ASSESSMENT OF ACOUSTICAL LEVEL IN HEALTHCARE DESIGN: IN COMPARISON WITH THE STANDARDS OF WORLD HEALTH ORGANIZATION

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ABSTACT

This research was undertaken to assess acoustical conditions in the hospital environment, researcher aimed at investigating sound levels of local hospitals and to evaluate how much their current status complied with recommendations levels given by World Health Organization.

To assess the actual noise impact, sound levels of six local hospitals were measured using non – probability sampling technique at five different locations of every hospital i.e. Waiting Area, Emergency Department, Corridor, Intensive Care Unit and General Ward. All readings obtained during morning, afternoon and night intervals were then compared with World Health Organization acoustic guidelines for hospitals (30-40dB)

Findings revealed that sound levels of all hospitals studied were significantly high as compared to standards given by WHO, the hypothesis was significant with $p<.005$, twice as high sound levels were observed in comparison to the recommended limits. Equivalent continuous sound levels (L_{eq}) in most hospitals of Lahore ranged between (70-80dB), irrespective of time of the day, indicating a serious issue of noise pollution. Results also indicated that the highest sound levels were observed in waiting area at Hameed Latif hospital (110dBA). While the lowest sound levels were observed in Intensive Care Unit of Sheikh Zayed hospital (59dBA), which despite being the lowest were high in comparison to standards given by World Health Organization.

Furnishings and interiors of a hospital usually have easy-to-clean surfaces that are hard and reflective in order to prevent infections, but such surfaces tend to propagate noise into the patient rooms and down the corridors causing sound to reverberate. Optimal sound levels in hospitals can only be achieved through regular sound assessment, proper zoning of high and low activity areas and use of sound absorbing materials in building design that do not compromise hygiene requirements of the place. Only then patients can truly receive the quality of care they deserve.

KEYWORDS: Noise, Healthcare Design, Interior, Acoustics

INTRODUCTION

Healthcare settings intend to improve the quality of care for patients but in their efforts to do so they often create an atmosphere that is bustling with noise. Pager bleeps, visitors' chatter in waiting areas and equipment hums are a continuous source of annoyance for patients and staff alike. If a patient's space is to be described in terms of sensory factors, the most pervasive and least controllable would be hospital's sound environment. It affects the way they hear, receive and interpret information. Sound has the tendency to proclaim every announcement and protect each whisper. In medical facilities, even if the staff is highly competent, interior design and architectural features noteworthy, the main question to be emphasized is whether the sounds resonating throughout corridors and patient rooms also are exhibiting the same high standards as well? According to a research selection of flooring materials are important to control sound in hospital corridors, patients and staff both were more comfortable in hard floor with high performance acoustical ceiling tiles (Lau & Roy, 2014)

It is a challenge to design a hospital ward because of high level of noise created by staff activities and equipment movement. It affects patients sleep in adjoining beds (Clarke, 2011). Patients and

their families often hear trauma and suffering through thin and voice-penetrable curtains (Ecophon, 2012). Spending most of their time being physically inactive, patients become more sensitive to the quality of comfort they receive during hospital stay (Taylor-Ford et al, 2008). Noise in the healthcare environment contributes to 12-30% awakenings (Armstrong, 2013). Startle reflexes can set off as a result of sudden noise causing increased respiratory rates and elevated blood pressure. Memory problems, pain intolerance and irritation arise due to prolonged sound intrusion in patient rooms (Mazer, 2005). A study conducted by Hagerman et al. (2005) revealed that in poor acoustic environment, patients with heart disease exhibited high pulse rates. (Montague, Blietz&Kachur, 2009) noise usually occurring within hospital rooms is termed 'background noise' (Ampt, Harris & Maxwell, 2008) short duration, loud or impulsive sounds are in the form of alarms, door slamming, metal to metal contact etc. (Timothy et al., 2012.).Among these, people talk is considered most troublesome by patients, sometimes leading to their abnormal heart rates (Lorenz, 2007). (de Ruiter, 2020) used the term " soundscape to explain useful and practicable approach to noise control in hospitals.

Sound is energy in the form of vibrations often characterized by its loudness and pitch. Loudness is how big the vibrations or pressure differences are. It is measured in 'decibels'.

