NOISE ENVIRONMENT CHARACTERIZATION IN MILITARY TREATMENT FACILITIES

A Thesis
Presented to
The Academic Faculty

by

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In Partial Fulfillment
of the Requirements for the Degree
Masters of Science in Mechanical Engineering in the
George W. Woodruff School of Mechanical Engineering

Georgia Institute of Technology
August 2012

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In memory of Walter and Virginia Tucker, this is for you.

ACKNOWLEDGEMENTS

I would like to thank all of the people who have had an influence on my work and time at Georgia Tech. I want to thank Dr. Ryherd, my advisor for all of her time, dedication and assistance in helping mold me into the young engineer that I have become. To the many teachers and faculty that have helped to educate me inside and outside the classroom environment, Dr. Sadegh, Dr. Graham, Dr. Donnell, Dr. Ferri, Dr. Zimring, I am appreciative of all you have done for me. To the other graduate students; Jonathan, Nathan, Tim, Arun, Altug, and Gabriel – thank you for all of your insight, guidance and helping to keep me on the right track. Also I would like to thank the HSI staff, especially Jennifer and Ross and to the Noblis staff for their help and assistance in this research project. I would also like to thank the numerous undergraduate students who assisted in various parts of this project; including Derek, Daniel, Amanda, William, Phillip, and Nikolaus. To my mother, father, sister and Chris: thanks for all of the support and always being there for me, I couldn't have done this without you.

Lastly, but not least, I would like to thank God for this opportunity, and for all of the help along my journey. To Him be the glory and honor for this work and all I do forever and ever.

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LIST OF ACRONYMS

ED	Emergency Department
ICU	Intensive Care Unit
IP	Medical/ Surgical Nursing Inpatient Unit
MB	Mother/Baby Unit
SDS	Ambulatory Same-Day Surgery Clinic
NS	Nurses' Station
Corr	Corridor
Pat	Occupied Patient/ Treatment Room
Xpat	Unoccupied Patient/ Treatment Room
Wait	Waiting Area
Amb	Ambulance Bay
Nrsry	Occupied Nursery
XNrsry	Unoccupied Nursery
dBA	A-weighted Decibels
dBC	C-weighted decibels
LAeq	A-weighted Equivalent Sound Pressure Level (dBA)
LCeq	C-weighted Equivalent Sound Pressure Level (dBC)
LAmin	A-weighted Minimum Sound Pressure Level (dBA)
LAmax	A-weighted Maximum Sound Pressure Level (dBA)
LCpeak	C-weighted Peak Sound Pressure Level (dBC)
Ln	Percentile Level (dBA)
NC	Noise Criterion Rating
RC/ RC Mark II	Room Criteria Mark II Rating

RT	Reverberation Time (sec)
SII	Speech Intelligibility Index
WHO	World Health Organization
BP	Bodily pain domain score
GH	General Health domain score
MCS	Mental health component summary score
MH	Mental health domain score
PCS	Physical health component summary score
PF	Physical health domain score
RE	Role of emotional health domain score
RP	Role of physical health domain score
SF	Social functioning domain score
VT	Vitality domain score
EBD	Evidence Based Design
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
MLS	Maximum Length Sequence

ABSTRACT/ SUMMARY

Hospital sound environments are complex and hard to understand. One of the most important factors in these environments is the effective communication between staff members in regards to patient care and successful communication depends in part on the hospital's sound environment. In this study, objective sound measurements as well as occupant perceptive data were collected at three hospitals. Sound pressure levels; including maximum, peak, minimum and equivalent levels were recorded in these hospitals, in addition to active impulse response measurements. Acoustic descriptors of the sound environment such as spectral content, level distributions, energy decay and temporal patterns were examined. The perception of the hospital soundscape (sound environment) was evaluated through surveys of the staff, patients and visitors to units. It was found that noise levels in all patient rooms and work areas were significantly higher than guidelines laid out in previous literature and by professional organizations. This work contributes to the field by broadening the metrics used to quantify hospital acoustic environments. In addition, this work added to the field by providing the most rigorous acoustic field measurement set published to date. This was done to create an accurate portrayal of the hospital soundscape environment.

CHAPTER 1

INTRODUCTION

Hospital sound environments are complex and hard to understand. Medical sensors, alarms, paging systems, telephones and patient care create noise that can hinder communication and concentration. Since this environment is hard to understand and fully describe, few studies have addressed the effectiveness of characterizing the acoustics in these critical spaces. Even in the few studies published to date, many of them have only focused on a few aspects of the sound environment and even less information about occupant perception.

In addition to limited published data on hospital acoustics, currently there are limited guidelines that cover the gamut of hospital units or hospital wards. The current ASHRAE/ ANSI/ WHO guidelines only cover a limited aspect of a hospital soundscape and often apply to idealized cases, which many hospitals are not. Having baseline data for several types of units would help to better understand the individual and overall soundscape for hospitals and be able to aid in the re-evaluation of these guidelines to better design hospital units.

The work presented in this thesis was part of a larger study on the overall health environment of the particular hospitals studied (US DoD 2011). Some of the goals of this larger body of work were:

- to characterize the physical environment of the hospitals (including materials, construction, room objects, and windows)

- to characterize the effects of patient falls, their occurrence and effect on patient care
- to characterize the transfers and transports of patients (including most often paths taken, quickest routes between units, and other safe patient handling procedures)
- to characterize the sound environment and its effect on occupants

All of these goals would add to the current literature to help determine a baseline of existing physical conditions in hospitals and develop a database to improve the evidence based design (EBD) of current and future hospitals.

However, this thesis specifically focuses on the soundscape characterization of the measured spaces. Therefore the goals of this thesis are fourfold:

a. to measure and describe the acoustic environment completely and accurately using traditional and novel acoustic metrics
b. to compare the measured acoustic environment to current guidelines
c. to collect data from staff, patients, and visitors on their perception of the acoustic environment
d. to establish a rigorous methodology for describing the hospital soundscape, including both acoustic and occupant perception, as a tool that can be used for future comparisons across numerous hospitals in varying unit types and with varying subject populations.

The results of this work is a collection of acoustic and occupant measures in the largest variety of unit types and locations within hospital units published to date. Also, this work contributes to the field of hospital acoustics by providing a wider range of acoustic measurements than previous work and providing comprehensive survey testing of occupant perception, including the first time that a visitor population has been studied in hospitals. This study helps lay the foundation for evidence based acoustic design of hospital wards.

CHAPTER 2

LITERATURE REVIEW AND BACKGROUND INFORMATION

Providing adequate patient care is the primary function of hospitals. However, if these spaces are not providing the best possible environment in one or more areas, it becomes harder to meet this primary function. One area of growing concern in literature is the sound environment in hospitals, as it has been shown that sound levels have been increasing steadily from the 1960's (Busch-Vishniac, et al., 2005). Current literature also suggests that noise effects hospital occupants, and may contribute to staff errors (Ryherd, Persson Waye, Ljungkvist 2008) and hinder recovery among patients (Meyer, et. al. 1994). However, while there is strong and growing evidence of the negative impacts of a poor soundscape, there is surprisingly little rigorous evidence about exactly *what characteristics* of the soundscape impact outcomes in hospitals. In contrast, there is rigorous research about metrics and occupant outcomes for other work environments, such as office spaces and concert halls. This lack of data for hospital acoustics hinders designers' ability to use architectural treatments, noise control, adjustments to everyday operations, or design guidelines to create healing soundscape atmospheres in hospitals. This literature review addresses issues such as the effects of noise on patients and staff occupants, the gap analysis from previous literature, and current academic and industry standards. A more detailed discussion of current literature can be found in the Health Care Environments – Baseline Assessment for Safety and Quality (HE-BASQ) report (US DoD 2011).

Effects of Noise on Patients and Staff

Noise has both psychological and physiological effects (Passchier-Vermeer & Passchier, 2000). Studies of patients have found that hospital acoustics have been related to cardiovascular arousal in certain patients (Baker et al., 1993), increased probability of re-hospitalization (Hagerman, et al., 2005), extended hospital stay (Fife & Rappaport, 1976), increased dosages of pain medication (Minkley, 1968), and sleep disturbance (Freedman et al., 2001).

Military hospitals, with their focus on the wounded from the Iraq and Afghanistan conflicts, have particular relevance to the effects of noise on patients. For example, traumatic brain injury (TBI) patients may be at particular risk because they are typically quite sensitive to noise (Okie 2005); the implications are well described by Duncan: "[TBI] Survivors are often easily over-stimulated by noise and activity. Following an injury, the brain often loses its ability to filter out environmental noise, light, and activity (Larsen 2007)." Soldiers with Post-traumatic Stress Disorder (PTSD) are also known to be particularly sensitive to noise and can exhibit hyper-arousal or hyperactive startle reflexes (Liberzon, et al. 1999; Zubieta, et al. 1999). For example, Liberzon et al. exposed three subject groups (veterans with PTSD, veterans without PTSD, and non-veterans) to white noise and combat sounds (1999). The PTSD patients were found to have exaggerated bio-responses to combat sounds such as skin conductance, heart rate, adrenaline, and stress hormones, while the control groups did not have any exaggerated responses. Various PTSD forums, blogs, and other sources are full of firsthand accounts describing how noise triggers them. These accounts include comments such as: "sudden or too much noise can be a trigger for me. If I'm very anxious or in an unfamiliar environment, it seems to get worse and my concentration and anxiety shoot through the roof (PTSD Forum, 2011)." Unfortunately, no studies have been published that specifically address the response of military patient populations to hospital noise. However, there is not hospital acoustic-specific literature on whether this particular patient population would require more intensive control on noise sources, or if the physiological arousal in these patients is similar to patients in civilian populations. Future research needs to address this concern as it may severely hinder the function of a military hospital to provide the best care to this special patient population.

Much less is known about the impact of the hospital soundscape on staff members, although it has been repeatedly shown that in other types of environments as offices that noise can hinder oral communication and task performance (Bowden & Wang, 2005; Bradley, 2003; Ryherd & Wang, 2007, 2008; Persson Waye et al., 2001). In recent years, researchers in environmental health have also linked noise exposure during the work day to a variety of negative stress, job satisfaction, and health effects for non-hospital workers; including linking decreasing job satisfaction in personnel who were exposed to increased noise levels (Sundstrom et. al. 1994). In another important study, Leather et al. (Leather et al., 2003) found that high noise levels amplified the impacts of stressful jobs. Their results showed:

> "…no direct effect of ambient noise levels upon job satisfaction, well-being, or organizational commitment. However, lower levels of ambient noise were found to buffer the negative impact of psychosocial job stress upon these same three outcomes. Psychosocial job stress is, therefore, seen as a valuable heuristic in operationalizing the context of sound events at work." (Leather, et al., 2003)

Thus, in order to understand the true effect of occupational noise, researchers must gather more than just perceptual physical environment information (e.g., how loud or how annoying?) from subjects. Several studies have shown that the negative effects of occupational noise exposure are contingent upon features of the broader work context. A few studies have found the interactive effect of occupational noise exposure and shift work demands on various health outcomes (Cesana et al., 1982; Nurminen & Kurppa, 1989; Ottman et al., 1987). Other studies have found that workers' blood pressure levels were impacted by an interaction of noise and job stress (Cottington et al., 1983).

While the majority of occupational noise research has focused on other settings (offices, etc.), there is evidence that the overall loudness of noise in healthcare settings can adversely affect hospital staff. Research has shown that noise may contribute to staff stress (Morrison et al., 2003; Topf, 1988), and hearing loss (Holmes et al., 1996). A recent study found that 91% of critical care nurses surveyed thought that noise negatively affected them in their daily work environment, contributing to stress symptoms such as irritation, fatigue, tension headaches, and difficulties concentrating (Ryherd & Persson Waye, 2007; Sunderstrom, et al., 1994).

In addition to their own well-being, the reaction of staff members to the hospital sound environment is important for the safety of patients. For example, oral miscommunication and increased medical errors are two additional, potentially hazardous effects of hospital noise that have been proposed, although these effects have not been thoroughly investigated (Berglund, et al., 1999; Busch-Vishniac, et al., 2005). Oral miscommunications could include incorrect dosages or incorrect medications given to patients due to communication errors. In 2000, the Institute of Medicine cited errors in incorrect medication as one of the top preventable causes of death (Kohn et al., 2000). Previous studies have also raised concerns over the density of the alarms in critical care units and the effects on occupants (Phillips & Barnsteiner, 2005). For example, studies have shown that no action is taken by staff for the majority of audible alarms (Busch-Vishniac, et al., 2005; Wallace et al., 1994) and that many alarms are incorrectly identified even by experienced staff members (Cropp et al., 1994). Again, this raises the issue that the acoustics of these spaces needs to be further investigated in order to provide adequate care for patients.

The World Health Organization (WHO) published guidelines of recommended hospital noise levels (Berglund, et al., 1999); yet, a recent landmark survey of hospital noise research revealed that not even one result published since 1960 complied with these guidelines (Busch-Vishniac, et al., 2005). Results from this study have led to questions of whether the WHO guidelines are too restrictive. One point toward this is that the current WHO guideline do not account for specific threshold levels in both occupied and unoccupied spaces; it sections them only into one category that does not specify occupancy, which could have a large impact on the noise level of any space. The Busch-Vishniac study mentioned above also found that hospital noise levels have been rising consistently since 1960, with the average day-time noise levels rising from 57 dBA in 1960 to 72 dBA currently, and night-time noise levels rising from 42 to 60 dBA (2005).

Another study conducted by Ryherd, et. al. (2011) showed that the day and night levels have continued to increase by a similar trend from 2005 to 2010, as seen in Figure 1.

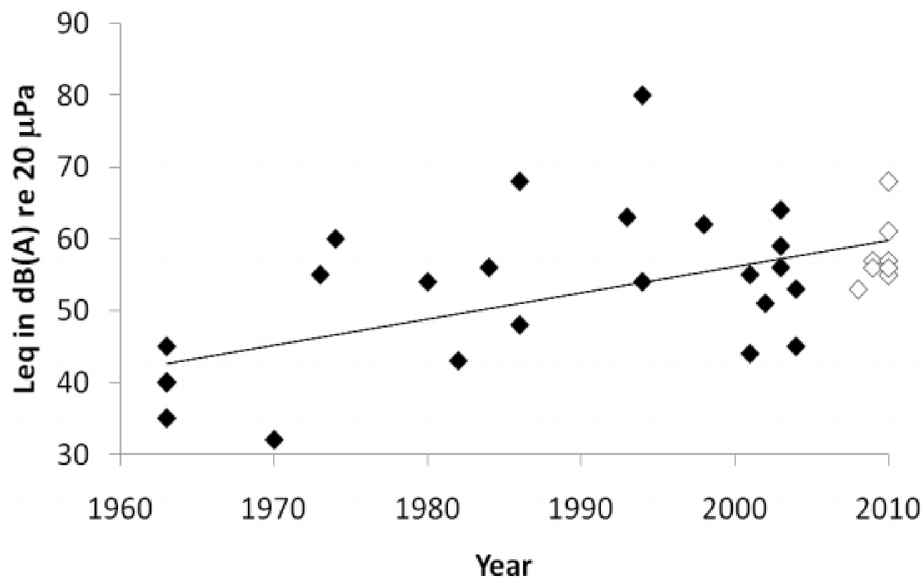


Figure 1: LAeq values by year from previous literature (Ryherd, et. al. 2011)

It is clear that overall noise levels in hospitals are problematic and getting worse, but future research must identify the specific target areas (i.e. unit types, locations, sources of noise, etc.) that require the most focus and effort.

Gap Analysis from Previous Literature

Clearly the hospital soundscape can have severe detrimental impacts on patients and staff. However, the majority of the previous work lacks sufficiently rigorous measurement and detailed analysis of the hospital acoustical environment. Specifically, the types of metrics used and the manner in which many of the previous acoustical measurements were conducted may give a misleading or incomplete description of the sound environment. The few hospital studies that do report more detailed acoustical information provide limited or no occupant evaluations for a true comparison (Aitken, 1982; Busch-Vishniac, et al., 2005; Falk & Woods, 1973; Kracht, et al., 2007; Orellana, et al., 2007). Without both detailed acoustical measurements and corresponding human reactions, it is difficult to understand how to actually improve the soundscape.

With regards to the types of metrics used, four key characteristics are inherent to the quality of background (ambient) noise (Rossing et al., 2002):

- *Level* relates to the overall loudness of sound
- *Spectral content* reflects how the loudness of noise is distributed across frequency (from low to high pitch)
- *Temporal pattern* reflects how much sound fluctuates over time.
- *Energy decay* relates to the rate at which sound energy tapers off over time

Previous research has shown that these key characteristics of noise can greatly impact human perception, oral communication, and task performance in indoor office environments (Bowden & Wang, 2005; Bradley, 2003; Holmberg et al., 1993; Landström et al., 1991; Ryherd & Wang, 2007, 2008; Persson Waye, et al., 2001). However, previous hospital research typically reports only overall loudness levels specifically through the metric of A-weighted equivalent sound pressure level (LAeq; Bies & Hansen, 1996). The LAeq represents overall loudness levels but gives no indication of the other three key characteristics of spectral content, energy decay, or temporal pattern.

With regards to the acoustical measurements, there are many opportunities for improving upon the previous work. For example, most of the previous measurements have been made with sound level meters set to a slow averaging response setting (often used in offices and spaces with a steady background noise), which likely resulted in decreased sensitivity to rapid changes in sound level. Future research must address this issue and require adequate settings to capture these rapid changes. Additionally, there tends to be a consistent error in much of the literature where the reported average sound pressure levels were computed incorrectly by taking the arithmetic mean, instead of the logarithmic mean of the decibel values (Busch-Vishniac, et al., 2005; M. Philbin, 2000). Reporting this data by taking the incorrect averaging could result in misleading data that fails to present the full picture of the acoustic environment. Finally, details on other important acoustical characteristics, aside from the background noise, are lacking in the previous research. One example of this is how quickly sound dies out in a space after a source has stopped (energy decay measured by reverberation time RT) (Mehta et al., 1999). Both SI (speech intelligibility) and RT (reverberation time) are directly related to the ability to communicate. As mentioned earlier, the communication of information is essential to the main function of a hospital. A simple oral miscommunication could result in improper patient care, medical errors, among numerous other terrible side effects for occupants.

The limitations in the existing literature are perhaps due to experimental methods; much of the previous research was undertaken by medical professionals with limited experience in engineering acoustics, noise measurement, and noise control. The work described in this thesis vastly improves on the current status of knowledge through a detailed measurement and analysis of key acoustical characteristics of the hospital soundscape and the comparative evaluation of staff, patient, and visitor response.

Current Academic and Industry Standards

In addition to the literature of previous work, there is also a list of published guidelines relevant to the design and research of healthcare spaces. The most relevant U.S. guidelines that were identified were:

- United Facilities Criteria (UFC) Guidelines for Medical Military Facilities (United States Department of Defense, 2009)
- ANSI S12 WG44 *Sound & Vibration Design Guidelines for Hospital and Healthcare Facilities* (American National Standards Institute, 2010)
- ASHRAE Applications Handbook Chapter 48: Noise and Vibration Control (ASHRAE, 2011)
- ANSI S12.2-2008 Criteria for Evaluating Room Noise (American National Standards Institute, 2008)
- World Health Organization Guidelines for Community Noise (Berglund, et al., 1999)
- American Institute of Architects (AIA) Design Guidelines (AIA & FGI, 2006)

Following a preliminary review of all the guidelines above, a focus was placed on the first three (UFC, ANSI, and ASHRAE), as these were identified as either the most applicable to these facilities (UFC), the most complete (ANSI S12 WG44), or often used (ASHRAE). The guideline review included an assessment of acoustic content included in the various guidelines, including metrics, thresholds, and design recommendations. Where applicable, the results of this study were compared to the guidelines to check compliance.

Summary

Although previous researchers have provided a good basis in understanding the hospital sound environment, there is limited information that characterizes all of the four main components of a hospital soundscape. This study develops upon the previous work by broadening the metrics used to quantify the entirety of the acoustic hospital environments in addition to characterizing the perception of staff, patients, and visitors. Chapter 3 will outline the methodology of this study and be arranged according to the objective acoustic measures from the SLM and IR tests, and the subjective perceptive measures from staff, visitors and patient surveys.

CHAPTER 3

METHODOLOGY AND EXPERIMENTAL DESIGN

Acoustical measurements and occupant surveys were conducted at three hospitals, and for de-identification purposes will be referred to as hospital 1, hospital 2, and hospital 3. Hospital 1 opened up in 1957, and is a 46-bed facility. It is also the central facility of a network which serves approximately 90,000 eligible military beneficiaries. Hospital 1 is comprised of a specialty care ward, medical/surgical ward, a labor and delivery ward, mother/baby ward, adolescent partial hospitalization program, and a 24-hour emergency room. Hospital 1 also offers additional services as PACU, GI OR, radiology, laboratory work, PFT, EKG, Holter monitoring, stress tests, and virtual colonoscopies. In the 2010 fiscal year, there were 1,564 staff workers. Table 1, below shows the inpatient workload of these staff from the 2008-2010 fiscal years. (US DoD 2011).

