed the principles of ISO/TS 12913-2 for sound source identification, although some methodological variations were observed (S11). Human-generated sounds, including both vocal and non-vocal activities, represented the most frequently reported sound source category, followed by medical equipment and alarm-related sounds. In contrast, natural sounds were rarely represented despite increasing evidence supporting their restorative role in healthcare environments (S03).

Overall, the findings suggest that hospital soundscape research continues to rely primarily on conventional acoustic descriptors (e.g., $L_{Aeq}$, $L_{den}$, and statistical percentile levels) despite the growing emphasis on user-centered soundscape assessments. Future research would benefit from integrating perceptual evaluations with a broader range of acoustic indicators, including psychoacoustic, speech-related, and room acoustic metrics, to achieve a more comprehensive characterization of hospital acoustic environments. In an Albanian case study, Alimadhi and coauthors [10] characterized the acoustic environments across various hospital units.

## 5. Limitations

The review is restricted to studies published in selected journals, which may have led to the exclusion of relevant work outside these sources [1][5]. No restrictions were applied regarding hospital typology in terms of clinical function; however, studies were limited to adult hospital settings, with pediatric or age-specific healthcare environments excluded from the analysis [2]. The literature search was conducted in November 2025.

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## Appendix A

**Table 1** Studies that met eligibility criteria and included for final analysis, studies 2008-2025

| | | Evidence Type | | | | Study Design | | Data Collection Method (source) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Studies | Experimental | Integrated perceptual and physical evidence | Subjective perceptual evidence | Data-driven computational evidence | Hybrid (Field+Lab) | Field | Survey (ISO 1291302, HCAHPS) | SPL (i.e.,LAeq) | Adcanced acoustic M. | ML |
| S03 | Alimadhi, E.; Yilmazer, S. | ✓ | | ✓ | | ✓ | | ✓ | ✓ | | |
| S07 | Hummel, K. et al., | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| S08 | Deng, Z. et al., | | ✓ | | | | ✓ | ✓ | ✓ | ✓ | |
| S09 | Nyembwe, J.-P.K.B. et al., | | ✓ | | | | ✓ | ✓ | ✓ | ✓ | |
| S10 | Lo Castro, F. et al., | | ✓ | | | | ✓ | ✓ | ✓ | ✓ | |
| S11 | Bhan, B. et al., | | | ✓ | | | ✓ | ✓ | ✓ | | |
| S16 | Bliefnick, J.M. | | ✓ | | | | ✓ | ✓ | ✓ | ✓ | |
| S21 | Salandín et al. | | ✓ | | | | ✓ | ✓ | ✓ | ✓ | |
| S22 | Okcu et al. | | ✓ | | | | ✓ | ✓ | ✓ | ✓ | |
| S23 | Tsiou et al. | | ✓ | | | | ✓ | ✓ | ✓ | ✓ | |
| S24 | Ryherd et al. | | ✓ | | | | ✓ | ✓ | ✓ | ✓ | |
| S25 | Fransson et al. | | ✓ | | | | ✓ | ✓ | ✓ | ✓ | |
| S29 | Marqués et al. | | | ✓ | | | ✓ | ✓ | | | |
| S32 | Chen | | ✓ | | | | ✓ | ✓ | ✓ | ✓ | |
| S34 | Tang et al. | | ✓ | | | | ✓ | ✓ | ✓ | | |
| S38 | Xuan et al. | | ✓ | | | | ✓ | ✓ | | | |
| **Total** | **16** | **1** | **12** | **4** | **1** | **1** | **15** | **4** | **13** | **12** | **1** |

Computational
Mixed Method
Perception Based
Experimental