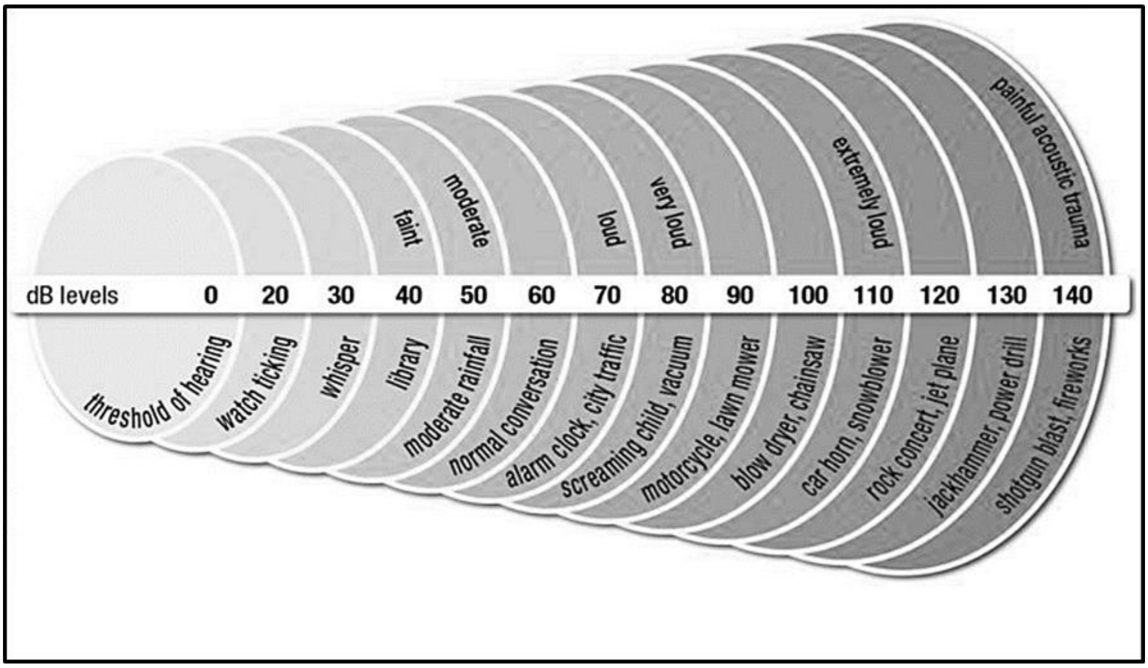

Figure 1.1 Decibel Scale (Armstrong, 2013)

Above Figure illustrates varying levels of loudness as perceived by human ear. Voice of someone shouting would be almost 80dB loud, while normal conversation is around (50-60dB). Sound levels between (30-45 dB) indicate whispering sounds. World Health Organization's acoustic standards for noise in healthcare buildings are 40dB during the day and 30dB at night.

Acoustics is the branch of physics that deals with sound. Application of acoustics in building design is crucial from the site layout of a large scale building to the small finishing details such as a cover strip or door seal (Bingelli, 2010). To create the desired acoustical performance within a building it is important to know how sound interacts with surface materials. When sound strikes a ceiling or wall surface, it might be reflected back into the space, absorbed or transmitted through the ceiling or wall into an adjacent space (see Figure 1.2).

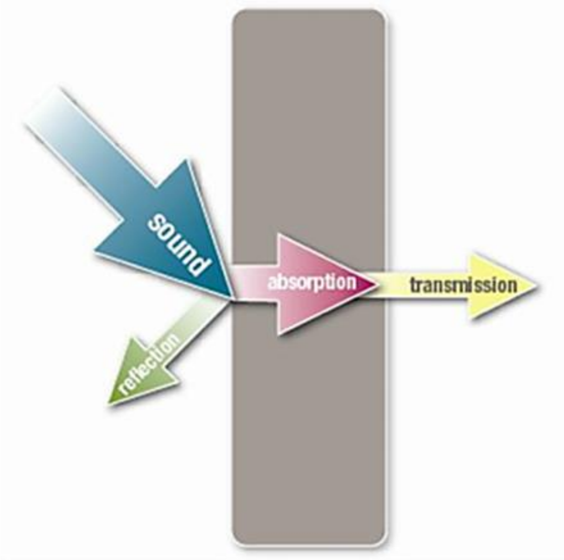

Figure 1.2 Sound Mechanism (Bradshaw, 2010, p.413)

Soft porous materials like fabrics and wood tend to absorb maximum sound energy striking them. If hard surfaces are abundant such as glazed tiles or polished concrete, most of the sound is reflected, creating a lot of flutter echo (Bradshaw, 2010). For hygienic reasons, the surfaces used in hospitals are often hard causing sound to bounce around creating discomfort for the occupants.