Table 1: Inpatient Workload at Hospital 1 from FY 08-FY 10 (US DoD 2011)

	FY08		FY09		FY10 ytd	
Clinic Name	Dispositions	Bed Days	Dispositions	Bed Days	Dispositions	Bed Days
Internal Medicine	121	188	132	207	78	132
General Surgery	218	475	178	419	84	220
Ophthalmology	4	10	3	5	0	0
Otolaryngology	14	21	22	44	8	19
Urology	28	41	22	49	18	22
Obstetrics & Gynecology	1,153	2,419	1,239	2,644	5,20	1,074
Pediatrics	89	131	107	134	45	87
Newborn Nursery	1,013	1,988	1,063	2,079	422	830
Orthopedics	26	101	21	52	6	24
Family Medicine	446	803	503	794	191	293
Family Practice OB/Gyn	54	116				
Family Practice Newborn Nursery	14	24	7	13		
	3,180	**6,317**	**3,297**	**6,440**	**1,372**	**2,701**

Hospital 2 opened up in 1973 after building consolidation, and is one of the largest health care-delivery systems to the military by providing more than 12,500 ambulatory surgeries and almost 8,000 inpatient admissions each year. Hospital 2 is also the regional headquarters for the regional Health Care System. Recently, a three-story outpatient structure and a seven story, 500 bed inpatient facility, with a combined area of more than 880,000 square feet were added. Hospital 2 offers a full range of services including: allergy, cardiology, dermatology, emergency, endocrinology, gastroenterology, genetics, hematology/ oncology, infectious diseases, internal medicine, neonatal, nephrology, neurology, optometry, pediatrics, pulmonary, respiratory, rheumatology, sleep lab and social work medical services. It also offers a wide range of surgical services as: ambulatory procedures, anesthesiology, audiology, cardio/thoracic, central sterile supply, ENT, general/neuro- surgery, OB/GYN, operating room, ophthalmology, oral maxillofacial, orthopedics, pain clinics, plastic reconstruction, podiatry, post anesthesia care, and urology. In the 2010 fiscal year, there were 4,959 staff workers and Table 2 shows the inpatient workload of these staff from the 2008-2010 fiscal years. (Us DoD 2011).

Table 2: Inpatient workload at Hospital 2 from FY08-FY10 (US DoD 2011)

	FY 2008		FY 2009		FY 2010 ytd	
Clinical Service	Dispositions	Bed Days	Dispositions	Bed Days	Dispositions	Bed Days
Internal Medicine	2,023	9,678	1,762	8,643	653	3,509
Cardiology	760	2,445	723	2,430	260	892
Gastroenterology	5	21	13	38	3	14
Hematology	51	349	81	326	25	106
Oncology	311	1,706	252	1,342	125	670
General Surgery	912	6,095	973	5,904	299	2,398
Cardiovascular & Thoracic Surgery	194	1,015	143	734	63	340
Neurosurgery	197	1,461	259	1,319	121	722
Oral Surgery	35	139	21	64	8	18
Otorhinolaryngology	66	255	75	154	18	52
Lastic Surgery	17	43	15	58	11	63
Urology	142	470	130	493	56	286
Obstetric	2,376	7,145	2,262	6,533	869	2,618
Pediatrics	74	582	109	708	44	270
Newborn Nursery	2,043	8,520	1,919	7,537	743	2,844
Orthopedics	230	1,069	271	1,239	110	605
Psychiatry	316	2,175	395	2,663	151	1,218
Total IP Workload	**9,752**	**43,168**	**9,403**	**40,185**	**3,559**	**16,625**

Hospital 3 opened up in 1909, with several renovations and additional expansions since then, including the most comprehensive finishing in 1977. Hospital 3 served more than 150,000 active and retired personnel from all branches of the military. There are 5,500 rooms covering approximately 28 acres of floor space and offered accommodations for 250 patients admitting more than 14,000 per year. Hospital 3 offers a full range of inpatient services including a birthing room, cancer services, end of life services, pain management, neonatal intensive care, neonatal intermediate care, heart surgery (adult and pediatric), heart catheterization – diagnostic and treatment for adult and pediatric patients, psychiatric care, partial hospitalization and psychiatric emergency services. In the 2010 fiscal year, there were approximately 6,000 staff workers. Table 3, below shows the inpatient workload of these staff from the 2008-2010 fiscal years. (US DoD 2011).

Table 3: Inpatient Workload for Hospital 3 from FY 08- FY 10 (US DoD 2011)

	FY 2008		FY 2009		FY 2010 ytd	
Clinical Service	Dispositions	Bed Days	Disps	Bed Days	Disps	Bed Days
Internal Medicine	2,471	15,672	2,492	15,715	919	5,552
Cardiology	1,275	3,370	1,206	3,558	423	1,327
Neurology	431	2,182	394	1,958	135	762
Oncology	251	1,924	320	2,491	180	1,299
Physical Medicine Wd57)	158	1,968	83	1,005	33	380
Bone Marrow Transplant	10	107	9	200	3	14
General Surgery	1,060	9,143	1,042	9,813	439	4,096
Cardiovas/Thoracic Surg	126	699	117	638	50	352
Neurosurgery	383	2,121	408	2,066	154	820
Tele-Neurosurgery	174	283	186	286	109	199
Ophthalmology	17	124	14	48	6	6
Oral Surgery	49	173	26	49	3	6
Otolaryngology	172	474	182	519	61	169
Plastic Surgery	33	167	32	187	16	106
Urology	537	1,905	513	1,796	220	757
Organ Transplant	72	372	126	611	32	162
Peripheral Vascular	225	1,837	208	1,325	86	395
Obstetrics & Gynecology	511	1,977	354	1,194	130	371
Pediatrics	993	3,137	1,018	3,495	444	1,671
Orthopedics	462	5,449	593	5,838	196	1,828
Hand Surgery	38	246	29	171	7	59
Psychiatry	656	7,588	614	7,145	176	2,177
Total IP Workload	**10,104**	**60,918**	**9,966**	**60,108**	**3,822**	**22,508**

Within each hospital, several units were studied: including Emergency Departments (ED), Intensive Care Units (ICU), Medical/Surgical Nursing Inpatient Units (IP), Mother/Baby Units (MB), and Ambulatory Same-Day Surgery Clinics (SDS). The exact units studied in each hospital are indicated below, in Table 4. These different types of units were selected for an adequate characterization of a typical hospital and to encompass multiple types of patients and care activities. The study of multiple combinations of hospital wards and occupants aids in developing the complete characterization missing from current literature as identified above.

As stated previously, the hospital soundscape encompasses both occupied and unoccupied spaces. In Table 5 below, the types of locations within each ward are shown. Detailed floor plans and exact measurement locations and measurement types can be found in Appendix B. Each unit was studied for approximately one day, including short term and overnight measurements, which are outlined in the next section. Collecting data in the specified locations covers the gamut of generalized and specialty locations within the measured units and covers a large percentage of the floor plan space within the units. For instance, most hospitals have nurses' stations (or pods), treatment rooms, patient rooms, corridors and waiting areas. In addition to the acoustic measurements, subjective nurse, patient and visitor data was collected.

Table 4: Hospitals and Individual units included in this research

Hospital ID	Unit				
	Emergency Department (ED)	Intensive Care Unit (ICU)	Med/ Surg. Inpatient Unit (IP)	Mother Baby Unit (MB)	Same Day Surgery Unit (SDS)
Hospital 1	X	X	X	X	X
Hospital 2	X	X	2X	X	
Hospital 3	X	X	X		X

Table 5: General measurement locations for each type of unit included in this research

Location ID	Location Name	Unit				
		ED	ICU	IP	MB	SDS
NS	Nurses' Station	X	X	X	X	X
Pat	Occupied Patient / Treatment Room	X	X	X	X	X
Xpat	Unoccupied Patient / Treatment Room	X	X	X	X	X
Corr	Corridor	X	X	X	X	X
Wait	Waiting Area	X	X	X	X	X
Amb	Ambulance Bay	X				
Nrsry	Occupied Nursery				X	
Xnrsry	Unoccupied Nursery				X	

The measurement locations are indicated in Table 5, for both sound level meter (SLM) and impulse response acoustic measurements (IR), which are explained in further detail below.

Figure 2: Sample floor plan with detailed acoustic measurement locations.

Figure 2 shows a sample floor plan from one of the hospital units. When selecting the locations within each unit, both occupied and unoccupied spaces were studied and kept separate for analysis. The main reason for this was two-fold: first to use for comparison against current guidelines of unoccupied spaces; and second to thoroughly investigate background noise levels in those spaces. If the levels in the unoccupied spaces were too high to begin with, then the addition of occupants to those spaces would never allow those spaces to meet the current guidelines. The result section, chapter 4, will discuss this in further detail.

Acoustic Measurements

As previously mentioned in Chapter 2, four key components of a hospital soundscape included in characterizing the sound environment are seen below:

Level relates to the overall loudness of sound
Spectral content reflects how the loudness of noise is distributed across frequency (from low to high pitch)
Temporal pattern reflects how much sound fluctuates over time.
Energy decay relates to the rate at which sound energy tapers off over time

In order to capture these qualities, sound level meter (SLM) and impulse response (IR) measurements were conducted. Between these two measurement types, it is possible to capture all four key components of the sound environment discussed above. Below is a detailed description of the particular equipment used in this research for the SLM and IR tests, followed by a description of the metrics that describe the aforementioned components.

Sound level meter measurements

The purpose of SLM measurements is to capture the noise environment, including loudness, spectral content (distribution of sounds across frequency) and temporal pattern (distribution of sound over time). At all measurement locations in this study, the same type of equipment was used. The equipment consisted of four identical Larson Davis SLMs. Each SLM setup consisted of a ½" Larson-Davis 2560 microphone, connected to a Larson-Davis PRM900C preamplifier, connected to a Larson-Davis 824 Sound Level Meter. All SLM's were setup with a predefined program with a fast response time, 1/3 octave band analysis and one-minute averaging intervals. The fast response time setting was used to better capture the nature of short transient sources, including speech and alarms.

As mentioned in the beginning of this section, the sound level meter measurements were conducted in multiple locations within each unit. The optimal measurements that could have been taken would be continuous recordings, 24 hours per day for several days at every location within the hospital. However, due to site availability and personnel, this was not possible. Therefore, the SLM measurements in each unit were broken into two different time lengths: longer term measurements (approx. 24-hour) and shorter term measurements (approx. 30 minutes). The 24-hour measurements were conducted for one day, in spaces where overnight access was more feasible. These spaces included nurses' stations, waiting rooms and unoccupied patient rooms. The shorter-term measurements were conducted one time during the day, in areas such as hallways, occupied rooms and unit unique locations, where access was more difficult. For the shorter term measurements, the microphone and SLM were mounted on top of a tripod, approximately 56-60" from the ground (ear height), and as far from reflecting surfaces as possible. In the longer term measurements, the microphone was hung from the ceiling or a medical boom, at a sufficient distance from reflecting surfaces. The microphone was also connected via cable to the SLM, which was housed in a locked case. Larson Davis Utility software and Excel software were used for all data analysis. A schematic of the SLM set-up is shown in Figure 3.

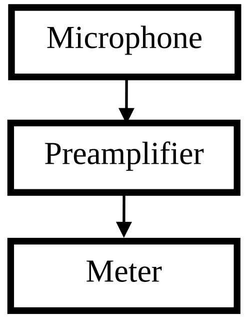


Figure 3: Schematic setup of the SLM measurement

Impulse response measurements

Impulse response measurements were made in several locations within units to capture energy decay. Impulse response measurements are important, as they help give a clear overview of the sound environment in terms of reflections and sound decay, which have been shown to relate to subjective perceptions of the spaciousness and reverberance of an environment. The same equipment was used for all IR measurements at all three hospitals. The measurement was performed by playing a known acoustic signal through a hemi-directional loudspeaker and measuring the signal's behavior with the use of one microphone receiver. Both the source and receiver are connected to a laptop computer controlled by EASERA software specifically designed for IR measurements. At each location, the IR measurements were conducted with 4 pre-sends and 2 averages, measured twice and averaged.

The IR measurement set-up therefore consisted of two sides: a source side (to produce sound), and a measurement side (to capture sound). The source side consisted of a loudspeaker connected to a laptop computer. The loudspeaker used for these measurements was a Norsonic 250. Since this loudspeaker was not self-powered, a

Norsonic 280 power amplifier was also used. The signal played through the loudspeaker was comprised of a broadband, pseudo-randomly generated signal played at a constant level over time, called a Maximum Length Sequence (MLS) signal (Stan et al., 2002). The measurement side consisted of a moveable ½" Goldline TEF04P microphone connected to a PreSonus Gateway recording interface that was connected to the laptop computer. EASERA V1.1 software was used for all measurements and data analysis. A schematic of the IR measurement set-up that was used can be found below in Figure 4.

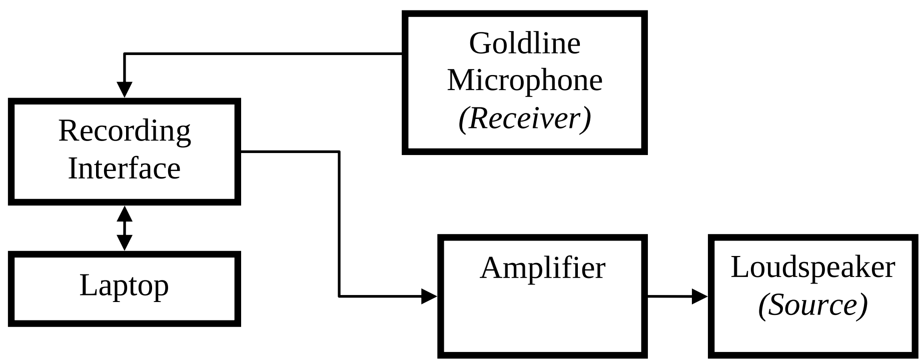


Figure 4: Schematic setup of the IR measurement

Metrics Analyzed

Within each measurement type, there were several metrics that were directly or indirectly obtained. Directly obtained measurements were outputs acquired directly from the test devices, and indirectly obtained metrics were those calculated through post-processing of the data. The metrics described below directly correspond to the four key components of the hospitals' soundscape.

Sound level meter measurement metrics

Within the sound level meter measurements, all of the metrics were based on the sound pressure levels recorded by the SLM as decibels (dB). These metrics were chosen because of their common use in acoustics or since they are those used in the current ANSI/WHO/ASHRAE guidelines. To provide the best description for the overall loudness level characteristic, A and C weighted levels and Noise criteria (NC) levels were used.

- *A-weighted equivalent, minimum, maximum, and C-weighted peak sound pressure levels* (*LAeq, LAmin, LAmax, LCpeak):* these metrics provide an idea of the overall loudness of the background noise (Bies & Hansen, 1996). The A- and C-weighted filters are applied to relate to certain aspects of human hearing. LAeq, LAmin, LAmax, LCpeak are given in decibels with a higher decibel indicating a louder sound.

- *Noise Criteria (NC):* The NC method was one of the earliest indoor noise rating systems to be widely accepted and is still widely used due in part to its simplicity (Beranek, 1957). This criterion provides a single-number level (loudness) rating, determined by comparing the background sound levels across frequencies to a set of pre-defined NC curves. A tangency method is used where the NC rating is given by the pre-defined NC curve, which lies above all the measured background noise.

In order to describe the spectral content of the measured spaces, Room Criteria Mark II (RC Mark II) was used.

- *Room Criteria Mark II (RC Mark II)*: The RC Mark II indoor noise rating method is slightly more complex than NC, but provides quite a bit of additional information (Blazier, 1997). A single-number level (loudness) rating is found by calculating the average of sound levels in the mid-frequencies (500 – 2000 Hz). To provide additional information on sound coloration, descriptors of "rumbly," "roaring," and "hissy" indicate excessive low, mid, or high frequency content, respectively, based on deviations of the measured background noise from a set of pre-defined, "neutral"-sounding RC curves. RC Mark II also provides an assessment of the probability of noise-induced vibration if there is excessive sound energy in the very low frequencies (16 to 63 Hz). Finally, a Quality Assessment Index (QAI) is calculated to provide an estimate of the probable response of occupants. The QAI is based on the deviation in decibels of the measured sound from a "neutral" sound, with higher QAI values indicating larger deviations from neutral. The value of the QAI determines whether occupants will perceive noise as acceptable, marginal, or objectionable.

To characterize the temporal patterns of the soundscapes, the occurrence rate and percentile level metrics were used. The occurrence rate metric was developed to measure the "peakiness" or sound fluctuations of loud events over time (Kracht, et al., 2007; Ryherd et al., 2011; Sunderstrom, et al., 1994; A. Williams, et al., 2007). It is derived from the traditional percentile metrics, which specify sound fluctuations of more average levels over time.

- *Occurrence Rate:* the percentage of time that maximum and peak levels (LAmax and LCpeak) exceed certain decibel values. The Occurrence Rate metric differs from the percentile metric because Occurrence Rate is specifically for maximum and peak sound pressure levels. Thus, the Occurrence Rate is a measure of the "peakiness" or the impulsive nature of the background noise environment. Occurrence Rate is given as a percentage of time with a higher percentage indicating a more "peaky" space.

- *Percentiles (Ln):* Ln is defined as the sound pressure level that is exceeded n% of the measurement time (e.g., L90 = 40 dB implies 40 dB is exceeded 90% of the measurement time) (Bies & Hansen, 1996). Ln is given in decibels with a higher decibel indicating a louder sound.

As previously noted the communication of speech is highly important in hospital design, though it is not necessarily one of the key physical components of noise. The metric used to characterize the speech intelligibility was Speech Intelligibility Index (SII).

- *Speech Intelligibility Index (SII):* provides an indication of how easy it is to understand speech. According to ANSI S3.5, the SII is "a physical measure that is highly correlated with the intelligibility of speech under a variety of adverse listening conditions, such as noise, filtering, and reverberation" (American National Standards Institute, 2007). Excessive noise can cover up or "mask" a speech signal and degrade speech intelligibility; likewise, long energy decays can smear a speech waveform in time. SII is expressed as a unitless value from 0 to 1, with a larger value indicating speech is more easily understood (1 indicates perfect intelligibility).

Impulse response measurement metrics

The primary metric calculated based on the IR measurements was Reverberation Time (RT).

- *Reverberation Time (RT):* a measure of a room's energy decay, or how quickly sound dies out (Mehta, et al., 1999). RT is defined as the time it takes sound to decay to one-millionth of its initial energy after a source is stopped, which correlates to a drop in sound pressure level of 60 dB. Since it is extremely hard to create a sound loud enough to be 60dB higher than hospital background noise, the measurements in this work took the reverberation time as T20, or a true drop in sound pressure level of 20 dB extrapolated out to a drop of 60 dB. The RT is related to the volume and absorption in a space with the relationship below, where V = room volume in m^3 and A is equal to the total sound absorption in the room. A is calculated by taking into account the absorption characteristics (i.e., absorption coefficient) and surface areas of major room surfaces.

$$RT = \frac{0.16V}{A} \quad \text{(sec)}$$

  Larger rooms with less absorption (e.g., more hard surfaces) will generally have longer reverberation times. RT is a concern for hospitals because excessive reverberance can blur a speech waveform in time and degrade speech intelligibility. Reverberation time is given in units of seconds with a longer time indicating a more reverberant space.

RT gives a clear picture into the last key component of soundscapes (energy decay and absorption). When describing these main components of the hospital soundscape environment, it also needs to be noted that tonality was not studied in this research, which is another common aspect of soundscapes that is studied. However, the metrics mentioned clearly describe the four key components of the soundscape, and therefore the rigor of this study is substantiated.

Subjective analysis: staff, patient and visitor surveys

Occupant surveys were administered at all three hospitals. Care was taken to ensure that the administration of the surveys did not disrupt any patient care activities. Full copies of all of the survey material used can be found in Appendix C. All of the surveys were entirely anonymous and voluntary. Subjects received an introductory letter and a paper based survey, due to hospital preference. The completed surveys were directly collected or placed in a locked drop box located at or near the nurses' station in each unit. Subjects were recruited during the week that measurements were conducted in a particular hospital. Additionally, extra staff introduction letters and staff survey forms were left in each unit and collected after several weeks. The collected surveys were scanned into electronic format. Results were then tabulated into spreadsheet format using Remark Office Optical Mark Recognition (OMR) v.7.0 software.

Staff surveys

The staff surveys were administered to nursing staff (full-time and part-time nurses, clerks and other staff) who were assigned to the units under study at the designated sites. The criteria for inclusion for respondents were: aged between 18 and 89 years old, able to understand, speak and write English, working on the unit for a minimum of six months, and Military/DoD employees. The staff survey content was split into four general categories: subject demographics, perception of the sound environment, perception of occupational factors, and perception of physical and emotional health.

The ***demographic*** questions gathered subject age, gender, job category, length of time worked in the department, length of nursing career, and typical working hours. Several different types of questions were asked in order to measure staff ***perception of the sound environment***. This included questions about overall noise levels, annoyance due to noise at specific locations (e.g., nurses' stations, corridors), and ability to communicate. The subjects were also given a series of noise sources (e.g., conversation noise, alarms) and asked to define the degree to which these sources affected work concentration.

The ***emotional and physical health*** of survey respondents was gathered through a set of survey items adapted from previous research (Lim & Fisher, 1999; Ware et al., 1995). These survey items asked about level of activity, overall physical and psychological health, overall hearing ability, and noise sensitivity. Specifically, the survey questions were based on the 12-item Short-Form (SF-12v2) Health Survey (Lim & Fisher, 1999). The SF-12v2 is a shorter form of the popular 35-item (SF-36) Health Survey. Both surveys cover 8 health domains: physical functioning, the role of physical health, bodily pain, general health, vitality, social functioning, and the role of emotional health. The SF-12v2 version consists of one to two questions per domain. Corresponding health scores were generated using Quality Metric Health Outcomes Scoring Software V3.0.

Staff ***perception of occupational factors*** was garnered through a series of questions about their job stress and satisfaction. The job stress questions asked about perceived job creativity, challenge, variety, pace, decision making, and demands (Sale & Kerr, 2002). The job satisfaction questions ask about overall satisfaction and organizational commitment. However, analysis of these survey items was beyond the scope of this thesis.

