

Soundproofing Materials and Design Strategies in Operation Theatres: An Architectural Approach for Noise Reduction

Sidra Jamal

Department of Architecture, Jamia Millia Islamia, New Delhi

Abstract

Noise in operation theatres (OTs) is a major environmental and occupational concern, affecting both surgical performance and patient safety. Studies report that noise levels in OTs often exceed recommended limits of 35–40 dBA set by national (NBC, NABH) and international (ASHRAE, WHO) standards, sometimes reaching 80–120 dBA during active procedures. This research explores soundproofing materials and architectural design strategies used to reduce noise through an engineering approach. A review of recent studies (2021–2025) highlights the use of high-STC partition walls, cleanable acoustic ceilings ($NRC \geq 0.7$), double-glazed windows, and vibration-isolated HVAC systems as effective technical measures. The findings emphasize that both behavioural and structural interventions are essential—strategic layout planning, staff education, noise monitoring, and low-noise equipment all contribute to sustainable reduction. The integration of acoustically optimized materials with hygienic and compliant design not only reduces decibel levels but also improves staff concentration, communication, and clinical outcomes. Therefore, adopting evidence-based acoustic strategies from the early planning stages is crucial for creating quieter, safer, and more efficient operation theatres.

Keywords: Acoustics, Soundproofing, Noise, Healthcare

1. Introduction

Operation theatres (OTs) are highly specialized environments where patient safety, surgical precision, and staff performance depend on carefully controlled indoor conditions. While factors such as sterility, ventilation, and lighting are well addressed in hospital design, **acoustic performance remains comparatively under-explored**. Elevated noise levels in operation theatres can negatively affect communication, concentration, and overall surgical efficiency, highlighting the need for focused research on acoustic control and soundproofing strategies.

1.1 Noise as an Environmental Concern in Operation Theatres

Operation theatres are exposed to continuous and intermittent noise generated by medical equipment, HVAC systems, alarms, and staff activity. Recorded noise levels during surgical procedures often exceed recommended limits prescribed by **WHO, ASHRAE, NBC, and NABH**. Such excessive noise contributes to auditory fatigue, increased stress among healthcare professionals, and disruption of critical clinical tasks, making noise control an essential environmental consideration in OT design.

1.2 Impact of Noise on Surgical Performance and Patient Safety

Effective communication is fundamental to safe surgical practice. High background noise and poor acoustic conditions reduce speech intelligibility and may mask critical auditory signals such as alarms and verbal instructions. This increases the risk of miscommunication and procedural errors. Additionally, excessive noise can heighten patient anxiety, particularly in procedures performed under regional or local anesthesia, thereby affecting overall patient experience and recovery.

1.3 Architectural and Material-Based Approaches to Acoustic Control

Architectural design plays a key role in mitigating noise within operation theatres. The use of sound-insulating partitions, acoustically treated ceilings, vibration-isolated flooring, and properly sealed doors helps reduce airborne and structure-borne noise transmission. Strategic spatial planning, zoning, and integration of building services further enhance acoustic performance while maintaining hygiene, fire safety, and functional efficiency.

1.4 Need for Standards-Based Acoustic Design in Operation Theatres

Despite the availability of established guidelines and standards, acoustic considerations are often inadequately implemented in practice. This research emphasizes the importance of **standards-based, evidence-driven acoustic design** for operation theatres. By evaluating soundproofing materials and architectural strategies aligned with regulatory norms, the study aims to support improved surgical environments that enhance staff performance, patient safety, and overall healthcare quality.

2. Methods

This research will use a multifaceted (multi-method) approach to fully understand fire safety in hospitals. Each method will provide different types of useful information:

2.1 ASHRAE Standards

ASHRAE standards provide specific and detailed requirements for HVAC noise control in hospitals and operating theatres (OTs). These guidelines ensure that mechanical system noise does not interfere with patient care or surgical communication.

2.1.1 Key ASHRAE Standards

ASHRAE Standard 170 – Ventilation of Health Care Facilities

This standard outlines environmental control parameters for healthcare spaces, emphasizing privacy, comfort, and noise reduction in critical zones such as operating rooms, recovery areas, and ICUs.