When importance of sound is ignored in design, result could be in the form of irritating and distracting noise. (Otenio and Cramer, 2007; Moshi etal, 2010) leaving the acoustic environment to chance or by making assumptions that noise within healthcare facilities is of little consequence healthcareenvironment fails to promote patient wellbeing (Mazer, 2001). For several years, hospital noise was only regarded as a nuisance instead of a major environmental concern. It is the need of the hour to address this issue so that healthcare buildings could provide a calm environment and promote total wellbeing of the patients. (Ampt, Harris & Maxwell, 2008, p.19)for years researchers are trying to figure out ways for quantifying effects of auditory environment. In an ideal scenario, healthcare environments should be conducive to the safety and recovery of patients, provide visitor comfort and improve employee productivity (Ryherd et al., 2008) (Ryherd et al., 2011). In hospitals where acoustical measures are needed, specifications are necessary for each source of noise (conversation of staff and visitors , trolly movement etc.) separately (de Ruiter, 2020).

Acoustic levels in hospitals are gradually increasing. Busch-Vishniacet al.(2005) reviewed noise levels of hospitals, highlighting consistent increase in hospitals' sound pressure levels since 1960. Khademi et al. (2011) reported noise levels of not a single study complied with the guidelines set by World Health Organization with maximum level reaching 85-86 dB in most wards. Moshi et al (2010) concluded that the lowest sound levels (Leq) in Iringa hospitals was (71.43dB)

World Health Organization has set the maximum noise criteria below 40 dBA. For various patient rooms, suggestions for the day are Equivalent continuous level (Leq) of less than 45 dBA and 30 dBA for night time (WHO, 1999). Guidelines provided by WHO are considered most valid internationally.

(Evans &Himmel, 2009) In general, day time levels accelerated 0.38 dB while night time levels increased 0.42 dB per annum. These findings portray an honest picture of all hospitals examined till years aforementioned, regardless of region and type, suggesting that hospital noise issue is universal and to ensure comfortable healing environment, acoustical issues must be dealt on the fore front.

In Pakistan, paucity of concern and lack of research regarding hospital noise has masked the

possible consequences. This research will create awareness among interior designers and architects to ascertain the need for balanced acoustical design and to interpret how various material selections influence acoustic environment. It will contribute to the body of knowledge guiding interior design students' perception that hospital plan should not only be functionally efficient but also psychologically supportive for patients. Identifying main acoustical issues in the healthcare setting would help governing bodies of existing hospitals to prioritize their improvement strategies as critical decisions need to be made regarding hospital noise by paying attention towards surface maintenance in healthcare design, creation of a noise free and calm healing environment.

The objective of this study was to compare the sound levels in hospitals of Lahore with the standards given by World Health Organization. Keeping in view objective of this study, following hypothesis was designed for this research:

- **H1: Sound levels of hospitals in Lahore are significantly high as compared to the standards given by WHO**

METHOD

For collection of data, non-probability sampling technique was employed for measurements of sound levels in local hospitals of Lahore. Six hospitals in Lahore vicinity were selected by purposive sampling technique namely, Hameed Latif Hospital, Sheikh Zayed Hospital, Jinnah Hospital, Services Hospital, Sir Ganga Ram Hospital and Punjab Institute of Cardiology. To be representative of the overall hospital environment, five enclosures within each hospital were studied waiting area, emergency ward, corridor, intensive care unit and general ward.

Measurements were taken with a digital sound level meter Model JTS-1357. In accordance with the methodology followed by Busch-Vishniacet al.(2005) at John Hopkins Hospital. The unit to measure sound levels is Equivalent continuous sound level (Leq) (Jaramillo & Steel, 2014). And in addition to it is the maximum sound level measured by the sound level meter over a specified period of time, usually associated with abrupt increase in noise called (Lmax), (Jaramillo & Steel, 2014).

Figure 1.1 Digital Sound Level Meters

Sound level meter used for this study is equipped with frequency weighting control switch between A and C. A-weighting is used for general sound level measurement. Its response is similar to human hearing. C-weighting is used to check the low frequency content of noise. For this research, 'A-weighting' was selected. Response or time weighting select switch in the sound level meter has two options, 'Fast' (for measuring varying abrupt noise) and 'Slow' (for assessing average level of fluctuating noise). To better adapt human ear's response of loudness across frequency, some filters are incorporated in sound level meters. Of these A – weighting dBA is considered most appropriate for measuring average levels of noise as it is less sensitive to very low and very high frequencies. C-weighting is applied in case of very loud noises. B filter is in between A and C, but is seldom used (Engineering toolbox, 2014).