Patient and visitor surveys

The ***patient*** surveys were administered to inpatients who were assigned to the units under study at the designated sites. The criteria for inclusion were that the respondents be 18-89 years old, able to understand, speak, and write English, and that they reside on the unit for a minimum of a few hours. The ***visitor*** surveys were administered to visitors in the units under study at the designated sites. The criteria for inclusion were that the respondents be 18-89 years old, able to understand, speak, and write English, and that they be employed by the DOD or be the family member of someone on active duty. The content of the patient and visitor surveys was split into two general categories: subject demographics and perception of the sound environment.

The ***demographic*** questions gathered subject age, gender, and length of stay in the hospital. Several different types of questions were asked in order to measure ***perception of the sound environment***. This included questions about anxiety and sleep disturbance due to noise in the patient's room, ease of hearing visitors and caregivers when spoken to, and personal expectations of speech privacy. They were also given a list of noise sources and asked to rate how annoying they found them to be during their stay or visit.

Statistical Analysis

Two types of statistical analyses were utilized: descriptive analysis of the survey responses (including differences in perception across hospitals and units), and statistical relationships between the measured acoustic metrics and the survey responses. The descriptive analysis consisted of analyzing subject demographics and frequency of responses. Next, one-way ANOVA and Games-Howell post hoc tests were used to assess differences in perception across demographic variables such as hospital and type of unit. The assumption of Homogeneity of Variance (or that the variances among different groups are approximately equal) was tested using the Levene Statistic. The next chapter will present the results obtained from the SLM and IR measurements and from the surveys that were outlined using the methods in this chapter.

CHAPTER 4

RESULTS AND DISCUSSIONS

Acoustic Measures

Sound Level Meter Measurement Metrics

<u>Average, minimum, maximum, and peak noise level</u>

The metric used by the WHO guidelines, is LAeq, or the A-weighted sound equivalent background noise level. Shown below in Figure 5 – Figure 7 are the LAeq levels for each hospital respectively, logarithmically averaged and shown by unit type, overlapped with the WHO guideline of 35dBA background noise level. From Chapter 3, the units studied were: Emergency Departments (ED), Intensive Care Units (ICU), Medical/Surgical Nursing Inpatient Units (IP), Mother/Baby Units (MB), and Ambulatory Same-Day Surgery Clinics (SDS).

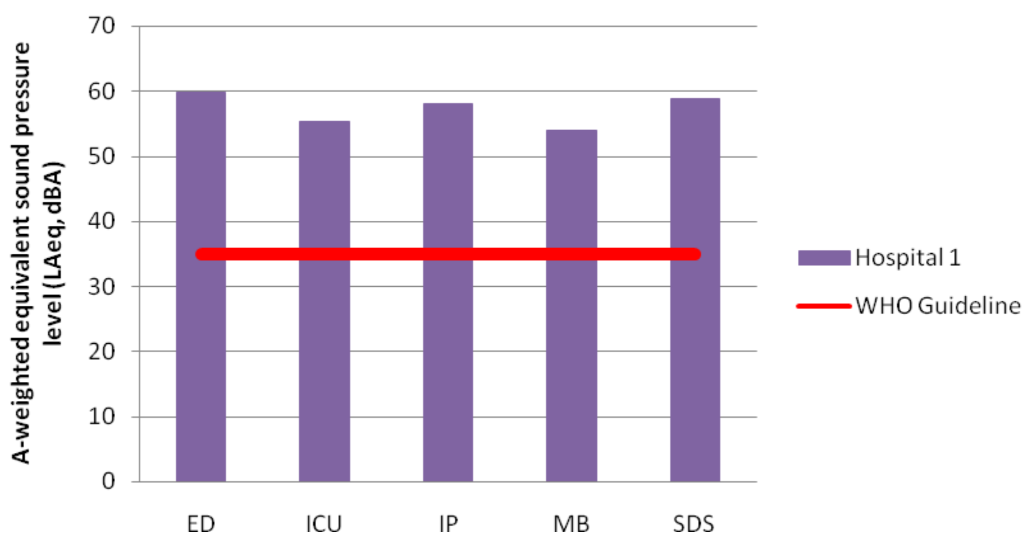


Figure 5: A-weighted equivalent sound pressure level (LAeq) for hospital 1, overlaid with the WHO 35dBA guideline. Shown are the Emergency Departments (ED), Intensive Care (ICU), Med./Surg. Inpatient (IP), Mother/ Baby (MB), and Same Day Surgery Units (SDS).

Figure 6: A-weighted equivalent sound pressure (LAeq) for hospital 2, overlaid with the WHO 35dBA guideline. Shown are the Emergency Departments (ED), Intensive Care (ICU), Med./Surg. Inpatient (IP), Mother/ Baby (MB), and Same Day Surgery Units (SDS).

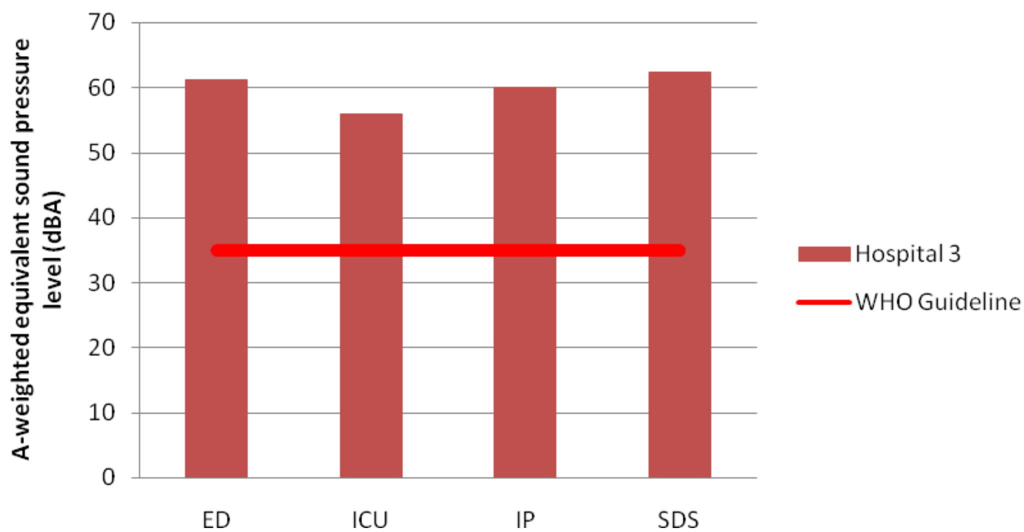


Figure 7: A-weighted equivalent sound pressure (LAeq) for hospital 3, overlaid with the WHO 35 dBA guideline. Shown are the Emergency Departments (ED), Intensive Care (ICU), Med./Surg. Inpatient (IP), Mother/ Baby (MB), and Same Day Surgery Units (SDS).

These figures indicate there is a significant loudness level increase above what the current WHO guidelines recommend for a hospital environment. However, as previously noted, these guidelines may be overly restrictive and may need to be modified for a true direct comparison for occupied spaces. Figures 5-7 present the LAeq levels logarithmically averaged using *both* the occupied and unoccupied spaces within each ward, for a direct comparison to WHO.

Tables 1 and 2 from Chapter 3 indicated the specific locations within each unit that were measured in this study. The specific locations were: Nurses' stations (NS), occupied patient rooms (Pat), unoccupied rooms (XPat), waiting areas (Wait), corridor locations (Corr) and unoccupied nurseries (XNrsry), and occupied nurseries (Nrsry). Shown below in Figure 8 - Figure 12 are the LAeq, LAmax, LAmin, and LCpeak metrics for hospital 1 across every location within each unit. These metrics begin to show the results from the first key component of soundscapes, overall loudness levels. In addition to LAeq, LAmin, LAmax, and LCpeak are shown to give an indication of how the minimum and maximum levels looked for the work day. Although LAmax and LC peak correspond to "maximum" levels, it needs to be re-emphasized that the same numeric value of A-weighted decibels and C-weighted decibels does not translate to the same sound pressure level measured, nor to its perception by humans.

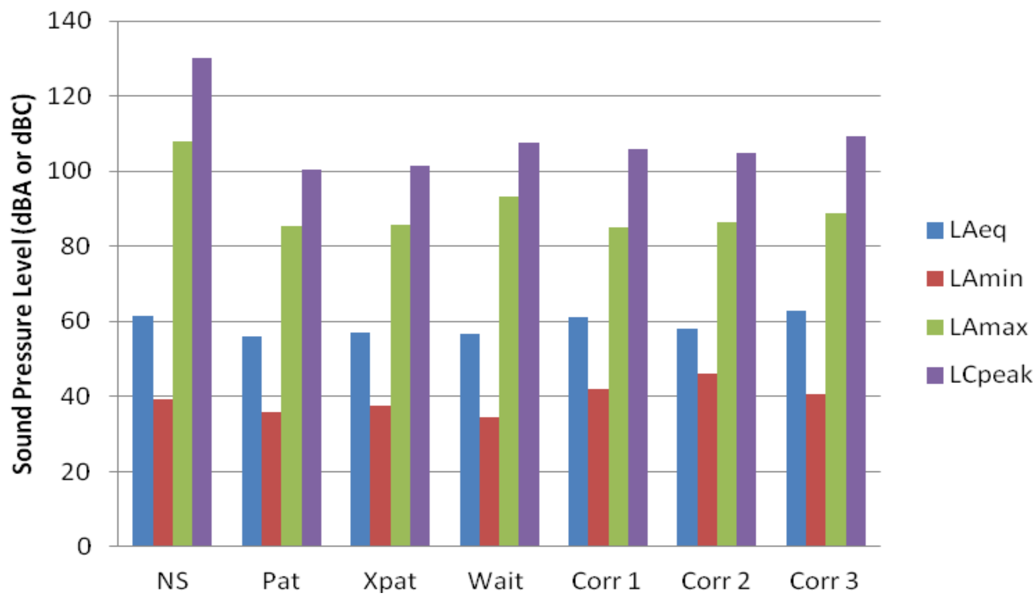


Figure 8: Average, minimum, maximum, and peak sound pressure levels for hospital 1 ED shown by location type. Location types shown are: Nurses' stations (NS), occupied patient rooms (Pat), unoccupied rooms (XPat), waiting areas (Wait), corridor locations (Corr) and unoccupied nurseries (XNrsry), and occupied nurseries (Nrsry).

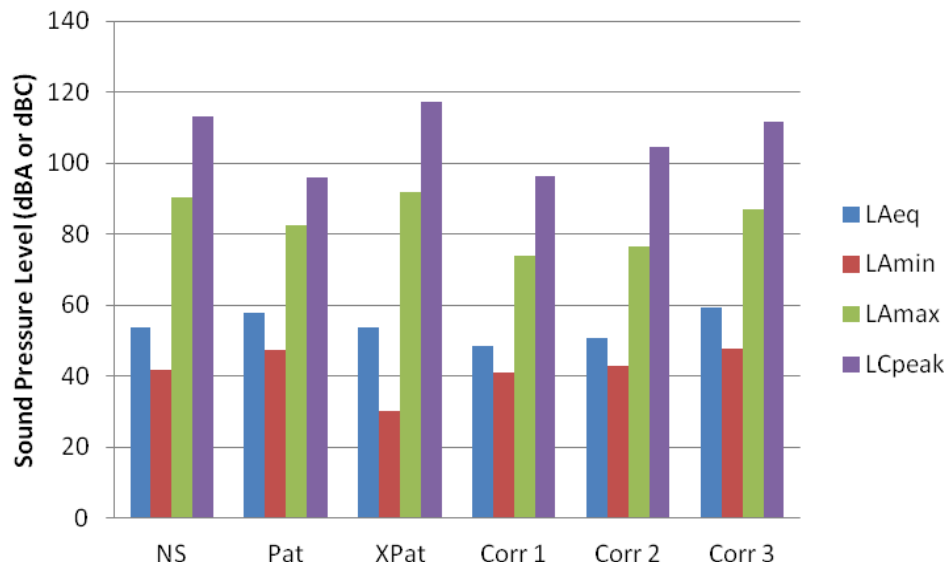


Figure 9: Average, minimum, maximum, and peak sound pressure levels for hospital 1 ICU shown by location type. Location types shown are: Nurses' stations (NS), occupied patient rooms (Pat), unoccupied rooms (XPat), waiting areas (Wait), corridor locations (Corr) and unoccupied nurseries (XNrsry), and occupied nurseries (Nrsry).

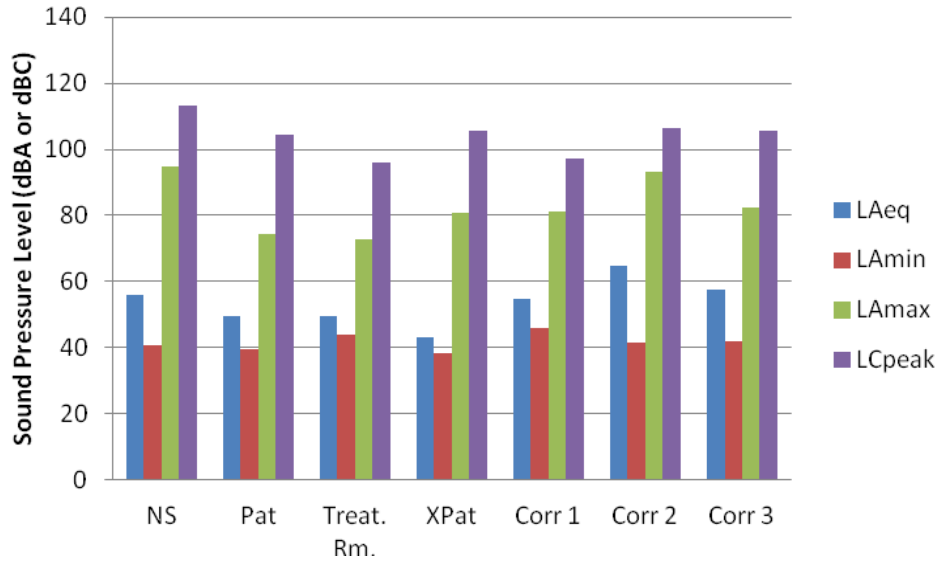


Figure 10: Average, minimum, maximum, and peak sound pressure levels for hospital 1 IP shown by location type. Location types shown are: Nurses' stations (NS), occupied patient rooms (Pat), unoccupied rooms (XPat), waiting areas (Wait), corridor locations (Corr) and unoccupied nurseries (XNrsry), and occupied nurseries (Nrsry).

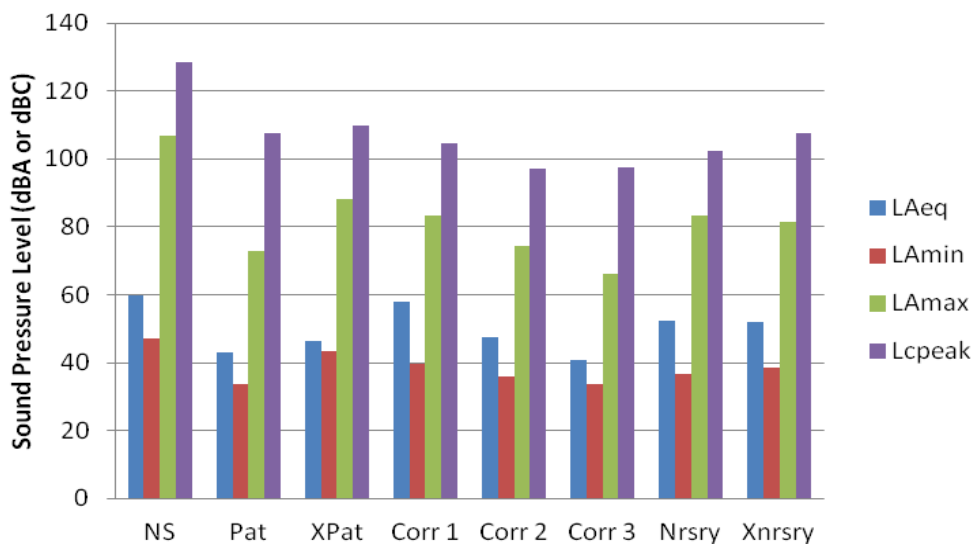


Figure 11: Average, minimum, maximum, and peak sound pressure levels for hospital 1 MB shown by location type. Location types shown are: Nurses' stations (NS), occupied patient rooms (Pat), unoccupied rooms (XPat), waiting areas (Wait), corridor locations (Corr) and unoccupied nurseries (XNrsry), and occupied nurseries (Nrsry).

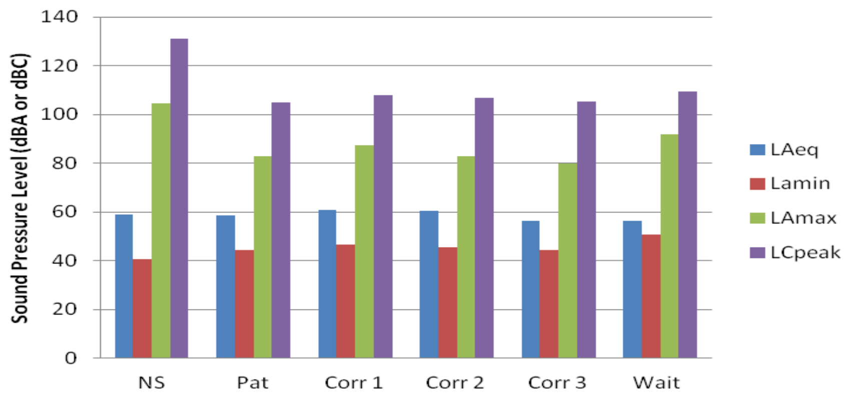


Figure 12: Average, minimum, maximum, and peak sound pressure levels for hospital 1 SDS shown by location type. Location types shown are: Nurses' stations (NS), occupied patient rooms (Pat), unoccupied rooms (XPat), waiting areas (Wait), corridor locations (Corr) and unoccupied nurseries (XNrsry), and occupied nurseries (Nrsry).

As can be seen, most of the maximum levels (LAmax, LCpeak) were within the range of 80-110dB for hospital 1. This raises the issue of how loud, objectionable and annoying this hospital soundscape could be perceived by an occupant. Within Figures 8-12 hospital 1's average LAeq value has a slight variation between locations within each unit (ranging from 40.7 to 64.8 dBA with an average of 57.7 dBA). This is not as large of a distribution as expected given the diversity of spaces.

The relatively constant LAeq values indicate that there may not be one dominant location that skewed the overall levels shown in Figures 5-7. Nurses' stations and corridors generally had the highest average levels; this was as expected as that is where the staff spends the greatest amount of time and where most communication and conversations occur. The result for LAeq for all hospitals is presented in Table 6. An interesting point to notice in these figures is that high levels were present even in the unoccupied spaces. Intuition might suggest that unoccupied spaces would have lower sound levels, but that was not the case in hospital 1. The primary source of noise in the unoccupied rooms was the heating, ventilating, and air conditioning (HVAC) system and measurements were made with doors closed. Outside the scope of this study was the analysis of sound transmission, which could potentially explain this phenomenon. For example, it is possible that the high levels measured in the unoccupied spaces were due to sounds from adjacent spaces transmitting through walls, doors, and ceilings, though this was not specifically measured.

Table 6: LAeq range and average values by hospital. Location types: NS – Nurses' Station, Corr – Corridor, Pat – Occupied Patient Rooms, XPat – Unoccupied Patient rooms, Wait – Waiting Areas.

	LAeq values			
	Location Type	Range		Average
		Low	High	
Hospital 1	**NS**	53.8	61.4	58.7
	Corr	40.7	64.8	59.1
	Pat	43.0	58.4	55.6
	XPat	43.3	58.4	54.7
	Wait	56.2	56.8	56.5
Hospital 2	**NS**	56.4	61.1	58.9
	Corr	51.1	58.7	55.9
	Pat	49.8	56.2	53.4
	XPat	41.6	47.4	44.6
	Wait	43.3	59.4	55.8
Hospital 3	**NS**	53.6	62.3	59.8
	Corr	46.6	64.3	66.7
	Pat	56.3	71.1	53.1
	XPat	44.8	56.6	58.3
	Wait	53.1	60.6	57.0

One consistent point from Table 6 and Figures 8-12 above, and from Figure 13-21 below, is that the unoccupied spaces have significantly lower levels in most cases than the occupied spaces(53-66dBA), but are still high themselves (44-58dBA). This brings up the issue again that studying locations with different occupancy is important as the unoccupied levels are high to begin with.

In hospital 2, the ED, ICU, 2 IP units, and MB units were studied. Figure 13 - Figure 17 below again show the LAeq, LAmin, LAmax, and LCpeak for each unit by location in hospital 2.