ASHRAE Handbook – HVAC Applications, Chapter 9 (Health Care Facilities)

Provides design recommendations for air distribution, acoustic separation, and vibration isolation in hospitals, ensuring compliance with patient safety and acoustic comfort requirements.

ASHRAE Handbook – Fundamentals & HVAC Systems and Equipment (Chapters 48–49)

These chapters offer detailed noise and vibration control guidance, covering Noise Criteria (NC) and Room Criteria (RC) rating systems for evaluating HVAC noise performance.

2.2 NBC Standards

The National Building Code of India (NBC 2016), Part 8 – Building Services, Section 4:Acoustics ,Sound Insulation and Noise Control, specifies the national framework for acoustical performance and noise control in hospitals, with particular guidance for operation theatres (OTs) and associated healthcare spaces.

2.2.1 Scope and Basis of NBC Acoustic Standards

NBC Part 8/Section 4 sets forth uniform requirements for sound insulation and noise control across all building types. It emphasizes:

1. Design strategies to prevent outdoor and indoor noise infiltration
2. Minimum acceptable indoor noise levels for sensitive occupancies
3. Integration of HVAC, plumbing, and medical systems without exceeding target decibel levels.

3. Discussion

3.1 Recommended Noise Levels for Hospitals

According to the ASHRAE Handbook (2021–2023 editions) and associated NC/RC guidelines:

Space Type	Recommended Level	NC	Equivalent Range	dBA	Typical Level	RC
Hospital – Private Patient Rooms	NC 25–30		35–40 dBA		RC 25–30 (N)	
Hospital – Operating Rooms	NC 25–30		35–40 dBA		RC 25–30 (N)	
Hospital – Wards	NC 30–35		40–45 dBA		RC 30–35 (N)	
Hospital – Laboratories	NC 35–40		45–50 dBA		RC 35–40 (N)	
Hospital – Corridors	NC 30–35		40–45 dBA		RC 30–35 (N)	

Table 1; ASHRAE Standards

OTs require $NC \leq 30$ (ideally NC 25) to prevent auditory fatigue and maintain verbal clarity during procedures.

RC (Room Criteria) offers an improved evaluation over NC by weighing low-frequency noise, which often dominates HVAC systems.

3.2 Measurement and Evaluation Procedures

ASHRAE defines survey and engineering methods for measuring HVAC background sound levels using octave-band sound meters.

Background noise must be measured with HVAC systems operational and then corrected for ambient baseline noise.

If ambient levels differ by less than 3 dB from HVAC noise, corrections are not permitted; otherwise, the measured equivalent continuous sound level (L_{eq}) is compared against NC or RC targets.

3.3 NBC Acoustic Standards for Hospitals and OTs

Recommended Noise Levels

The NBC specifies typical acceptable ambient noise levels for hospital environments:

Area	Recommended Noise Level (dBA)
Hospital general areas	35–40 dBA

Area	Recommended Noise Level (dBA)
Operation theatres	35–40 dBA
Intensive care and recovery areas	35–40 dBA
Laboratories and diagnostics	40–45 dBA
Corridors and nurse stations	40–45 dBA

Table 2; NBC Standards

Sound Insulation Ratings

NBC recommends partition insulation values based on sound reduction index (Rw):

1. Walls between OTs and adjacent areas: $R_w \geq 45$ dB
2. Walls between patient rooms or patient areas and service zones: $R_w \geq 40$ dB
3. Ceilings and floors between OTs and other departments: $R_w \geq 50$ dB
4. Doors/windows in critical areas should achieve at least $R_w \geq 30$ dB with tight acoustic seals.

HVAC and Equipment Noise

As outlined in NBC Annex G:

1. Employ low-noise diffusers and maintain air velocities below 6–7 m/s in ducts.
2. Use vibration isolators at fan and pump bases.
3. Encapsulate noisy HVAC terminals or use silencers and plenum boxes near equipment serving OTs.

3.4 Comparison Between National and International Standards

A comparative overview of national (NBC, NABH, WHO) and international (ASHRAE, FGI, HTM, ISO) standards for HVAC-related noise control in operation theatres (OTs), focusing on permissible sound pressure levels, acoustic design intent, and compliance measures.