Because measurement of average sound levels was desired, response was set to 'Slow'. Among

the four measurement ranges available in the sound level meter (i.e. 30dB-80dB, 50dB-100dB, 60dB-110dB, 80dB-130dB), 50dB-100dB was employed for this study. Sound levels of various hospital areas were measured with a sound level meter for 1 minute at three time periods during the day: Morning 9-10 a.m., Afternoon 2-3 p.m. & Night 7-8 p.m.

Ethics

The working personnel were informed about the study and their consent was taken but they were asked to continue with their routine work without giving them any noise caution so that findings portray an honest picture of the current acoustical scenario. No identities were revealed and proper research ethics were followed. Written consent of the above mentioned hospital administration and also form University's research committee was sought before the commencement of this study. Furthermore no patients were harmed in any way in this study and no interventions were planned on them.

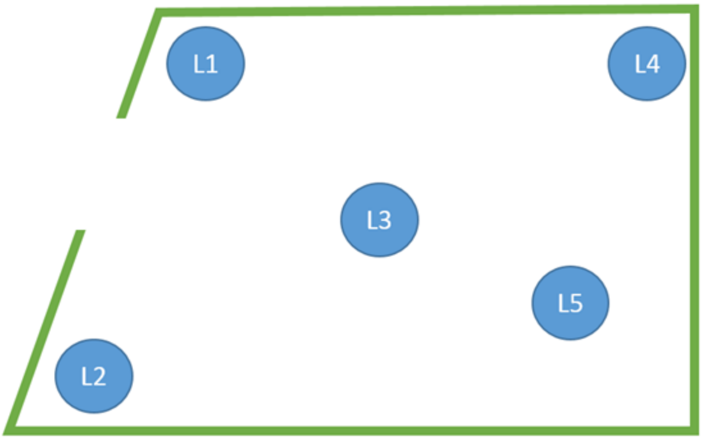

Figure 3.2 Measuring sound levels in a hospital enclosure

To get the cumulative sound level, measurements were taken at five different locations in each hospital enclosure and then added together. Above figure is a sample illustration of how this process was carried out. Sound level meter was held at the height of approximately 3.5 feet for every measurement taken.

Results were checked for compliance with WHO guidelines. For assessing sound level measurements, Microsoft Excel software was used. Decibel addition of all five locations studied within each hospital enclosure was calculated. Graphical presentation of (Leq) and (Lmax) measurements along with WHO recommended limits helped to ascertain the degree of difference among them. Sound levels are generally expressed in decibels, which are logarithmic and cannot be manipulated without being converted back to a linear scale. When two sound sources are combined, the sum of their decibels is generally determined with the help of a measurement scale:

Table1.1 DECIBLE ADDITION SCALE (OSHA, 2014)

Difference in dB Values	Add to Higher Level
0-1 dB	3 dB
2-3 dB	2 dB
4-9 dB	1 dB
10 dB or more	0 dB

For example, adding 63dB + 60 dB = 65 dB (3dB is the difference calculated in the dB values, so

2dB are added to the higher value i.e. 63 dB + 2dB = 65 dB). More than two sources can be added by taking combinations in pairs. Any order will work. To ensure valid results, the following equation is used to add decibels and get the cumulative sound levels:

First take antilog of each number, add and then log them again in the following way:

For example, adding three levels 94.0 + 96.0 + 98.0will be

MS Excel formula for the above equation is:

=10*LOG (SUM (10^ (User Range/10)))

The cumulative sound levels were compared with WHO recommended guidelines for hospital acoustics. Major findings of the study are outlined

RESULT

This section exhibits the results after computation with the help of formulas mentioned above. MS excel and SPSS were used to generate inferential findings of the current study.