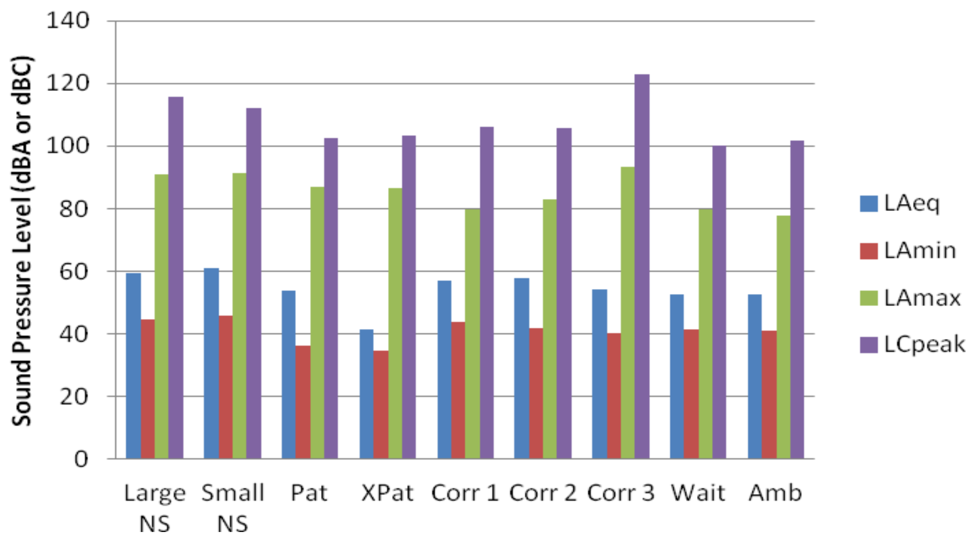


Figure 13: Average, minimum, maximum, and peak sound pressure levels for hospital 2 ED shown by location type. Location types shown are: Nurses' stations (NS), occupied patient rooms (Pat), unoccupied rooms (XPat), waiting areas (Wait), corridor locations (Corr) and unoccupied nurseries (XNrsry), and occupied nurseries (Nrsry).

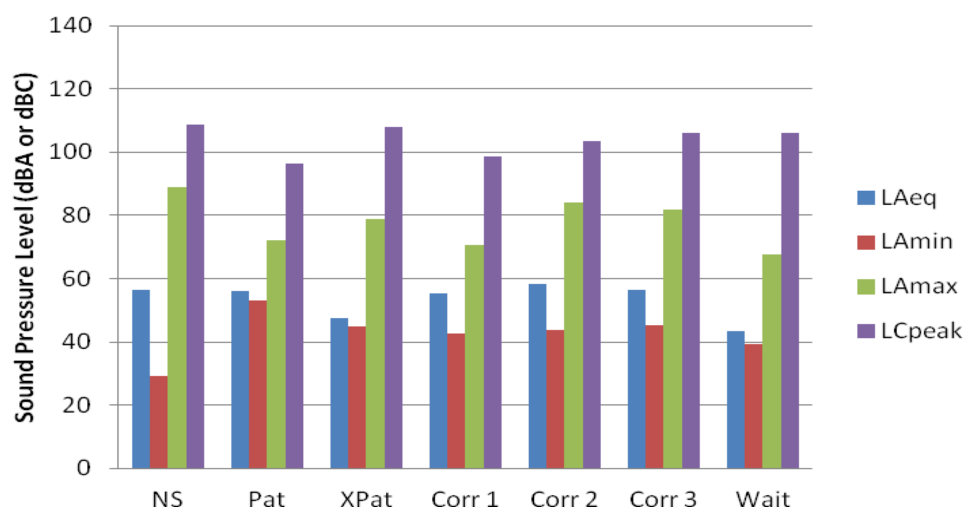


Figure 14: Average, minimum, maximum, and peak sound pressure levels for hospital 2 ICU shown by location type. Location types shown are: Nurses' stations (NS), occupied patient rooms (Pat), unoccupied rooms (XPat), waiting areas (Wait), corridor locations (Corr) and unoccupied nurseries (XNrsry), and occupied nurseries (Nrsry).

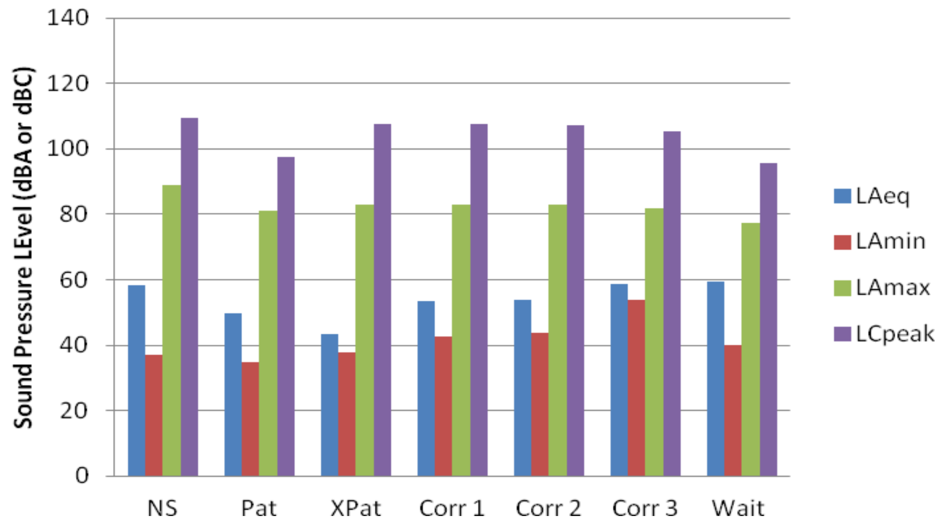


Figure 15: Average, minimum, maximum, and peak sound pressure levels for hospital 2 IP 5E shown by location type. Location types shown are: Nurses' stations (NS), occupied patient rooms (Pat), unoccupied rooms (XPat), waiting areas (Wait), corridor locations (Corr) and unoccupied nurseries (XNrsry), and occupied nurseries (Nrsry).

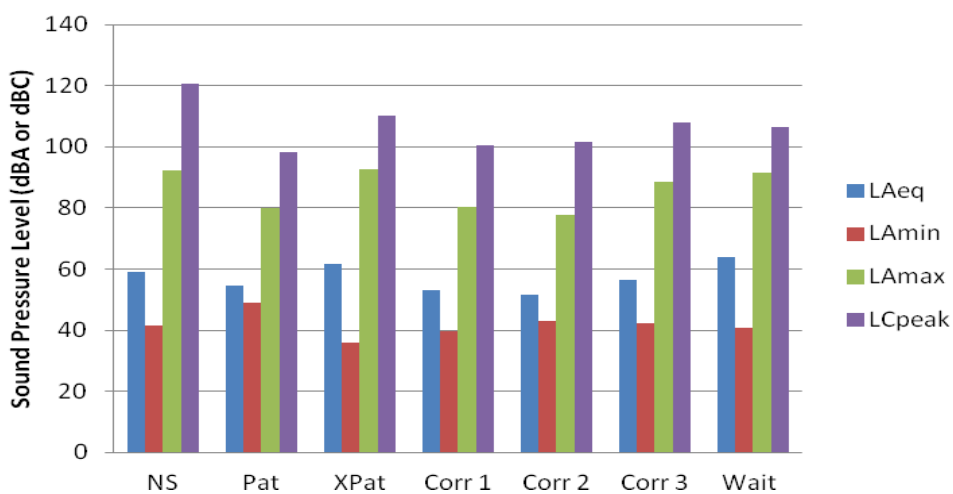


Figure 16: Average, minimum, maximum, and peak sound pressure levels for hospital 2 IP 5C shown by location type. Location types shown are: Nurses' stations (NS), occupied patient rooms (Pat), unoccupied rooms (XPat), waiting areas (Wait), corridor locations (Corr) and unoccupied nurseries (XNrsry), and occupied nurseries (Nrsry).

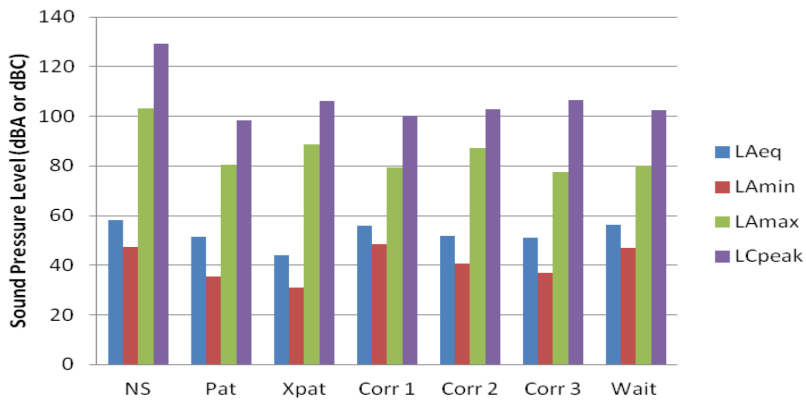


Figure 17: Average, minimum, maximum, and peak sound pressure levels for hospital 2 MB shown by location type. Location types shown are: Nurses' stations (NS), occupied patient rooms (Pat), unoccupied rooms (XPat), waiting areas (Wait), corridor locations (Corr) and unoccupied nurseries (XNrsry), and occupied nurseries (Nrsry).

As seen in these figures, the nurses' stations and corridors again appear to have the loudest level as measured by almost all of the metrics presented. With the units in hospital 2, the trends are similar to those found in hospital 1. The maximum levels were in the range of 80-110dB, with most locations measured close to 80dBA.

The next four figures (Figures 18-21) will show the same four loudness level metrics in the hospital 3 ED, ICU, IP and SDS units.

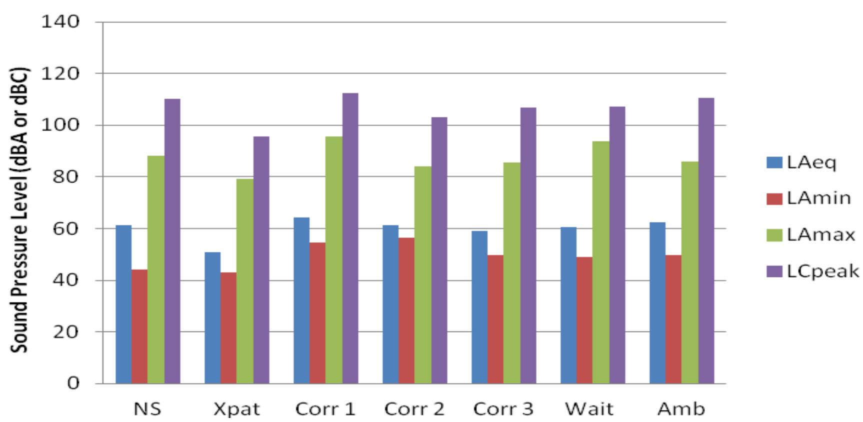


Figure 18: Average, minimum, maximum, and peak sound pressure levels for hospital 3 ED shown by location type. Location types shown are: Nurses' stations (NS), occupied patient rooms (Pat), unoccupied rooms (XPat), waiting areas (Wait), corridor locations (Corr) and unoccupied nurseries (XNrsry), and occupied nurseries (Nrsry).

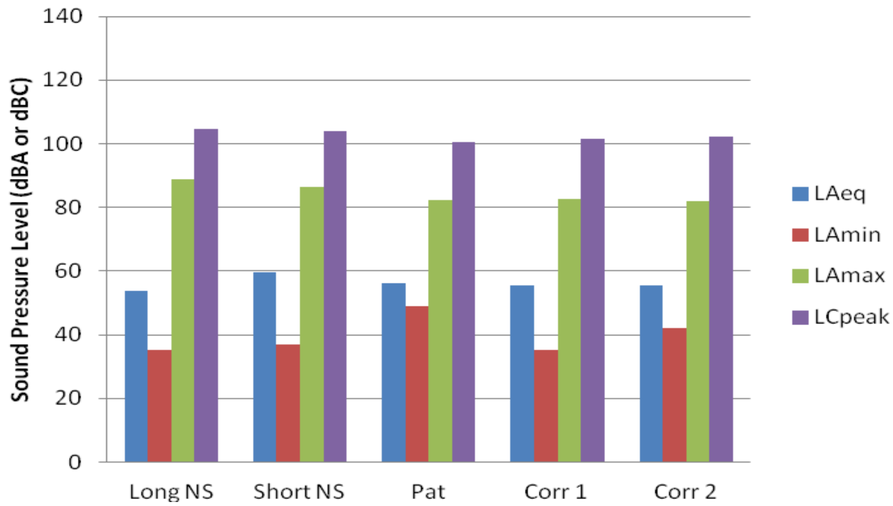


Figure 19: Average, minimum, maximum, and peak sound pressure levels for hospital 3 ICU shown by location type. Location types shown are: Nurses' stations (NS), occupied patient rooms (Pat), unoccupied rooms (XPat), waiting areas (Wait), corridor locations (Corr) and unoccupied nurseries (XNrsry), and occupied nurseries (Nrsry).

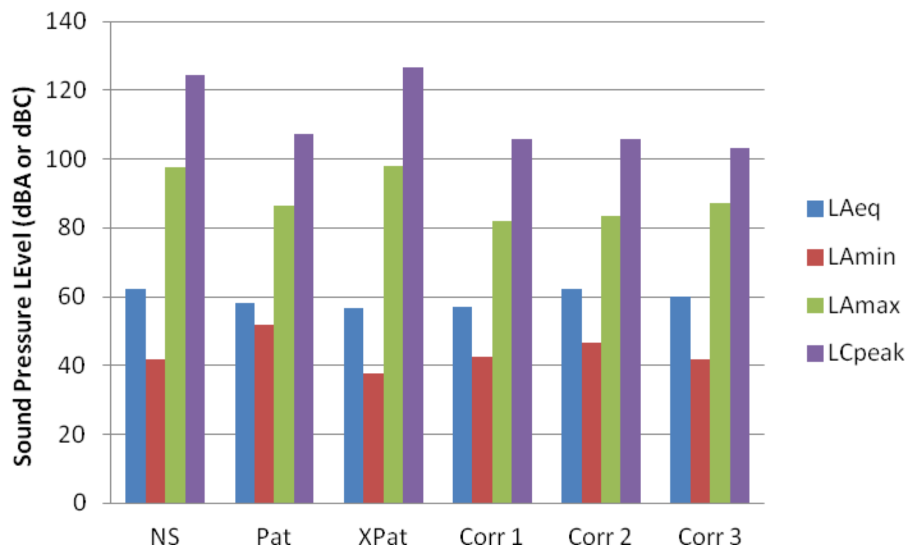


Figure 20: Average, minimum, maximum, and peak sound pressure levels for hospital 3 IP shown by location type. Location types shown are: Nurses' stations (NS), occupied patient rooms (Pat), unoccupied rooms (XPat), waiting areas (Wait), corridor locations (Corr) and unoccupied nurseries (XNrsry), and occupied nurseries (Nrsry).

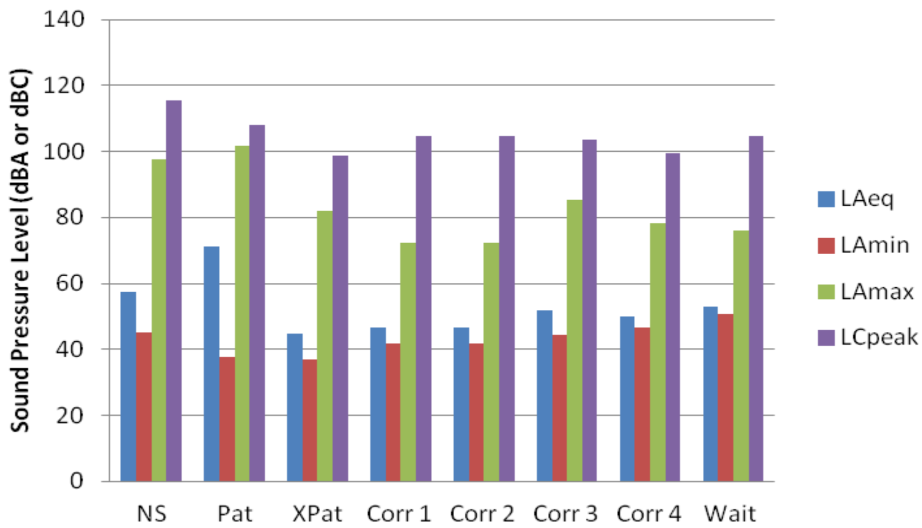


Figure 21: Average, minimum, maximum, and peak sound pressure levels for hospital 3 SDS shown by location type. Location types shown are: Nurses' stations (NS), occupied patient rooms (Pat), unoccupied rooms (XPat), waiting areas (Wait), corridor locations (Corr) and unoccupied nurseries (XNrsry), and occupied nurseries (Nrsry).

As can be seen, most of these maximum levels are within the range of 80-110dB, but were closer to the 90 dBA threshold. Even with the maximum and minimum levels recorded here; these metrics do not lend insight into how often they are occurring. The loudest level for any of the units shown could be presented for 1 second, 1 minute, or even possibly the unit could have that level of background noise for a considerable time throughout the day. Use of these four single number metrics (LAeq, LAmax, LAmin, and LCpeak) gives a better picture than current guidelines, but there is a large portion of the acoustic picture on temporal patterns (or time duration) that is being missed.

Occurrence Rates

To address the temporal pattern of the acoustic space, this section presents the occurrence rate metric averaged by unit and hospital in order to quantize the time pattern of the sound pressure levels. This data is presented as the occurrence rate based on both

LAmax and LCpeak data. Since similar trends were found between the occurrence rates within each location that data has been omitted from this section.

Figures 22- 25 show the occurrence rate based on LAmax and LCpeak averaged across all of the hospitals. The occurrence rate is a metric corresponding to the percentage of time that the maximum (based on rms pressure) or peak (based on peak pressure) level within a measurement period exceeds a certain sound pressure level. The rms averaging is based on a one-minute windowed average. An interesting point is that these figures show a distinct difference between unit types. According to this trend, ED units are the loudest unit type and the MB/SDS units are the quietest. It needs to be re-mentioned here that the acronyms for the following figures is: Emergency Departments (ED), Intensive Care (ICU), Med./Surg. Inpatient (IP), Mother/ Baby (MB), and Same Day Surgery Units (SDS).

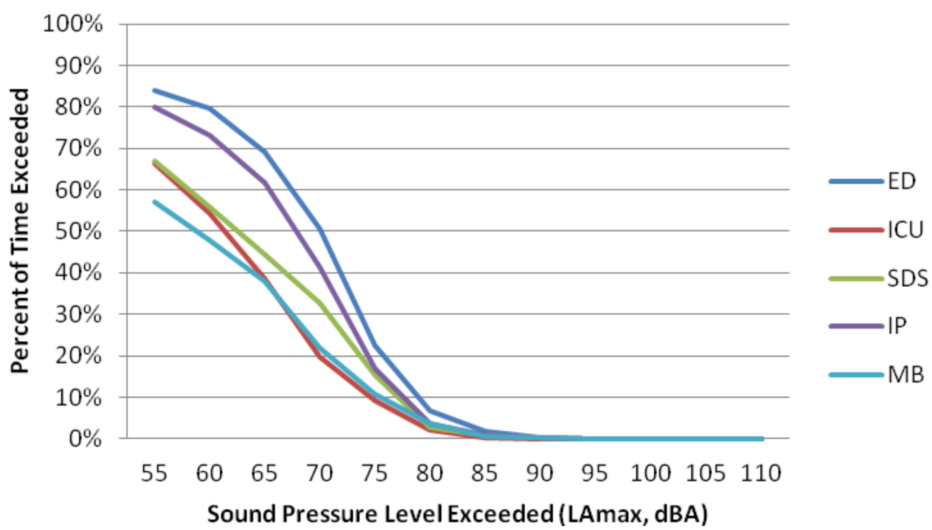


Figure 22: Occurrence Rates based on LAmax averaged across all hospitals for each type of unit. Shown are the Emergency Departments (ED), Intensive Care (ICU), Med./Surg. Inpatient (IP), Mother/ Baby (MB), and Same Day Surgery Units (SDS).

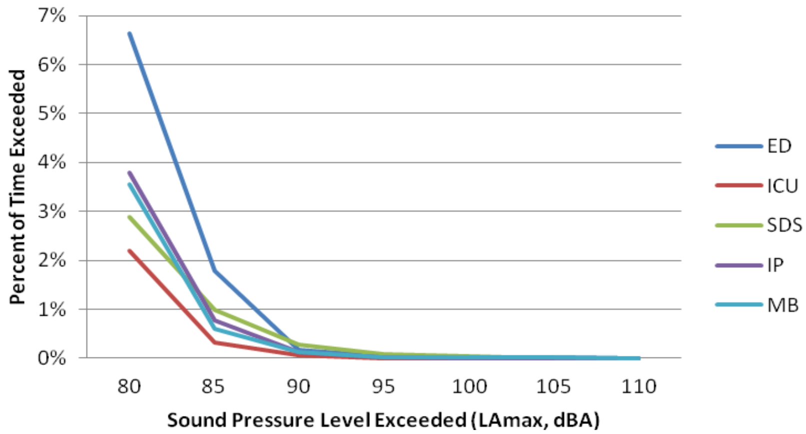


Figure 23: Zoomed in section of LAmax Occurrence Rate, from Figure 22. Shown are the sound pressure level occurrences above 80 dBA.

One point of note in figures 22-23 is the percentage of occurrence at the high levels (LAmax > 85dBA). Even though the maximum levels above 85dBA occur less than 2% of the time, they can potentially be a significant issue to occupants. However, the specific effects of how long exposure to these levels is needed before negative impacts such as hearing damage occurs is somewhat unknown. Future research must address this concern for any hospital environment, especially since 2% of a workday equates to roughly 10 minutes during a normal work shift.