3.3.1 Comparative Overview of Noise Standards for Operation Theatres

Standard Organization	Type	Recommended Noise Level in OTs	Acoustic Criteria Type	Key Design/Control Guidelines
NBC (National Building Code of India, 2016 – Part 8, Sec 4)	National (India)	35–40 dBA	$NC \leq 30$ equivalent	Uses dense partitions ($R_w \geq 45$ dB), sealed doors, duct liners, and vibration isolation; reverberation time ≤ 0.6
NABH (National Accreditation Board for Hospitals, India)	National (India)	35–40 dBA	Follows WHO benchmarks	Mandates low HVAC noise in critical care zones to maintain staff concentration and patient comfort; no $NC > 30$

Standard Organization	Type	Recommended Noise Level in OTs	Acoustic Criteria Type	Key Design/Control Guidelines
WHO Health Organization, 1999/2023 guidelines)	(World International)	≤ 35 dBA daytime ≤ 30 dBA night-time	A-weighted sound level	Focuses on health effects of environmental noise; hospitals must maintain ≤35 dBA in patient and surgical areas
ASHRAE Standard 170-2021	International (USA)	35–40 dBA for ORs	NC 25–30	Specifies acoustic design for HVAC in healthcare; requires isolated vibration mounts, lined ducts, and quiet air terminals

Table 3; Comparison Table

3.5 Comparison of Soundproofing and Acoustic Aspects in Operation Theatre Standards

This table condenses explicit requirements and recommendations for acoustic and noise control in hospital operation theatres, based on regulatory standards and evidence in research.

Table 4; Comparison between standards with respect to specific aspects

Aspect	ASHRAE	NBC (India)	WHO	NABH	IS Codes	Literature (Research Papers)
Wall	High-STC partitions (≥45), insulated	Rw ≥ 45 dB, sealed gypsum partitions	Not specified	Not specified	IS 1950:1962 (insulation)	Double gypsum, mineral wool, sealed (Ayoola et al., 2024; Li et al., 2025)
Ceiling	Acoustic panels, NRC ≥ 0.7, cleanable	NRC ≥ 0.7, cleanable panels	Not specified	Not specified	IS 11050 (impact/airborne)	Absorptive, wipe-clean, NRC ≥ 0.7 (Louis et al., 2024; Fu et al., 2021)
Buffer Spaces	Buffer zones (corridors, storage)	Sterile corridors, storage as buffer zones	Not specified	Not specified	Not specified	Spatial zoning, buffer layout (Bereuter et al., 2024; Li et al., 2025)

Floor	Vibration isolated, resilient underlay	$R_w \geq 50$ dB floor/ceiling between departments	Not specified	Not specified	IS 11050	Vinyl/composite, sound-dampening (Li et al., 2025)
Doors/Windows	Acoustic doors, gaskets, double-glazed windows	$R_w \geq 30$ dB, tight seals	Not specified	Not specified	IS 1950:1962	Solid-core doors, double-glazing (Ayoola et al., 2024)
Materials	Cleanable, absorptive, infection compatible	Cleanable, hygiene-compatible	Not specified	Not specified	IS 1950, IS 11050	Mineral wool, rockwool, closed-cell foam (Peisl et al., 2024; Li et al., 2025)
Acoustic Materials	Acoustic wall/ceiling panels, duct lining	Duct acoustic lining, panels	Not specified	Not specified	IS 3483:1965	NRC panels, mineral wool, absorptive finishes (Louis et al., 2024; Fu et al., 2021)
HVAC Strategy	Lined ducts, vibration isolators, silencers	Acoustic duct lining, vibration isolators	Not specified	Low-noise HVAC systems	Not specified	Silenced ducts, isolated equipment (Bereuter et al., 2024; Li et al., 2025)
Noise Limit	35–40 dBA, NC \leq 30	35–40 dBA	≤ 35 dBA (patient/surgery)	≤ 35 –40 dBA	Not specified	58–85 dBA measured, often exceeds codes (Peisl et al., 2024; Ayoola et al., 2024)
Reverberation	$RT_{60} \leq 0.6$ s	$RT_{60} \leq 0.6$ s	Not specified	Not specified	IS 11050	Low RT improves speech, ceiling treatment (Louis et al., 2024; Fu et al., 2021)
Measurement/Testing	NC/RC rating, octave-	SPL, R_w , RT60	SPL, dBA (A-weighted)	SPL monitoring	ISO/IS methods	dBA, NC, NR, RT60, field surveys

	band analysis						(Bereuter et al., 2024; Li et al., 2025)
General Strategy	Early acoustic planning, architectural + mechanical	Multidisciplinary design, hygiene, fire, acoustics	Focus on patient health, must be low	on Comfort, noise infection, quality	Abatement, insulation, measure ment codes	Layered: materials, spatial design, staff education (Li et al., 2025; Ayoola et al., 2024)	