Table 1.2.ANOVA

	Sum of Squares	df	Mean Square	F	Sig
Between Groups	3320.31	2	1660.16	3.49	.002
Within Groups	84005.27	177	474.61		
Total	87325.57	179			

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Table 1.3.*SOUND LEVELS MEASUREDIN MORNING AT DIFFERENT HOSPITALS*

Location	Sound level measured	Hameed Latif	Sheikh Zayed	Jinnah	Services	Sir Ganga Ram	PIC
Waiting	(Leq)	77	57	91	70	79	83
Room	(Lmx)	110	61	94	74	81	87
Emergency		66	81	83	80	69	78
Ward		70	84	100	86	72	83
Corridor		75	69	79	75	74	77
		80	71	94	82	85	83
ICU		66	60	84	71	73	71
		70	66	99	77	79	86
General		75	67	71	69	64	71
Ward		79	69	83	74	75	75
WHO		40	40	40	40	40	40
		45	45	45	45	45	45

The table above depicts mean Leq and Lmax levels measured at six different hospitals at five hospital locations at morning, in comparison with the standards given by World Health Organization.

Table 1.4 ***SOUND LEVELS MEASURED IN AFTERNOON AT DIFFERENT HOSPITALS***

Location	Sound Level Measurement	Hameed Latif	Sheikh Zayed	Jinnah	Services	Sir Ganga Ram	PIC
Waiting Room	(Leq)	70	59	84	71	76	73
	(Lmax)	78	72	100	73	80	77
Emergency Ward		66	79	73	80	68	80
		69	83	75	84	72	91
Corridor		74	71	73	74	77	75
		76	74	75	79	79	78
ICU		64	59	73	73	74	84
		68	64	86	76	85	94
General Ward		71	70	72	84	77	70
		74	73	80	84	81	75
WHO		40	40	40	40	40	40
		45	45	45	45	45	45

Exhibited in the table above are the mean values (Leq and Lmax) taken inafternoon

Table 1.5 ***SOUND LEVELS MEASUREDAT NIGHT IN DIFFERENT HOSPITALS***

Location	Sound level meaured	Hameed Latif	Sheikh Zayed	Jinnah	Services	Sir Ganga Ram	PIC
Waiting Room	(Leq)	72	54	81	66	73	74
	(Lmax)	79	60	84	73	77	79
Emergency Ward		67	78	74	81	71	79
		70	81	80	91	72	83
Corridor		71	70	77	72	74	76
		75	73	82	85	77	81
ICU		69	56	68	72	76	74
		73	59	77	78	79	77
General Ward		71	67	65	80	69	69
		73	79	79	84	74	74
WHO		30	30	30	30	30	30
		35	35	35	35	35	35

Mean Leq and Lmax levels measured at night of six different hospitals at five hospital

The table above depicts mean Leq and Lmax levels measured at six different hospitals at five hospital locations at morning, in comparison with the standards given by World Health Organization.

Mean Leq and Lmax levels measured at night of six different hospitals at five hospital locations, in comparison with the standards given by World Health Organization.

- **Table (1.2) exhibits ANOVA results, conducted to test the hypothesis. Findings revealed that sound levels of hospitals in Lahore are significantly high as compared to the standards given by WHO, [1660.16 (2,177) p< .005] Resulting in the acceptance of H1 and rejection of H0**
- **Table (1.3) clearly illustrates the mean continuous sound levels (Leq) measured in morning. The Leq values measured in morning were highest in ICU at Jinnah hospital and lowest at General Ward at Sir Ganga Ram hospital**
- **Maximum sound levels (Lmax) were highest in morning in waiting room of Hameed Latif hospital and lowest was of waiting area of Sheikh Zayed Hospital as illustrated by (table1.3)**
- **(Table1.3) also highlights that the lowest values of Leq observed at General Ward of Sir Ganga Ram i.e. 64 is still high as compared to the benchmark given by WHO. Similarly it was also depicted that the Lmax lowest value .i.e. 61 was high as compared to standards given by WHO.**
- **Mean values of Leq and Lmax taken at afternoon are depicted in (table1.4) it was found that among the six hospitals the highestLeq value were observed at Jinnah hospital's waiting room 84 and also at Services hospital's general ward i.e. 84. While the lowest Leq value was of Sheikh Zayed's ICU i.e. 59 in the afternoon.**
- **The highest Lmax value in afternoon was of waiting room of Jinnah Hospital i.e. 100 and lowest was of ICU at Sheikh Zayed i.e. 64 (table 1.4)**
- **(Table 1.3) established that both the Leq and Lmax values recorded in afternoon far exceed the values given by WHO.**
- **Readings of Leq and Lmax at night are exhibited in (table 1.5) and it was revealed that the highest Leq value was at waiting area of Jinnah hospital and emergency ward of services hospital both 81 and lowest at waiting area of Sheikh zayed i.e. 54**
- **(table 1.5) highest Lmax value was of Services Hospital Emergency ward i.e. 91 and lowest at night Lmax value was of ICU of Sheikh Zayed i.e.59**
- **It was also found that even the lowest values of Leq and Lmax were high as compared to the standards given by WHO (table 1.5)**

DISCUSSION

Measured data of existing sound levels in six major hospitals of Lahore confirm the existence of a critical acoustic problem. Sound levels studied were too high than WHO recommendations i.e. 30-40dBA. High sound levels were detected at all three times of the day indicating that necessary measures should be taken to deal with this issue.