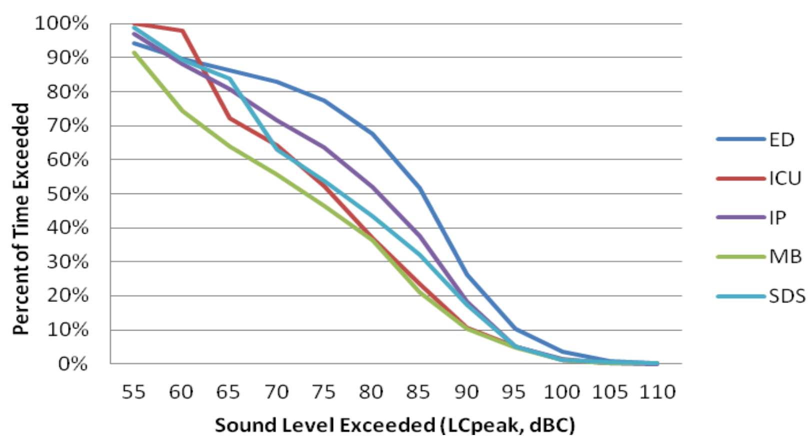


Figure 24: Occurrence Rates based on LCpeak averaged across all hospitals for each type of unit. Shown are the Emergency Departments (ED), Intensive Care (ICU), Med./Surg. Inpatient (IP), Mother/ Baby (MB), and Same Day Surgery Units (SDS).

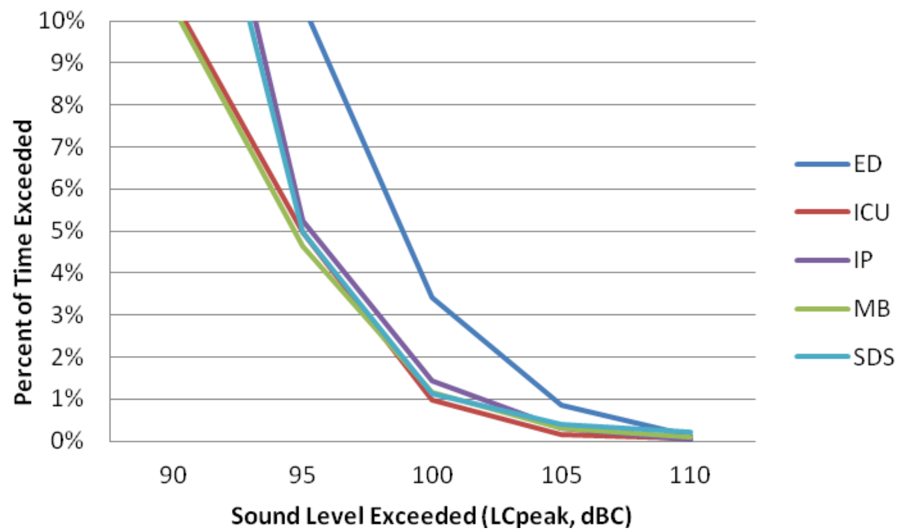


Figure 25: Zoomed in section of LCpeak Occurrence Rate, from Figure 24. Shown are the sound pressure level occurrences above 90 dBC.

One point of note in figures 24-25 is the percentage of occurrence at the high levels (LCpeak > 100dBC), and that peaks exist over 110dBC. Even though the peak levels above 100dBA occur less than 3% of the time, it can still be a significant issue to occupants, as discussed above.

As can be seen in figures 26-28 below, occurrence rates based on LAmax for each hospital, the units with the highest LAmax occurrence rates are the IP and ED unit types. When looking at these figures, the 50% exceedance level was in the range from 60-75dBA, much higher than single number expressions shown from the bar figures 1-3 for simply looking at LAeq.

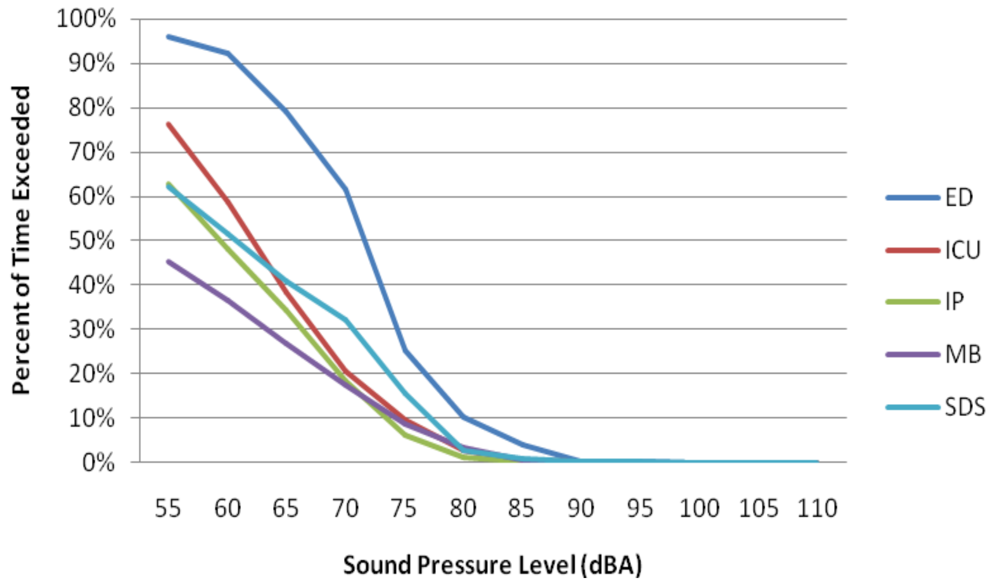


Figure 26: Occurrence Rates based on LAmax for Hospital 1 averaged by unit type. Shown are the Emergency Departments (ED), Intensive Care (ICU), Med./Surg. Inpatient (IP), Mother/ Baby (MB), and Same Day Surgery Units (SDS).

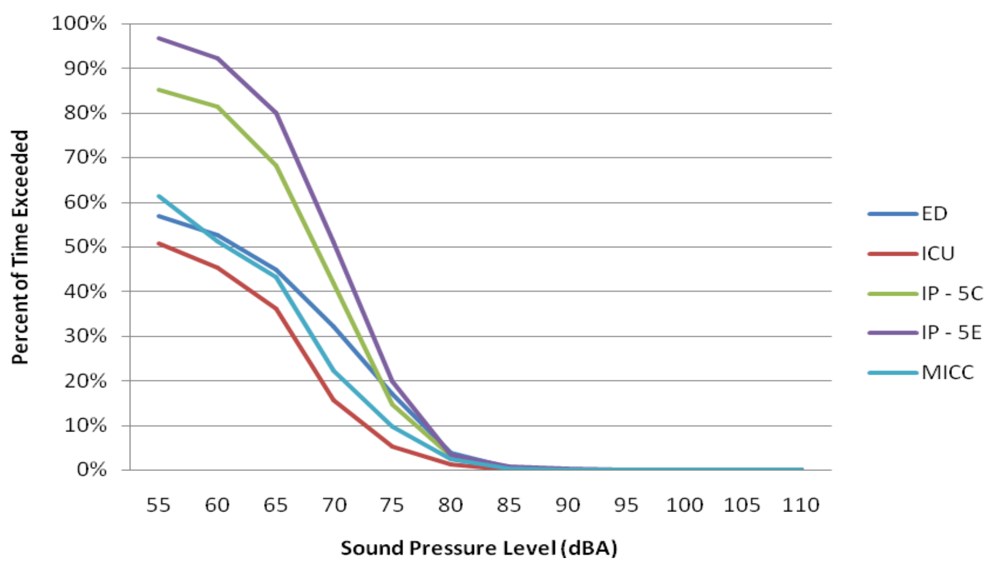


Figure 27: Occurrence Rates based on LAmax for hospital 2 averaged by unit type. Shown are the Emergency Departments (ED), Intensive Care (ICU), Med./Surg. Inpatient (IP), Mother/ Baby (MB), and Same Day Surgery Units (SDS).

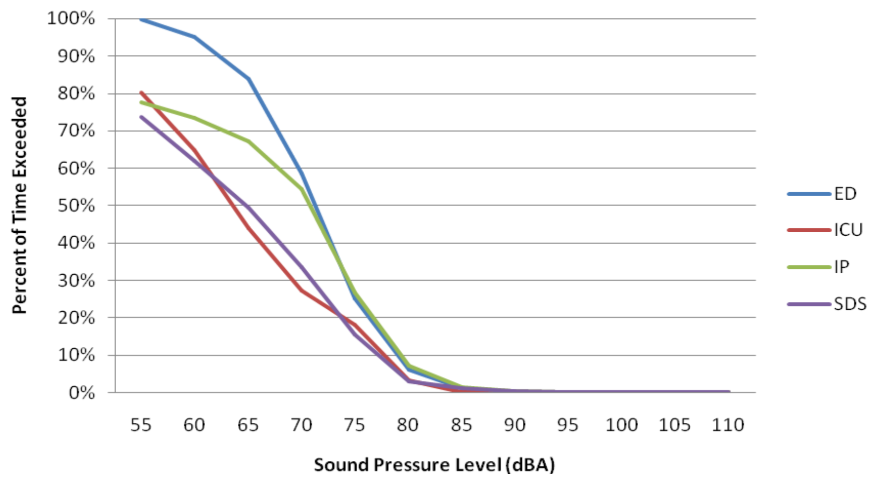


Figure 28: Occurrence Rates based on LAmax for hospital 3, averaged by unit type. Shown are the Emergency Departments (ED), Intensive Care (ICU), Med./Surg. Inpatient (IP), Mother/ Baby (MB), and Same Day Surgery Units (SDS).

In addition to those trends, it appears that all unit types drop to lower than 1% LAmax occurrence for levels 85dBA or higher. One percent of 24 hours is still roughly 15 minutes, which means that staff, patients and visitors were exposed to these extreme noise levels 15 minutes out of every work day. When looking at the occurrence rates for LCpeak, trends similar to that of LAmax occurrence rates were observed.

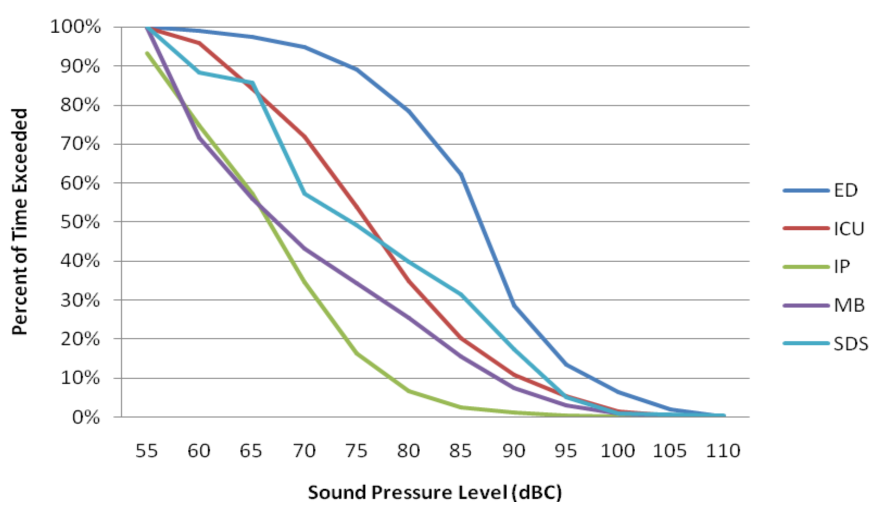


Figure 29: Occurrence Rates based on LCpeak for Hospital 1 averaged by unit type. Shown are the Emergency Departments (ED), Intensive Care (ICU), Med./Surg. Inpatient (IP), Mother/ Baby (MB), and Same Day Surgery Units (SDS).

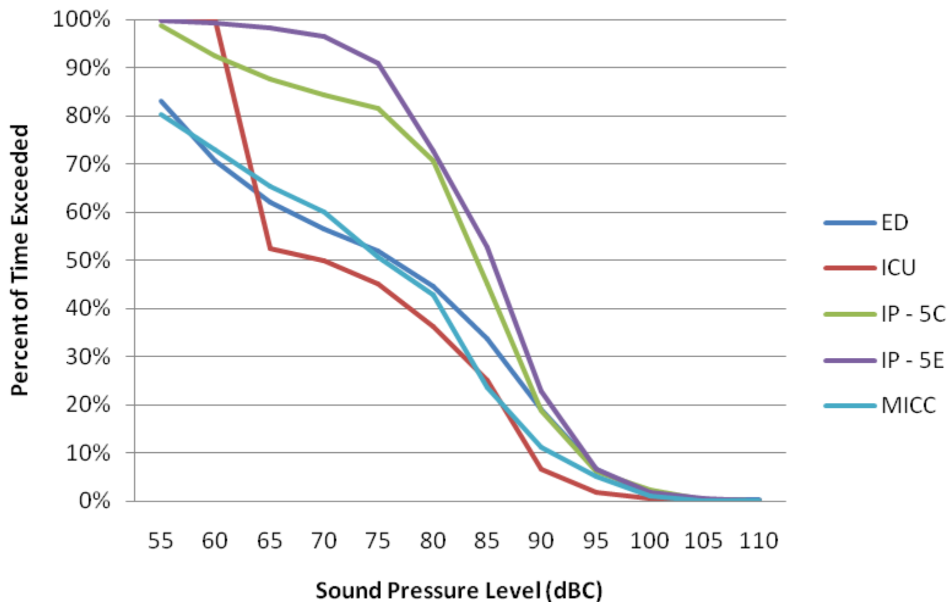


Figure 30: Occurrence Rates based on LCpeak for hospital 2 average by unit type. Shown are the Emergency Departments (ED), Intensive Care (ICU), Med./Surg. Inpatient (IP), Mother/ Baby (MB), and Same Day Surgery Units (SDS).

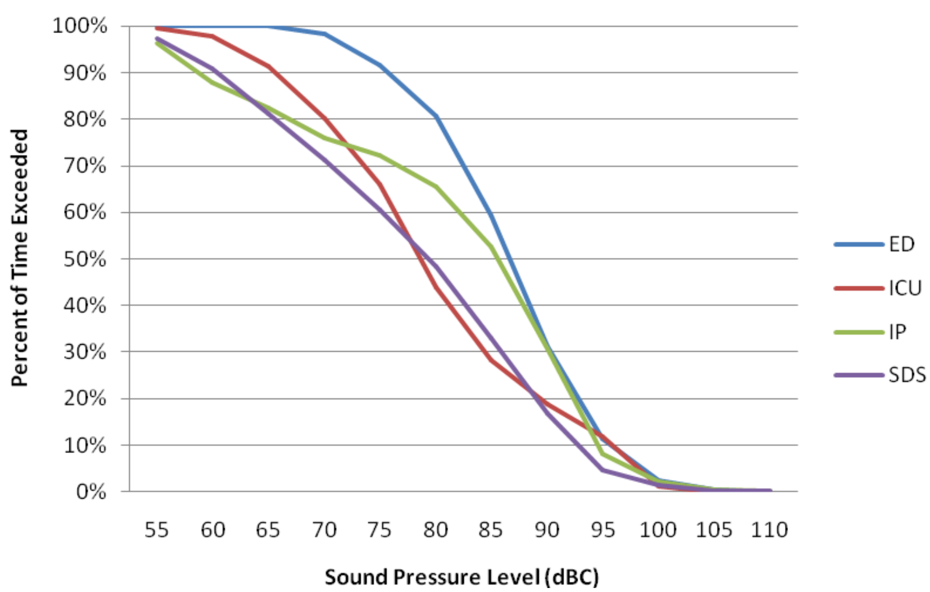


Figure 31: Occurrence Rates based on LCpeak for hospital 3 averaged by unit type. Shown are the Emergency Departments (ED), Intensive Care (ICU), Med./Surg. Inpatient (IP), Mother/ Baby (MB), and Same Day Surgery Units (SDS).

Figures 29-31 above show the occurrence rate metric based on LCpeak for each hospital measured in this study, with emergent trends similar to those noticed based on LAmax. From this occurrence rate analysis, the loudness levels and temporal patterns appear to be adequately defined and quanitzed by location. Growing this information and stating specifically which units and locations directly correspond to the background noise and spatial floorplan soundscape levels will prove to be useful for hospital design and redesign in the future.

<u>Percentile Levels</u>

Another approach is to utilize percentile levels, which provide insight into the steady (e.g. HVAC) versus impulsive (e.g., occupants) types of sounds. The L10 is more indicative of impulsive sounds (e.g., alarms, doors closing, clanging objects on metal trays, dropping items), whereas the L90 is more indicative of steady background noise from HVAC systems. The L90 is therefore particularly interesting for unoccupied spaces, where the primary noise source was likely HVAC noise, as seen in table 7, below. The LAeq metric roughly corresponds to the sound level during approximately 33% of the duration that each unit was studied.

In addition, Figure 32 shows the L90, L33 and LAeq for all of the unoccupied spaces in all units and hospitals. These spaces are mostly unoccupied patient rooms, with a couple being treatment rooms. A couple points are worth noting: first, the L90s are always less than LAeq, with differences ranging from 1 to 17 dBA. Recall that normally for unoccupied spaces dominated by HVAC noise we would expect that L90 to be roughly equivalent to the LAeq (www.cassafe.com, accessed Aug 2011). The fact that there are such major differences between L90 and LAeq supports the conclusion that there is another major noise source, and indicates that there was likely still some source of occupant noise intruding from adjacent spaces during the measurements. The L90 levels are likely to be more indicative of the HVAC system performance. Almost all of the spaces were measured to be less than L90 = 45 dBA; this is much more in-line with the recommended guidelines for unoccupied patient rooms in the range of 30-45dBA, depending on the specific guideline referenced. A few of the spaces were in the 35 dBA range. To determine exactly whether or not the HVAC systems in these spaces are meeting recommended guidelines, it is also recommend that in future measurements outside sources be more specifically controlled.

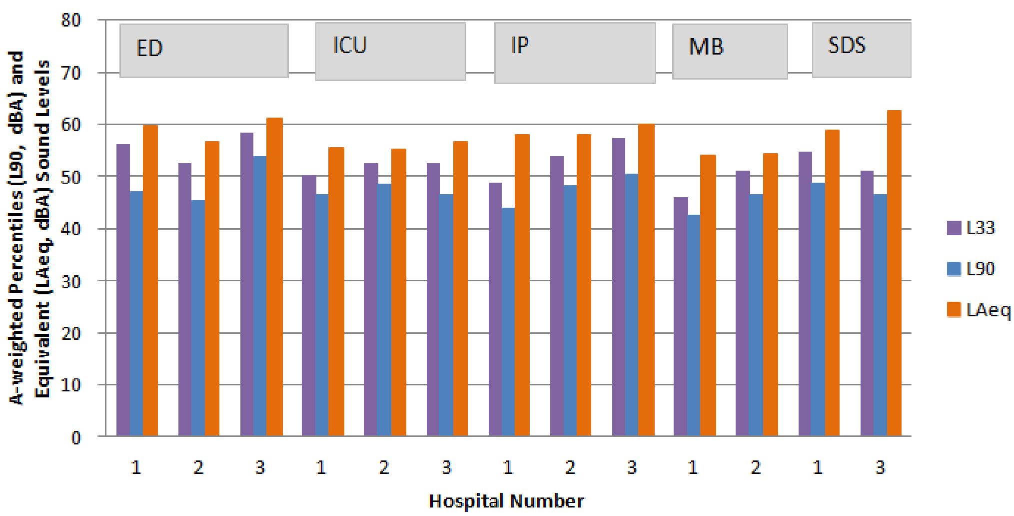


Figure 32: 90th percentile levels (L90, shown as dark blue bars) compared to the A-weighted equivalent sound pressure level (LAeq, shown as orange bars), and 33rd percentile levels (L33 shown in purple) in the unoccupied spaces in all three hospitals.

From Figure 32, another interesting point arises. It can be more clearly seen that there is a difference between hospitals when looking at L33 and L90 (the percentile levels) than when looking at LAeq alone. When looking at the orange bars for each unit type (for example the IP units), it appears that according to LAeq, that the units would sound roughly the same since they have close to the same level (~58dBA). However, in looking at those same three units by L90 or L33, it becomes apparent that a significant difference exists. L33 shows a range of 48-57dBA, as compared to the 58-60dBA range by the LAeq metric. This suggests that simply looking at only one metric might miss some of the big picture differences between units.

Table 7: Measured A-weighted equivalent (LAeq), L10, L33 and L90 Percentile Levels

		Measured Noise Levels (dBA)			
Location Type	**Hospital + Unit**	L10	L33	L90	LAeq
Unoccupied Treatment Room	Hospital #1 ED	62	56	47	60
	Hospital #2 ED	59	52	45	57
	Hospital #3 ED	63	58	54	61

<u>Noise Criteria (RC Mark II)</u>

The RC Mark II method, used to describe the spectral content, takes the background noise from a measured space, calculates a level rating, a spectral imbalance, and offers an occupant evaluation. The spectral imbalance is broken into categories of vibrational (low frequency), rumbly, roaring, and hissy (high frequency) content. While this method does not directly state the sound source causing this imbalance, it does give information regarding the problem areas that will require the most focus for future remediation or research.

Table 8 below shows the RC Mark II rating for the major occupied and unoccupied spaces within each unit, ignoring corridors and large open spaces. Most (81%) of the locations measured were rated by this method as "objectionable". This objectionable rating is based on the spectral imbalance of the measured space, and is not based on nor related to the level rating. Almost all (90%) of the spaces were "hissy," or dominated by high frequency energy content.