Note: STC: Sound Transmission Class, Rw: Weighted sound reduction, NRC: Noise Reduction Coefficient, NC: Noise Criterion, RT: Reverberation time, SPL: Sound Pressure Level

4. Results

The comprehensive review of fire safety standards—NBC (India), British Standards (UK), and WHO guidelines—along with analysis of past hospital fire incidents, reveals critical insights into global fire safety challenges and opportunities for improvement. While all frameworks prioritize life safety, their approaches differ significantly in technical rigor, evacuation strategies, and enforcement mechanisms.

4.1 Key Findings from Standards Comparison

• Noise Control Strategies per ASHRAE Guidance

ASHRAE Handbooks recommend the following engineering controls for maintaining $NC \leq 30$ in OTs:

- Vibration isolation mounts for air handling units, fans, and compressors.
- Acoustically lined ducts and low-velocity diffusers to minimize air turbulence noise.
- Flexible duct connectors and plenum silencers to block structure-borne transmission.
- Sound-dampened terminal units rated per ASHRAE Standard 130, ensuring accurate sound power data for system selection.

▪ Design Guidelines for Noise Control

NBC Annexes F and G detail design techniques for acoustic optimization in mechanically ventilated areas such as OTs:

- Use heavy, airtight wall assemblies and double-layer gypsum partitions for sound blocking.
- Acoustic buffering zones (corridors, sterile storages) should separate noisy service areas from OTs.
- Ducts and HVAC connections must be equipped with acoustic linings and flexible joints to limit structure-borne noise.
- Air handling units and compressors should be placed in isolated mechanical rooms or on vibration-insulated platforms.
- Maintain reverberation times (RT60) below 0.6 seconds in OTs to ensure speech intelligibility.
- Use only cleanable sound-absorbing surfaces compatible with infection control protocols.

Analysis and Key Differences

• Permissible Noise Level

- Both NBC and ASHRAE set similar internal noise limits for operating rooms (35–40 dBA).
- WHO and NABH recommend slightly stricter values (≤ 35 dBA), emphasizing medical team focus.

- HTM 08-01 and ISO standards align acoustically but formalize through Noise Rating (NR) curves instead of NC values.
- **Evaluation Criteria (NC vs NR vs A-weighting)**
- ASHRAE use Noise Criterion (NC) and Room Criterion (RC) ratings.
- HTM and ISO prefer Noise Rating (NR) and LAeq (A-weighted) noise metrics.
- NBC/NABH draw broadly from WHO dBA limits without separate room spectral evaluation.
- **HVAC and Equipment Requirements**
- All standards mandate vibration isolation, low-velocity air distribution, and acoustic duct/tank lining for mechanical systems.
- ASHRAE provides specific NC-based equipment ratings under Standard 130 for terminal units.
- NBC and NABH emphasize hygienic maintainability alongside noise attenuation.

4.3 Key Soundproofing Materials Identified

4.3.1 High-STC Gypsum Partition Walls

Multiple studies recommend double-layer gypsum board assemblies with insulation (mineral wool, rockwool, or fiberglass) inside the wall cavity. These constructions can achieve Sound Transmission Class (STC) ratings of 50 or higher, effectively blocking external and room-to-room airborne noise.

(Ayoola et al., 2024) Advocated the use of dense walls and meticulous sealing techniques to prevent surgical noise from spreading to adjacent recovery or patient zones.

4.3.2 Cleanable Acoustic Ceiling Panels

Newer research supports the incorporation of acoustically absorptive ceiling panels with a noise reduction coefficient (NRC) of ≥ 0.7 . These panels are designed for easy cleaning and sterilization, meeting both infection control and acoustic criteria.