Most values also surpassed typical speech level (50-60 dBA), suggesting that staff might require to raise their voice time and again in order to be properly heard above this background noise. Given the literature evidence that in many hospitals of the world, sound levels are continuing to rise annually, eventually a time would come when it will become difficult for oral communication to take place without shouting (Busch-Vishniac et al, 2005). The present sound levels in local hospitals ranged between (70-80dBA) which pose an impediment to patient recovery. Sound levels greater than (80-85 dBA) are dangerous, particularly when sustained or repetitive. Any sound at 85 dBA is 100,000 times higher in sound pressure than the recommended daytime level for patient areas. These findings support the research of (Luzzi & Falchi, 2002) about hospital design and noise pollution. Researcher suggested that insulation between walls is necessary to control noise.

Peak sound levels were observed in Waiting Area and ICU. Along with equipment beeps, constant circulation of staff in and out of the ICU resulted in this additional noise build up. Sound levels in most locations surpassed the threshold of hearing normal speech. In the afternoon, Leq measurements at all locations studied showed massive increase from the WHO noise criteria.

Auditory clutter continued to impact average sound levels. Excessive flow of people including hospital personnel and visitors contributed to this noise burden along with continued activity bustle in emergency wards. While measuring noise levels, beeping sound of alarms near the source could be a reason for such excessive reading observed in the ICU. Even at night, a consistent spike in noise levels as compared to 30-35dBA WHO recommendations was observed, these results highlighted the findings of (de Ruiter, 2020) , according to this hospital acoustic specification implemented carefully.

Good room acoustics can be thought of as an invisible medicine. As (Hsu, 2012) proved that traditional and non-traditional sound level metrics are statistically related to patient physiological outcomes of heart rate, respiratory rate, oxygen saturation, and blood pressure. Other factors are also working intermittently to contribute to this massive noise buildup. Size and layout of each location measured was different. To reiterate a few key observations during research, it can be said that in Hameed Latif Hospital, sound pressure levels were high enough to interfere with patients' sleep pattern. Apart from high activity noise, a reason could be lack of acoustic materials in hospital design. In all location types studied, highly reflective surfaces e.g. glazed marble and ceramic tiles are used for flooring. Even walls are partially covered with tiles to avert microbial infections. Installation of efficient absorbing materials could help to alleviate noise concerns as mentioned in (Lau & Roy, 2014) article.

Acoustical interventions are also needed in Jinnah Hospital as Emergency Ward, Corridor and General Ward had excessive noise. Although most hospital locations observed in the Sheikh Zayed Hospital had metal perforated ceilings that tend to improve noise control, but their impact was not significant. Lack of acoustic materials, reflective wall surfaces in ICU, noise from HVAC equipment and activity bustle all contributed to noise buildup in the Services Hospital, Punjab Institute of Cardiology and Sir Ganga Ram Hospital.Therefore, to lower staff fatigue, encourage uninterrupted sleep and alleviate stress, noise levels in hospital units should be significantly reduced.

Sound requirements of every location within hospital vary considerably depending on the factors like room's shape, surfaces, volume, furniture and equipment. Knowing how sound interacts with materials and surfaces can affect the overall integrity of a space. Installing carefully developed sound absorbing materials for healthcare environments would help to reduce the negative impacts caused by them.

Observed maximum sound levels significantly deviate from the WHO guidelines indicating a strong need to mitigate hospital noise.

Acoustical conditions in hospitals of Lahore are no different. However, it can be said that the values prioritized by WHO for acoustics are overly restricting. As none of the hospitals are meeting the said criteria, maybe the guidelines themselves need to be revised or PMDC should issue guidelines for our native settings, since no such guidelines exist for our indigenous environment one has to borrow the guidelines given by WHO. Keeping in view the massive crowds and activity hustle round the clock, achieving noise control as close to a whisper in the hospitals might not be possible.

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