Table 8: RC Mark II Ratings by Location (Nurses' Station, Occupied Patient Room, and Unoccupied Patient Room) in Each Unit in the Three Hospitals

Unit	Hospital	Location	RC Mark II Rating		
			Level Rating	Spectral Imbalance	Occupant Evaluation *(spectral, not level)*
ED	3	Nurses' Station	RC -56	QAI 14 Hissy	Objectionable
	3	Unocc. Room	RC-56	QAI 10.9 Hissy	Objectionable
	2	Nurses' Station	RC-54	QAI 15 Hissy	Objectionable
	2	Occ. Room	RC-48	QAI 19.7 Hissy	Objectionable
	2	Unocc. Room	RC-35	QAI 9.6 Hissy	Marginal
	1	Nurses' Station	RC-56	QAI 20.6 Hissy	Objectionable
	1	Occ. Room	RC-51	QAI 17.8 Hissy	Objectionable
	1	Unocc. Room	RC-51	QAI 13.9 Hissy	Objectionable
ICU	3	Nurses' Station	RC-49	QAI 9.1 Hissy	Marginal
	3	Occ. Room	RC-51	QAI 14 Hissy	Objectionable
	3	Unocc. Room	RC-38	QAI 7.3 Rumbly	Marginal
	2	Nurses' Station	RC-51	QAI 16.6 Hissy	Objectionable
	2	Occ. Room	RC-49	QAI 20 Hissy	Objectionable
	2	Unocc. Room	RC-39	QAI 3.8 Rumbly	Marginal
	1	Nurses' Station	RC-49	QAI 12.7 Hissy	Objectionable
	1	Occ. Room	RC-53	QAI 18 Hissy	Objectionable
	1	Unocc. Room	RC-53	QAI 19.6 Hissy	Objectionable
IP	3	Nurses' Station	RC-58	QAI 19.4 Hissy	Objectionable
	3	Occ. Room	RC-53	QAI 18.7 Hissy	Objectionable
	3	Unocc. Room	RC-55	QAI 19.1 Hissy	Objectionable
	1	Nurses' Station	RC-51	QAI 17.9 Hissy	Objectionable
	1	Occ. Room	RC-44	QAI 17.5 Hissy	Objectionable
	1	Unocc. Room	RC-45	QAI 12.4 Hissy	Objectionable
	2	Nurses' Station	RC-53	QAI 22.2 Hissy	Objectionable
	2	Occ. Room	RC-45	QAI 14.6 Hissy	Objectionable
	2	Unocc. Room	RC-38	QAI 8.9 Hissy	Marginal
	2	Nurses' Station	RC-54	QAI 21 Hissy	Objectionable
	2	Occ. Room	RC-48	QAI 31.1 Hissy	Objectionable
	2	Unocc. Room	RC-57	QAI 27.3 Hissy	Objectionable
MB	2	Nurses' Station	RC-53	QAI 18.2 Hissy	Objectionable
	2	Occ. Room	RC-47	QAI 14.1 Hissy	Objectionable
	2	Unocc. Room	RC-38	QAI 12.7 Hissy	Objectionable
	1	Nurses' Station	RC-55	QAI 19.4 Hissy	Objectionable
	1	Occ. Room	RC-36	QAI 6.6 Hissy	Marginal
	1	Unocc. Room	RC-40	QAI 14.4 Roaring	Objectionable
SDS	3	Nurses' Station	RC-52	QAI 13 Hissy	Objectionable
	3	Occ. Room	RC-66	QAI 27.1 Hissy	Objectionable
	3	Unocc. Room	RC-39	QAI 10.4 Hissy	Objectionable
	1	Nurses' Station	RC-54	QAI 17.4 Hissy	Objectionable
	1	Occ. Room	RC-53	QAI 19.6 Hissy	Objectionable
	1	Unocc. Room	RC-39	QAI 8.9 Hissy	Marginal

Some of the additional trends observed were that all locations measured in ED, ICU and SDS environments had hissy background noise. In addition, Hospitals 2 and 3 had unoccupied ICU rooms that would be perceived as being spectrally marginal. At least one space within each unit type would be rated as spectrally marginal, and even two occupied spaces (Hospital 2 MB occupied room, and Hospital 3 Nurses' station) would be perceived as spectrally marginal.

The exact implication of a "hissy" environment is not entirely known. However, the fact that 90 percent of the units were "hissy" is of concern, as previous research has shown that perception of hiss in background noise can negatively influence task performance, even in simple office tasks (Bowden & Wang, 2007). Generally, spectral imbalance of any kind is thought to negatively impact occupants (Wang & Bowden, 2006). In addition to the RC Mark II offering spectral content analysis, there is also evidence of a high degree of tonality (not many discrete tones present) due to the wide range of RC ratings within the same hospital.

Conformance with Guidelines

The ANSI S12 WG44 standard provides some recommendations based on the type of location, shown in Table 9 (American National Standards Institute, 2010). As with WHO, these guidelines are more geared towards ***unoccupied*** spaces with the exception of the nursery, where some guidance for occupied levels are provided as noted.

Table 9: Recommended ANSI A-weighted equivalent sound pressure levels (LAeq) for non-occupant noise in interior spaces [adapted from references [American National Standards Institute, 2008, 2010; ASHRAE, 2011)].

Location type in this study	Equivalent location type in ANSI guidelines	Recommended LAeq in ANSI guidelines (dBA)	Measured Occupied LAeq in this study (dBA)
Nurse Station	Corridors and public spaces	40-50	55-62
Occupied Patient / Treatment	N/A	N/A	50-71
Unoccupied Patient / Treatment	Patient rooms	35-45	44-54
Corridor	Corridors and public spaces	40-50	54-59
Waiting Area		40-50	43-59
Occupied Nursery	NICU[1]	30-40	55
Unoccupied Nursery	N/A	N/A	52
Ambulance Bay	N/A	N/A	60

Notes: [1]NICU building mechanical noise levels were set for compliance with AIA requirements when added to NICU activity noise (American National Standards Institute, 2010).

ASHRAE and the UFC also provide unoccupied recommendations based on the type of location (ASHRAE, 2011; United States Department of Defense, 2009). Although ANSI S12 WG 44 aimed to incorporate the primary ASHRAE recommendations, but ASHRAE does actually specify an additional criteria not contained in ANSI: LCeq (dBC). The UFC specifies an NC level. In this study, the only unoccupied spaces that were easily accessible were patient / treatment rooms. Thus, the general recommendations for the unoccupied spaces measured in this study are (American National Standards Institute, 2010; ASHRAE, 2011; United States Department of Defense, 2009):

- UFC: NC = 30-35
- ANSI: LAeq = 35-45 dBA; NC/RC(N) = 30-40
- ASHRAE: LAeq = 35 dBA; LCeq = 60 dBC; NC/RC(N) = 30

The LAeq, LCeq, NC, and RC Mark II values for the unoccupied spaces measured in this study are provided in Table 10.

Table 10: Measured A- and C-weighted equivalent (LAeq, LCeq), Noise Criteria (NC), and Room Criteria (RC) Mark II values for unoccupied spaces. Spaces meeting the various guidelines are highlighted. (ED – Emergency Department, ICU – Intensive Care Unit, IP – Inpatient Unit, SDS – Same Day Surgery Unit, MB – Mother/Baby Unit).

Hospital	Unit	Values Measured in this Study				
		LAeq (dBA)	LAeq Std. Dev (dBA)	LCeq (dBC)	NC	RC Mark II
Hospital 3	ED	51	3.34	66	NC-45	RC-56 Hissy
	ICU	44 (ANSI)	2.94	67	NC-37 (ANSI)	RC-38 Rumbly
	IP	57	8.49	64	NC-61	RC-55 Hissy
	SDS	45 (ANSI)	3.62	62	NC-41	RC-39 Hissy
Hospital 2	ED	42 (ANSI)	2.63	55 (ASHRAE)	NC-35 (UFC,ANSI)	RC-35 Hissy
	ICU	47	0.62	63	NC-42	RC-39 Rumbly
	IP (5E)	62	7.4	65	NC-57	RC-57 Hissy
	IP (5C)	43 (ANSI)	2.24	54 (ASHRAE)	NC-37 (ANSI)	RC-38 Hissy
	MB	44 (ANSI)	2.99	53 (ASHRAE)	NC-37 (ANSI)	RC-38 Hissy
Hospital 1	ED	57	2.99	66	NC-53	RC-51 Hissy
	ICU	54	5.18	61	NC-53	RC-53 Hissy
	IP	50	2.29	58 (ASHRAE)	NC-44	RC-45 Hissy
	MB	46	1.19	58 (ASHRAE)	NC-47	RC-40 Roaring
	SDS	58	2.28	64	NC-39 (ANSI)	RC-39 Hissy

Regardless of the guideline or metric used, very few spaces meet the criteria (44% maximum). The general non-compliance of these unoccupied spaces can be interpreted in several ways: being that the recommended levels are unreachable, the HVAC systems or another noise source contributed largely to this non-conformance. Regarding the second point, it should be noted that it is extremely difficult to fully isolate noise from HVAC systems in a busy hospital. Another approach is to utilize percentile levels, which provide insight into the steady (e.g. HVAC) versus impulsive (e.g., occupants) types of sounds. The L10 is more indicative of impulsive sounds (e.g., alarms, doors closing, clanging objects on metal trays, dropping items), whereas the L90 is more indicative of steady background noise from HVAC systems. The L90 is therefore particularly interesting for unoccupied spaces, where the primary noise source should be HVAC noise.

Impulse Response Measurement Metrics

From the IR measurements, the calculated reverberation time tells about the energy decay of the measured space. Reverberation times will be presented first by hospital (Figure 33), then averaged by unit type (Figure 34), and by location type within each type of unit (Figures 35-39).

The overall average reverberation times for each hospital across frequency are shown in Figure 28. The times shown are averaged across all unit types and locations. The times are relatively short for all hospitals (< 0.7 seconds), which is desired for speech intelligibility and overall noise reduction. It can also be seen that the reverberation is somewhat lower in Hospitals 1 and 2.

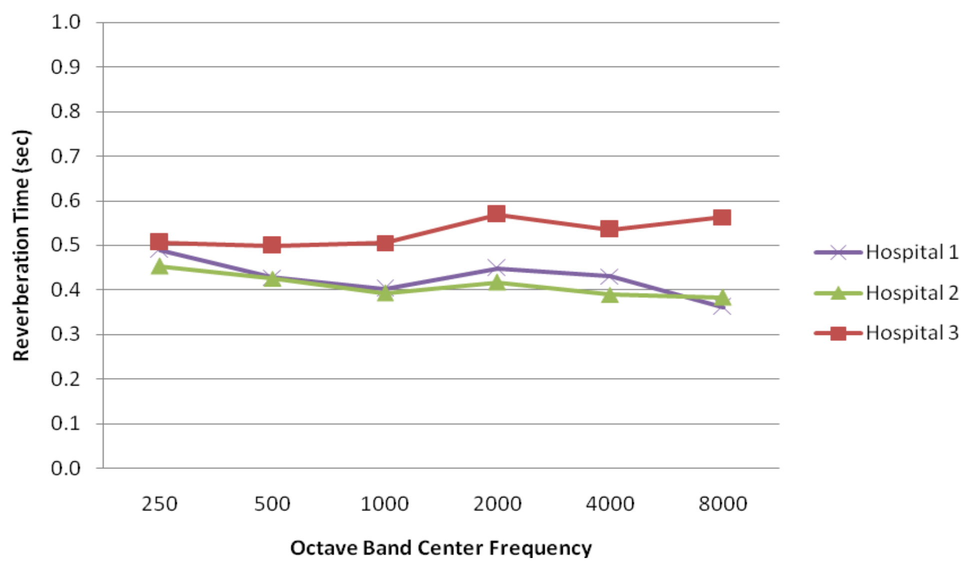


Figure 33: Reverberation time (RT) values by hospital (averages across unit types and locations).

The overall average reverberation times (RT) for each type of unit across frequency are shown in Figure 34. The results shown are averaged across all hospitals and locations (e.g., NS, Pat). The times are relatively short for all types of units (< 0.6 seconds), which is desired for speech intelligibility. It can also be seen that the reverberation is somewhat higher in the ED and SDS unit types, which could negatively impact speech intelligibility.

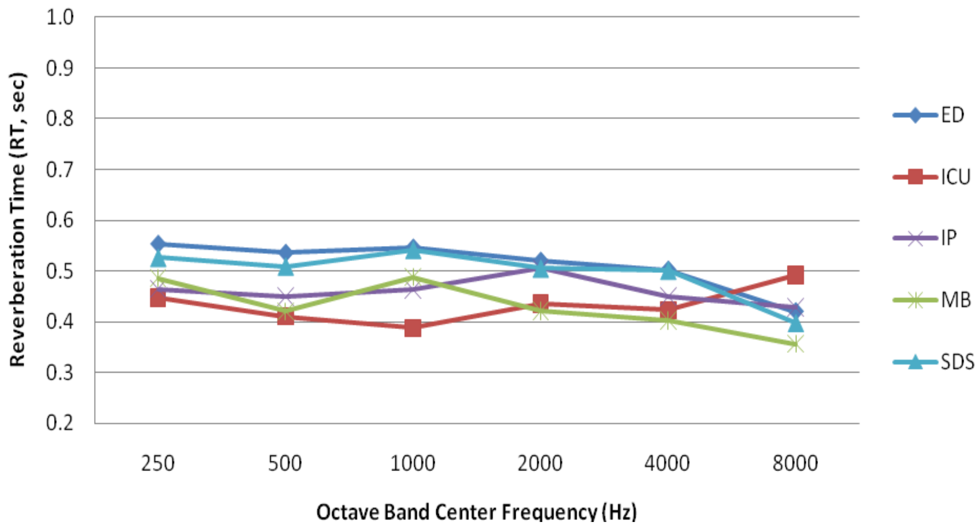


Figure 34: Reverberation time (RT) values by unit type (averaged across hospitals and locations). Shown are the Emergency Departments (ED), Intensive Care (ICU), Med./Surg. Inpatient (IP), Mother/ Baby (MB), and Same Day Surgery Units (SDS).

With the reverberation time keeping within an acceptable range across frequencies, it can be learned that this reverberation pattern across frequency is not influenced too much, or distorted. This quantization of the spectral content of the measured locations tells a significant amount about the acoustic spectral pattern.

The overall average reverberation times (RT) across frequency for each type of location are shown in Figure 35 through Figure 39. Because reverberation time is commonly presented across frequency and due to the number of locations measured, separate graphs are presented for each type of unit. The times shown are averaged across all hospitals. Generally, the reverberation times were longest in the nurses' stations and corridors, though this varied somewhat by unit. This makes sense based on the volumes and surface materials in these spaces. The nurses' stations and corridors are relatively large volumes (because they are coupled to other spaces) and usually have minimal absorption.

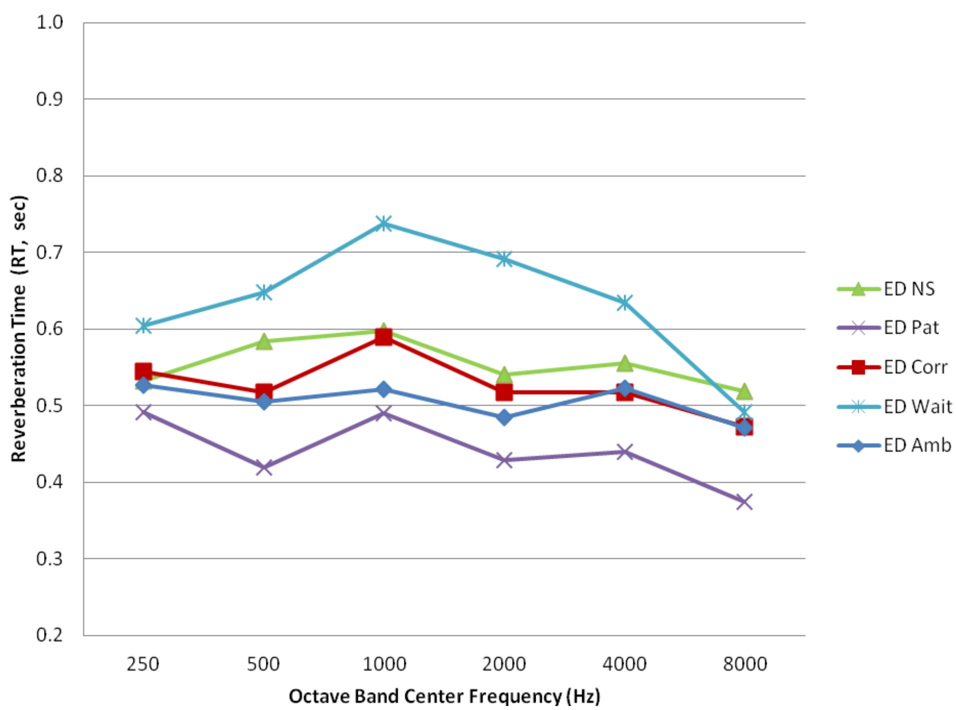


Figure 35: Reverberation time (RT) values by type of location (averaged across hospitals) for the Emergency Departments. Shown are the Nurses' Stations (NS), occupied patient rooms (Pat), Corridors (Corr), waiting rooms (Wait), and Ambulance Bays (Amb).

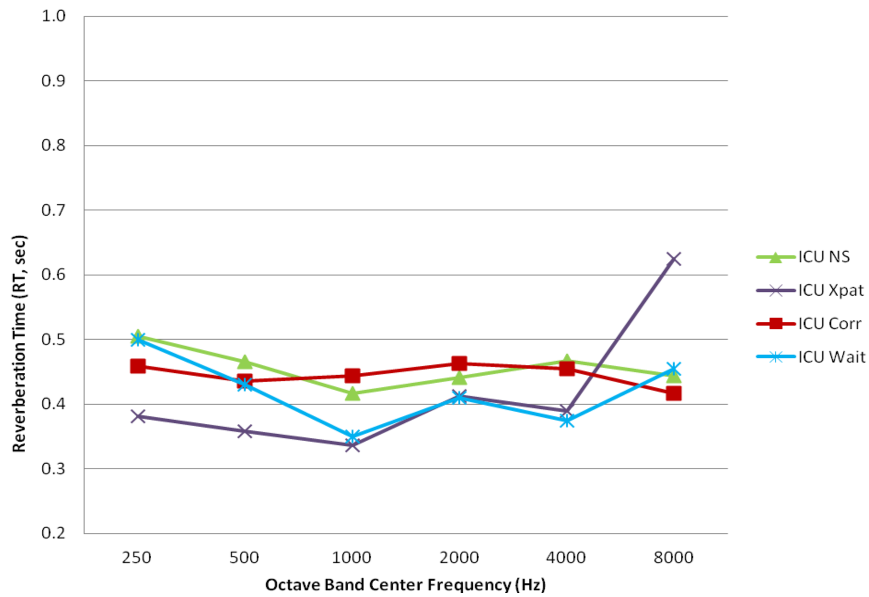


Figure 36: Reverberation time (RT) values by type of location (averaged across hospitals) for the Intensive Care Units. Shown are the Nurses' Stations (NS), unoccupied patient rooms (XPat), Corridors (Corr), and waiting rooms (Wait).

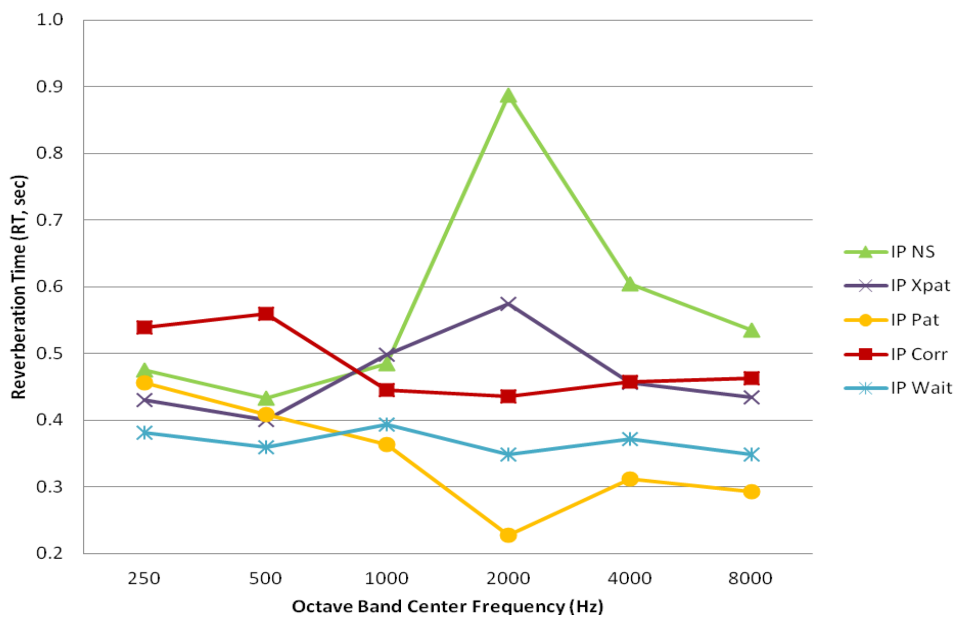


Figure 37: Reverberation time (RT) values by type of location (averaged across hospitals) for the Medical/Surgical Inpatient Units. Shown are the Nurses' Stations (NS), occupied patient rooms (Pat), unoccupied patient rooms (XPat) Corridors (Corr), and waiting rooms (Wait).