(Louis et al., 2024; Fu et al., 2021) Found that adding absorptive ceiling tiles reduced reverberation times and improved verbal communication among surgical teams.

4.3.3 Double-Glazed/Sealed Windows

ORs equipped with double-glazed window assemblies, featuring air gaps of 12 mm or more, demonstrate significant external noise attenuation (up to 40 dB reduction).

(Li et al., 2025) Reported substantial improvements where external noise sources (like traffic or adjacent labs) previously led to staff disturbance.

4.3.4 Acoustic Doors and Gaskets

Doors with high-density core materials (e.g., solid wood, steel, engineered composites) and perimeter acoustic gaskets enhance the overall sound isolation efficacy of walls and partitions. Proper door sealing prevents leakage of critical noise frequencies.

4.3.5 HVAC Duct and Plenum Linings

Lined HVAC ducts using flexible acoustic insulation materials (closed-cell foam, mineral fiber) absorb turbulent airflow noise, which is a major contributor to background sound in OTs. Additionally, vibration isolators used at fans and compressors address structure-borne transmission.

(Bereuter et al., 2024) Demonstrated that well-lined ducts and isolated mechanical systems reduced average HVAC noise by 6–12 dB in simulated surgical scenarios.

5. Conclusion

This study highlights the importance of acoustic control in operation theatres as a critical yet often overloo-

ked aspect of hospital design. Excessive noise levels in surgical environments adversely affect communication, concentration, staff performance, and patient safety. Although national and international guidelines recommend acceptable noise limits, acoustic performance is frequently compromised due to inadequate integration of sound control measures during planning and design.

The research demonstrates that effective noise reduction in operation theatres requires a **comprehensive architectural approach**, combining appropriate spatial planning, selection of soundproofing materials, and coordination with building services such as HVAC systems. Elements such as acoustically insulated partitions, treated ceilings, vibration-isolated flooring, and well-sealed doors significantly reduce both airborne and structure-borne noise while maintaining sterility and operational efficiency.

Compliance with standards issued by **WHO, ASHRAE, NBC, and NABH** is essential for achieving safe acoustic conditions. Addressing acoustics at the early design stage is more efficient and cost-effective than implementing corrective measures after construction. Early integration also ensures compatibility with infection control, fire safety, and maintenance requirements.

In conclusion, acoustics should be recognized as a **fundamental design parameter** in operation theatre planning, alongside ventilation, lighting, and hygiene. By adopting evidence-based and standards-driven acoustic strategies, healthcare facilities can improve surgical performance, staff wellbeing, and overall quality of patient care.

6. Bibliography

1. **World Health Organization (WHO)**. WHO Guidelines for Community Noise. Geneva: World Health Organization; 1999. (Provides official recommended noise limits in healthcare and patient care environments.)
2. **ASHRAE Handbook—HVAC Applications**. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). (Includes sections on hospital HVAC design and acoustics.)
3. **National Building Code of India (NBC) 2016**. Bureau of Indian Standards. Part 4: Fire & Life Safety; Part 9: Building Services. (Includes recommended design criteria for acoustics, HVAC, and healthcare facilities.)
4. **NABH Standards for Hospitals**. National Accreditation Board for Hospitals & Healthcare Providers. (Contains accreditation standards, including environmental safety and facility services.)
5. Busch-Vishniac, I. J., West, J. E., Barnhill, C., Hunter, T., Kolman, D., & Orellana, D. (2005). Noise levels in Johns Hopkins Hospital. *The Journal of the Acoustical Society of America*, 118(6), 3629–3645. <https://doi.org/10.1121/1.2129730>
6. (Empirical study on actual noise levels in hospital departments; often cited in healthcare acoustics research.) Berglund, B., Lindvall, T., & Schwela, D. H. (1999).
7. Guidelines for Community Noise. World Health Organization. (WHO’s foundational guideline frequently referenced for noise limits in healthcare settings.)
8. Flindell, I. H., & Stout, D. (2005). Hospital sound environment: acoustical design considerations. *Journal of Healthcare Engineering*, 6(3), 123–135
9. Sepehri, M., & Moshfegh, B. (2017). Reducing sound transmission in hospital buildings: Strategies and materials. *Journal of Architectural Engineering*, 23(1), 04016019. (Focuses on architectural materials and strategies for noise control.)