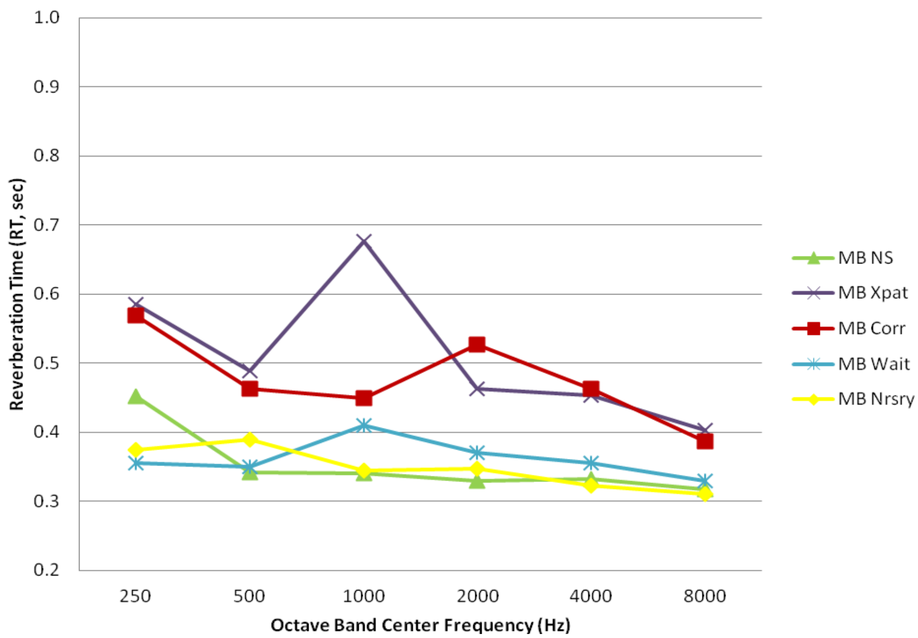


Figure 38: Reverberation time (RT) values by type of location (averaged across hospitals) for the Mother/Baby Units. Shown are the Nurses' Stations (NS), Occupied Nurseries (Nrsry), unoccupied patient rooms (XPat) Corridors (Corr), and waiting rooms (Wait).

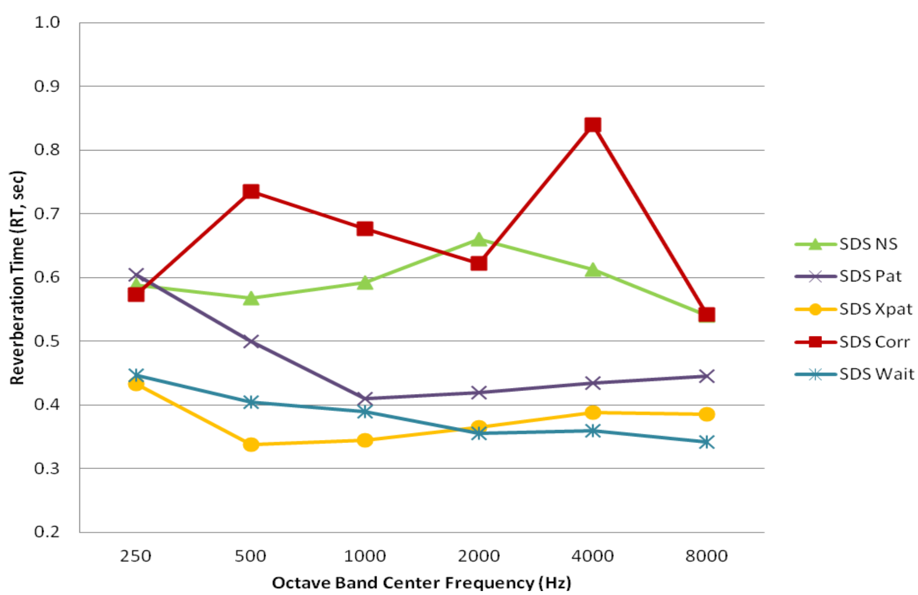


Figure 39: Reverberation time (RT) values by type of location (averaged across hospitals) for the Same-Day Surgery Units. Shown are the Nurses' Stations (NS), occupied patient rooms (Pat), unoccupied patient rooms (XPat) Corridors (Corr), and waiting rooms (Wait).

A summary of the reverberation times at 500 Hz for each hospital by unit type is shown in Figure 40. From the RT analysis, it is apparent that all units are relatively "dry," meaning that they have relatively low reverberation times (< 0.7 sec). Within all ED units, the materials used in construction were similar, so no noticeable difference can be identified relating to material selection. In the ICU units, hospitals 1 and 3 had roughly the same averaged RT, which can be attributed to a similar material selection in walls and ceiling. In hospital 2 ICU, however, concrete walls, and harder wall surfaces were used, which would account for the longer reverberation times. Within the hospital 2 IP, the lower reverberation time was most likely caused by carpet flooring in the entire unit and the use of a higher air gap in the suspended ceiling tiles. Hospital 1 and 3 IP units had a similar average reverberation time, which makes sense, as they had similar wall and ceiling material selection. There was no noticeable difference in material selection in the MB units of hospital 1 and 2, nor was there any noticeable difference in material selection in hospital 1 and 3 SDS units that would account for the similar energy decay properties.

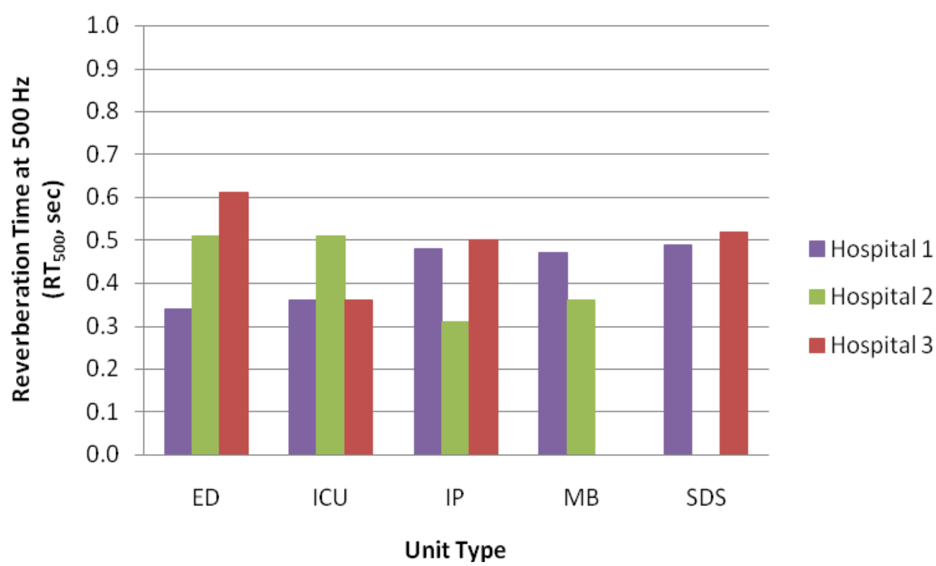


Figure 40: Reverberation time at 500 Hz (RT500) by hospital and type of unit (averaged across location type)

Although the types of surface materials appear to have some relationship to the reverberation times presented in the analysis above, other factors seem to influence reverberation time greatly. For example, the variation in volume of the measured spaces can have a huge effect on the calculated reverberation time, as discussed in the methodologies section of this thesis. Also, the unit design (e.g. single corridor, racetrack) could also have had a large impact on the average reverberation times measured in the units.

Speech Intelligibility Index (SII) Levels

SII is presented overall by hospitals, then by unit and location within each unit to quantize and identify the areas that may require further development in future studies.

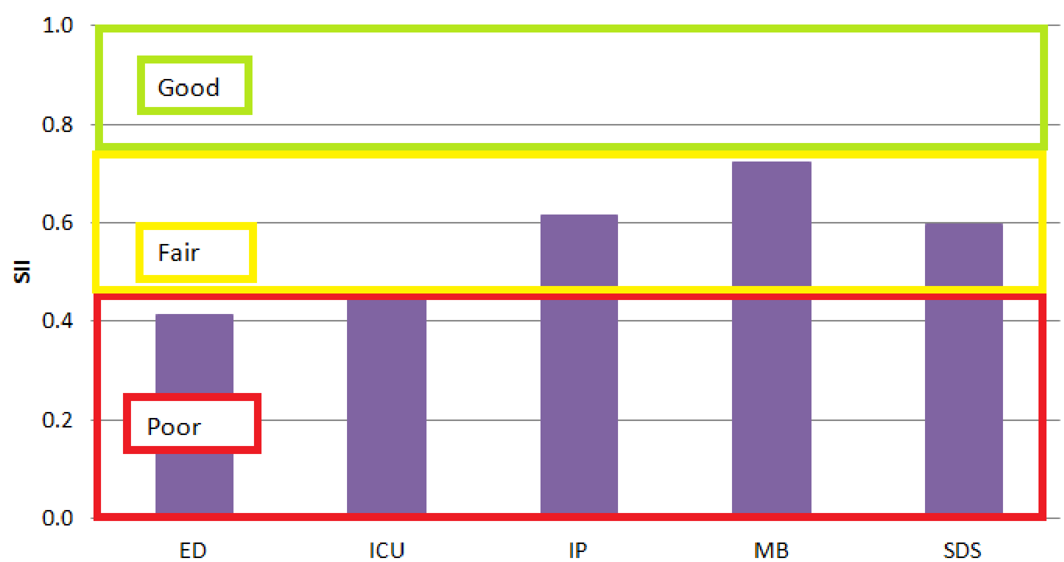


Figure 41: SII averaged by unit type in Hospital 1. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0). (ED – Emergency department, ICU – Intensive Care Unit, IP – Med/Surg Inpatient unit, MB – Mother/Baby Unit, SDS – Same Day Surgery Unit)

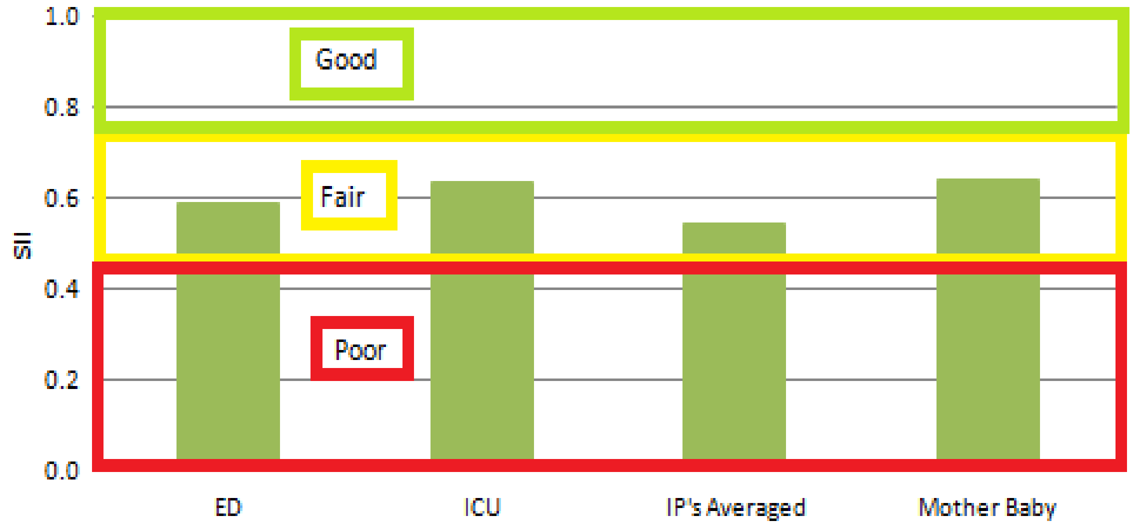


Figure 42: SII averaged by unit type in hospital 2. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0).

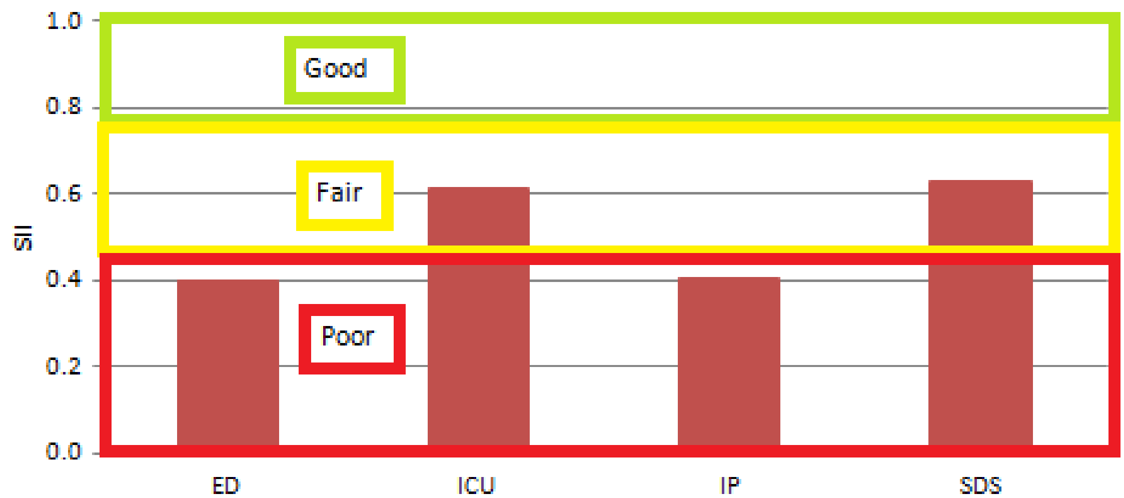


Figure 43: SII averaged by unit type in hospital 3. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0).

Figures 41-43 indicate the unit-averaged SII for each of the hospitals studied. As can be seen, there are no units that would be qualified as having "good" overall speech intelligibility.

In addition, it becomes interesting that Inpatient units and Emergency departments in the three hospitals have the lowest speech intelligibility index values. This indicates that there may be an excessive amount of talking, moving patients, or commotion in those units. However, as mentioned above, there is no true insight into the locations within each unit that may be problematic when results are averaged across location. Figures 44-46 below, as well as Appendix A, show the full SII picture across unit type and unit specific locations.

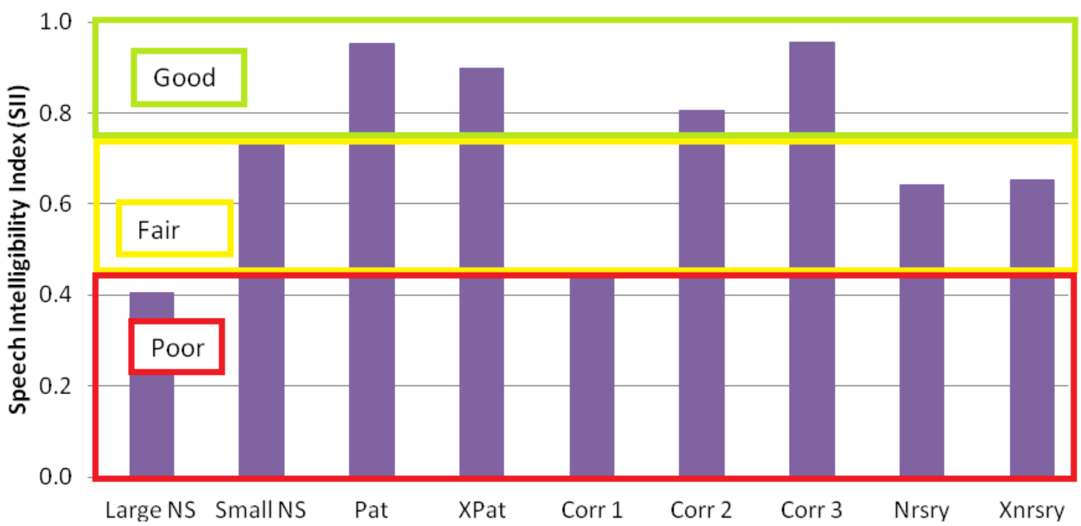


Figure 44: SII shown by location in hospital 1 Mother Baby unit. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0). Locations shown: NS – Nurses' Station, Pat – Occupied patient room, XPat – Unoccupied patient room, Corr – Corridor, Wait – Waiting room, Nrsry – Occupied Nursery, XNrsry – Unoccupied Nursery

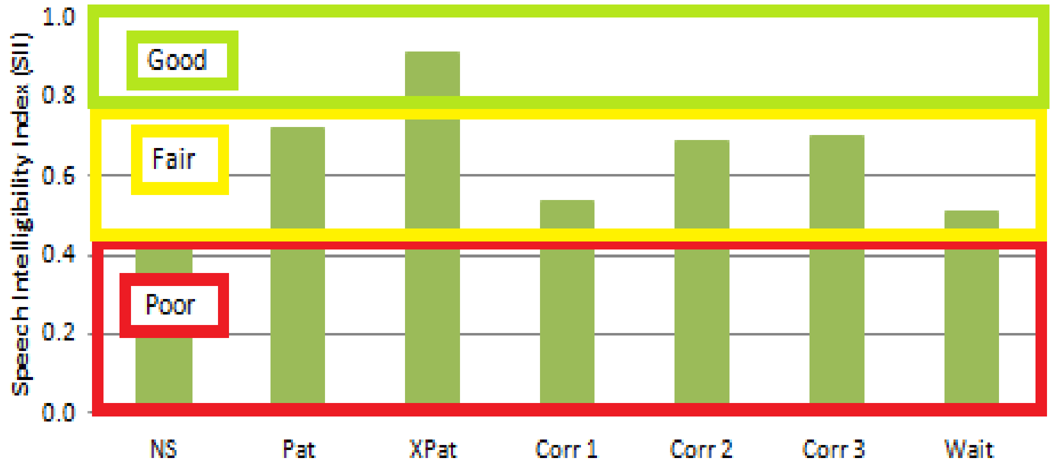


Figure 45: SII shown by location in hospital 2 MB unit. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0).

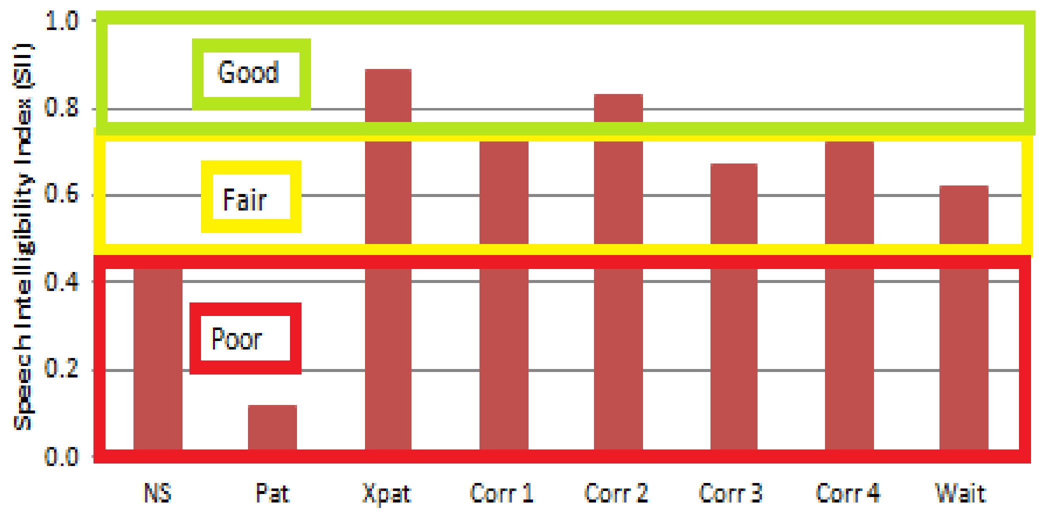


Figure 46: SII shown by location in hospital 3 SDS unit. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0).

As can be seen from Figure 46, the overall speech intelligibility of hospital 3 is in the fair range (0.4-0.6). Upon further analysis, there were differences between types of locations. For example, unoccupied treatment rooms had higher SII, and nurses' stations had lower SII. The SII levels in the nurse' stations analyzed were averaged to be near 0.4 (in the poor range), which is detrimental to communication. This is especially important to note, because critical information regarding patient care is often communicated in these spaces.

Survey Data Analysis: Staff Perception

Staff Respondent Demographics

Seventy total ward staff responded to the survey; 13 from hospital 3, 17 from hospital 2, and 40 from hospital 1. The respondent demographics are presented in Figure 47- Figure 48. Age was split into 6 categories, and as shown in Figure 47 the most common age of respondents was 18-29 (41%), followed by age 30-39 (23%). Very few (10%) of respondents were 60 years or older. Staff were also asked, "How many years have you worked in the kind of department to which you are now primarily assigned during your entire career?" with responses split into 4 categories; less than 1 year, 1-5 years, 6-10 years and 11 or more years. The majority of staff had worked for 1-5 years total in a similar type of unit during their entire career (41% Figure 48).

Additional information about the respondents in particular hospitals and units is shown in Table 11. The percent of full-time nurses (F.T.N.) respondents is shown; the remaining percent were part-time nurses, clerks, or other. The majority of staff worked day shifts or combination shifts and 79% of respondents were female.

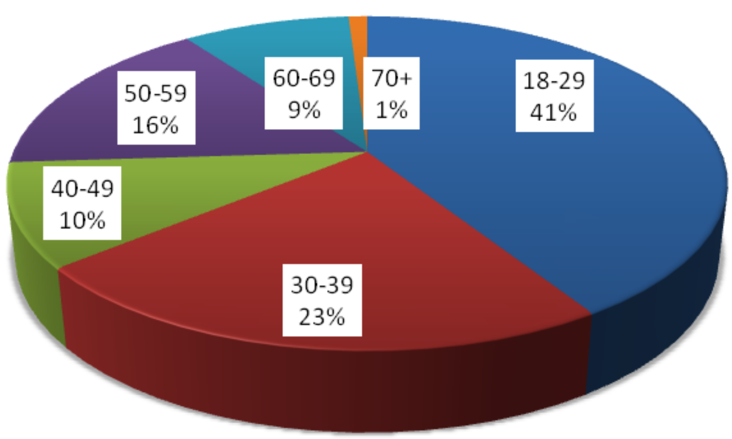


Figure 47: Percentage of staff respondents in each age category

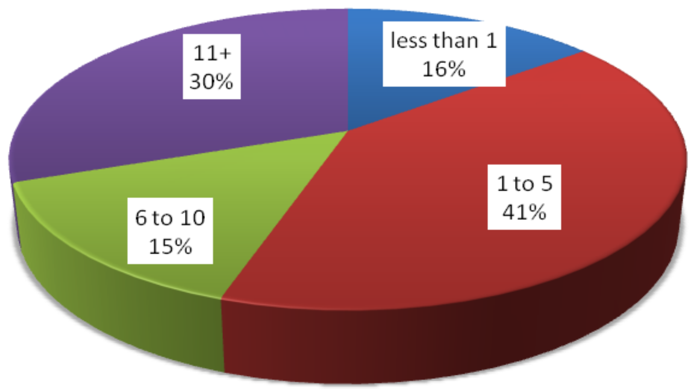


Figure 48: Percentage of staff respondents in each category of 'number of years working in current unit [ED, ICU, etc.] in entire career'. One staff member declined to answer

Table 11: Staff survey respondent demographics

Hospital ID	Demographic	Unit				
		ED	ICU	IP	MB	SDS
Hospital 3	Gender [% female]	67%	88%	100%	–	–
	% Full-time nurses	67%	100%	50%	–	–
	Typical Work Shift [%Day/Night/Combo]	27/27/45%	27/27/45%	36/27/36%	–	–
	Total Respondents	3	8	2		
Hospital 2	Gender [% female]	45%	–	100%	50%	–
	% Full-time nurses	38%	–	100%	67%	–
	Typical Work Shift [%Day/Night/Combo]	46/0/54%	–	30/20/50%	42/8/50%	–
	Total Respondents	9	–	2	6	–
Hospital 1	Gender [% female]	90%	50%	75%	100%	100%
	% Full-time nurses	44%	100%	83%	83%	75%
	Typical Work Shift [%Day/Night/Combo]	57/0/43%	42/42/17%	50/14/36%	38/38/23%	54/15/31%
	Total Respondents	10	2	12	12	4
	Total Respondents	22	10	16	18	4

Staff Perception of the Sound Environment

The basic staff perceptions of overall noise in their units are shown in Figure 49 and Figure 50. In Figure 49, the respondents are summed across all types of units. Most staff perceived their departments as "moderately noisy." The difference in perception between hospitals was not statistically significant. However, in general, hospital 1 appeared to be perceived as a bit less noisy (mean rating between "a little" to "moderately noisy"), whereas hospital 3 was perceived as the most noisy (mean rating between "moderately" to "quite" noisy).

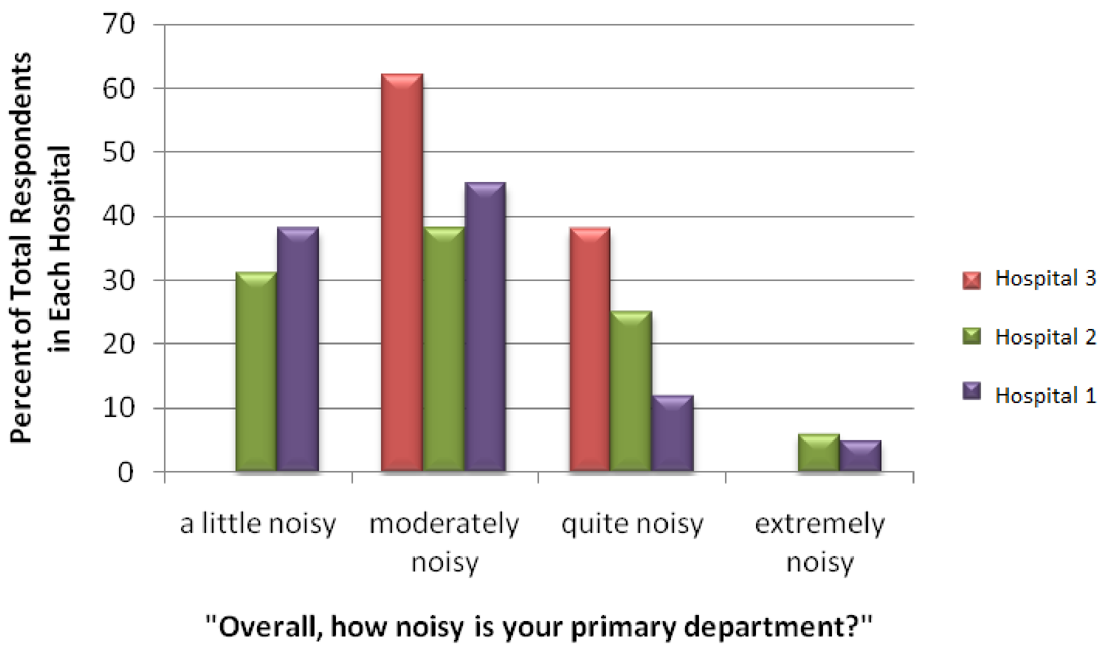


Figure 49: Staff perception of overall noise in their units, presented for each hospital

In Figure 50, the respondents are summed across all hospitals. The differences between units were statistically significant overall with a medium effect size [($F(4,65)=2.86$, $p<0.05$, $r=0.39$]. Noise was perceived as highest in the SDS, ED, and ICU ("moderately" to "quite noisy") and somewhat quieter in the IP and MB ("a little" to "moderately" noisy).

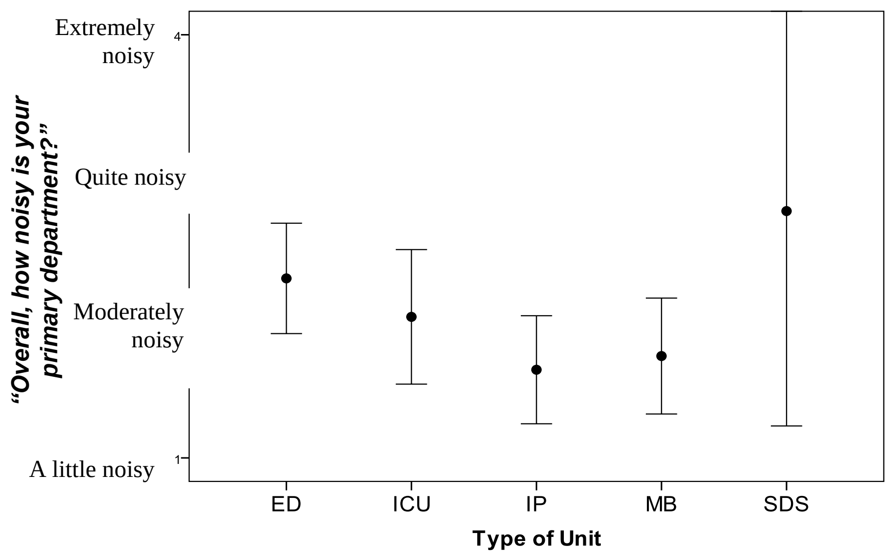


Figure 50: Staff perception of overall noise in their units, presented for each type of unit. Mean noise ratings are shown with 95% confidence interval bars

A small percentage (7.1%) reported that they had a diagnosed hearing impairment, but over 25% reported that they had difficulties understanding speech in noisy environments. Despite this, most subjects reported that they felt that their hearing was "normal" (24.3%) or "good to very good" (65.7%).

Staff Health

Each subject was asked 12 questions related to their health. The aggregate results are shown in Figure 51 for all ward staff surveyed. The first two bars show an overall physical component summary (PCS) score and a mental component summary (MCS) score. Next, eight health domains (four physical and four mental) were calculated from the responses. The domains are ordered, from left to right, as physical health (PF), the role of physical health (RP), bodily pain (BP), general health (GH), vitality (VT), social functioning (SF), the role of emotional health (RE), and mental health (MH). To calculate the various scores, responses to the 12 individual questions were summed into each score according to pre-specified weights that are based on the U.S. general population (Lim & Fisher, 1999). A score of 50 is designated as the mean of the general U.S. population. The aggregate scores from all the staff surveyed were close to or above the national average on all physical and mental domains, indicating relatively normal health for the staff subject population.

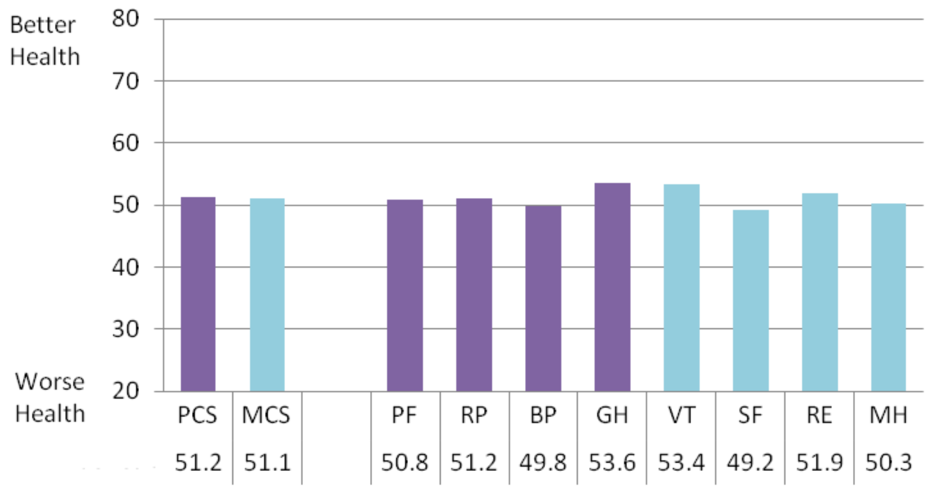


Figure 51: Aggregate staff physical and mental health scores

Survey Data Analysis: Patient and Visitor Perception

Respondent Demographics

Twenty-five patients responded to the survey; 5 from hospital 3, 1 from hospital 2, and 18 from hospital 1. Eighty-three visitors responded to the survey; 33 from hospital 3, 12 from hospital 2, and 38 from hospital 1. The respondent demographics are presented in Figures 52-54. Age was split into 6 categories, and, as shown in Figure 52, three categories were equally common for patients (18-29, 50-59, and 60-69); all at 21%. Very few (5%) of respondents were 70 years or older.

Patients were also asked, "How many days have you been in the hospital?" As shown in Figure 53, almost half of the patients had been in the hospital for 2-3 days at the time of the survey (44%). Similarly, visitors were asked, "How many days have you visited or accompanied the patient in this unit?" As shown in Figure 54, the majority of the visitors had been visiting the unit for 1 day at the time of the survey (60%). Additional information about the respondents in particular hospitals and units is shown in Table 12 and Table 13. For the patients, 44% of respondents were male and 56% were female. For the visitors, 39% of respondents male and 61% were female.

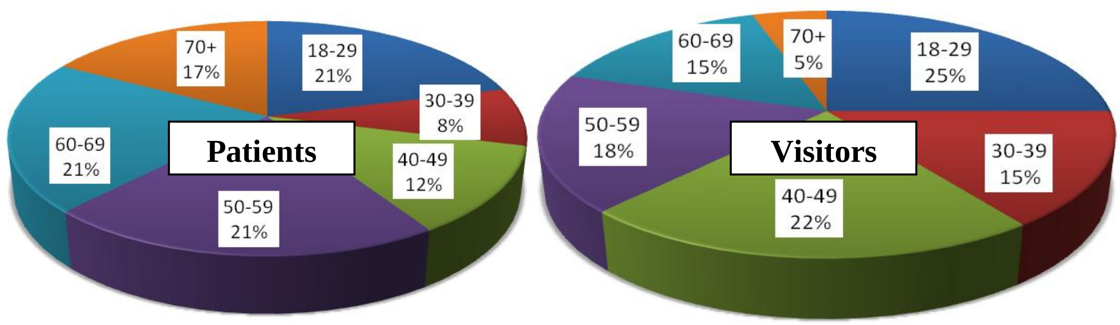


Figure 52: Percentage of patient (top) and visitor (bottom) respondents in each age category. One patient and four visitors declined to answer

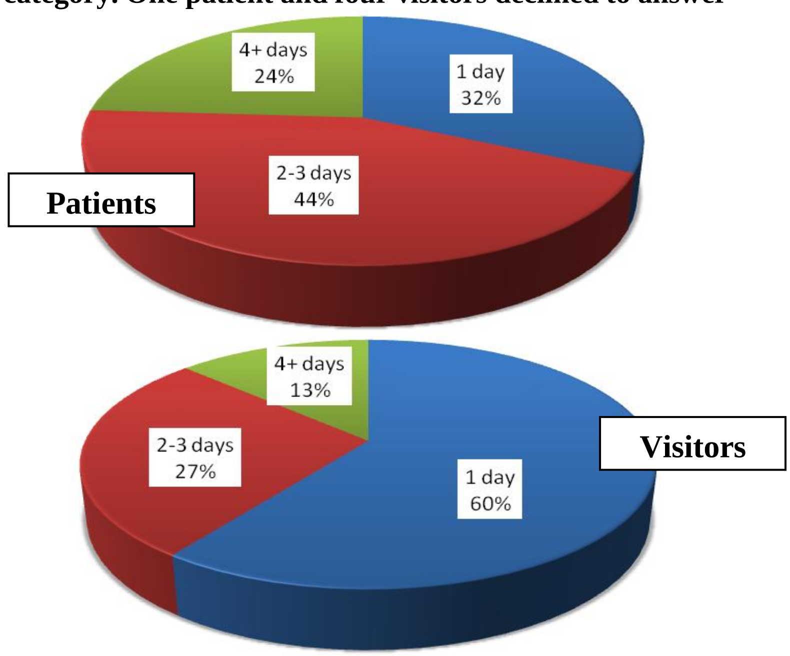


Figure 53: Percent of patient (top) and visitor (bottom) respondents in each category of 'how many days have you been in/visiting this hospital?' One visitor declined to answer.

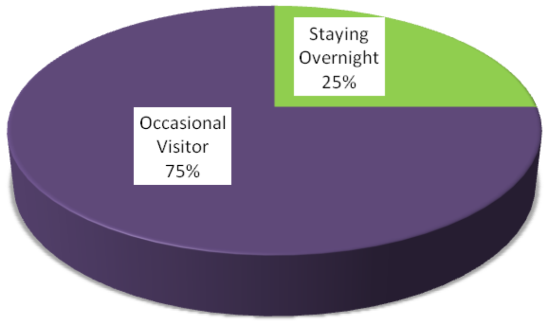


Figure 54: Percent of visitor respondents in each category of 'Are you staying overnight or an occasional visitor?' Two visitors declined to answer

Table 12: Patient survey respondent demographics

Hospital ID	Demographic	Unit[1]				
		ED	ICU	IP	MB	SDS
3	Gender [% female]	–	0%	75%	–	–
	Total Respondents	–	1	4	–	–
2	Gender [% female]	–	–	0%	–	–
	Total Respondents	–	–	1	–	–
1	Gender [% female]	33%	50%	50%	100%	50%
	Total Respondents	3	2	4	5	4
	Total Respondents	3	3	9	5	4

Notes: [1]one patient at hospital 3 did not indicate their unit. (ED – Emergency Department, ICU – Intensive Care unit, IP – Med/Surg Inpatient unit, MB – Mother/Baby unit, SDS – Same Day Surgery unit)

Table 13: Visitor survey respondent demographics

Hospital ID	Demographic	Unit[1]				
		ED	ICU	IP	MB	SDS
3	Gender [% female]	0%	73%	61%	–	50%
	% staying overnight	0%	33%	46%	–	0%
	Total Respondents	2	15	13	–	2
2	Gender [% female]	0%	50%	40%	50%	–
	% staying overnight	0%	0%	80%	50%	–
	Total Respondents	3	2	5	2	–
1	Gender [% female]	67%	–	67%	50%	78%
	% staying overnight	0%	–	33%	100%	0%
	Total Respondents	21	–	6	2	9
	Total Respondents	26	17	24	4	11

Notes: [1]one visitor at hospital 3 did not indicate their unit

Perception of the Sound Environment

Although these results provide some insight, the knowledge gained is somewhat limited for patients in particular due to the small sample size. Patient and visitor perception of noise-induced sleep disturbance is shown in Figure 55. Somewhere between a quarter to a third (24 to 33%) of both patients and visitors agreed that the noise was disruptive to sleep or that it increased anxiety. This large percentage is problematic as it suggests that nearly 30% of patients and visitors are disrupted by at least one aspect of this noise environment.

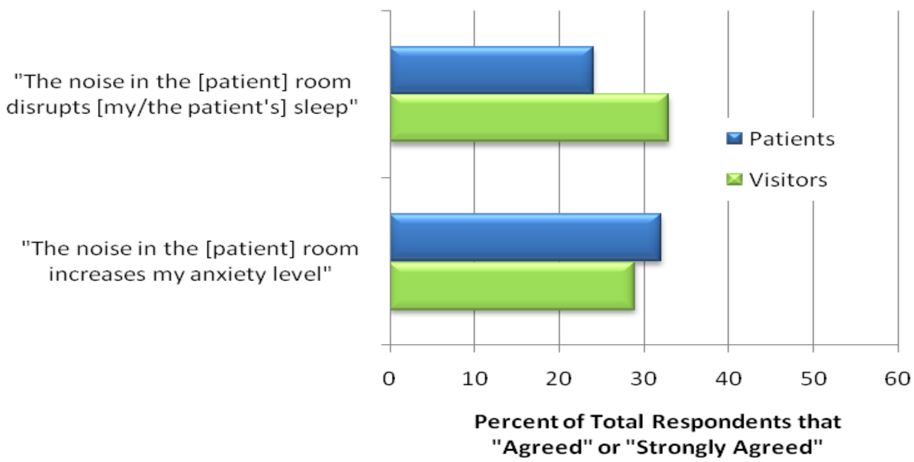


Figure 55: Patient and visitor perception of noise-induced sleep disturbance and anxiety (composite of all hospitals and units).

Patients and visitors were also asked, “How easily can you hear [visitors / the patient] and caregivers when they speak to you?” As shown in Figure 56, most subjects reported that it was very easy or easy to hear. These results could be interpreted in a couple of ways. First, it indicates that the speech intelligibility was probably high at locations where conversations between patients / visitors and caregivers were taking place, such as at patient bedsides or in waiting rooms. Secondly, because very few reported that it was “difficult” or “very difficult” to hear, it is possible that this population did not have significant hearing impairments. It would be preferred to ask subjects directly about their hearing impairments, but unfortunately this was not allowed in this study.

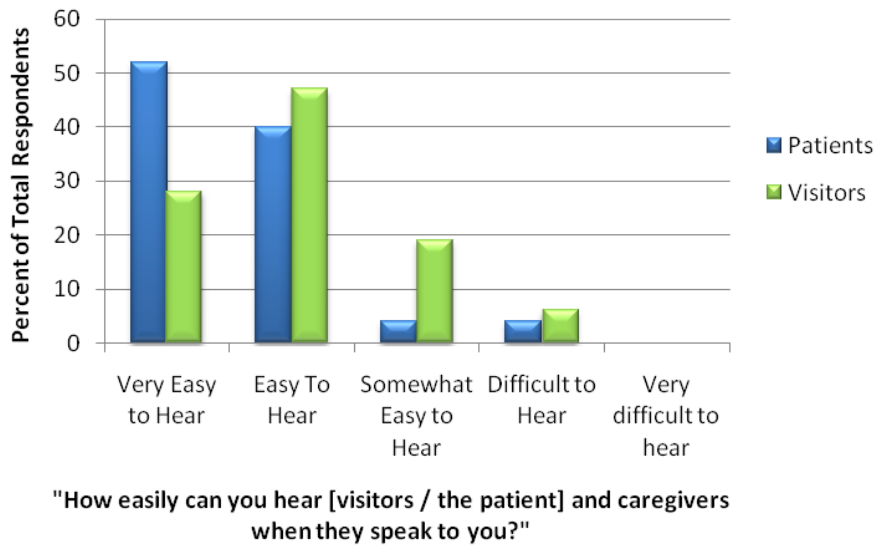


Figure 56: Patient and visitor perception of speech intelligibility

The responses to the items above (noise-induced sleep disturbance, anxiety, speech intelligibility perception) were not significantly different across hospitals or type of unit.

Perception of specific Sound Sources

All respondents were asked how annoying (if at all) they found specific noise sources to be. Factor analyses with varimax rotation were run to determine if the various noise sources could be combined into more general, overall categories. Staff were asked about a slightly different set of noise sources than patients and visitors, in accordance with the types of noises they were likely to encounter.

The staff's perception of noise sources was reduced to five factors explaining 77.4% of the variance, for which the results are shown in Table 14. The five factors derived were named “Human activity sounds”, “Human speech, bodily sounds”, “Patient monitoring sounds”, “Building systems and service sounds”, and “Hospital communication, procedure sounds” to categorize the noise sources into overall factor categories. One item “noise from bed” corresponded with multiple factors and is not included in Table 14.

Table 14: Results of staff noise source perception factor analysis

Questionnaire Item	Factor Number 1	2	3	4	5	Name of Factor
TV	0.88	0.21	0.03	0.18	-0.06	Human activity sounds
Footsteps	0.82	0.17	0.17	0.18	0.05	
Exterior noise from outside hospital	0.79	-0.05	0.08	0.11	0.17	
Falling objects	0.77	0.01	0.24	0.15	0.24	
Toilets flushing	0.67	0.37	0.04	0.34	0.36	
Doors	0.57	0.24	0.14	0.35	0.28	
Visitor Conversation	-0.02	0.86	0.06	0.25	0.14	Human speech, bodily sounds
Other visitor sounds (e.g., coughing, laughing)	0.27	0.83	0.18	0.08	0.17	
Patient sounds (e.g., coughing, snoring)	0.26	0.72	0.23	0.07	0.41	
Staff Conversation	0.08	0.69	0.42	0.11	-0.22	
Beeping patient monitoring devices	0.07	0.14	0.92	0.18	0.08	Patient monitoring sounds
Operational sounds of medical equipment	0.24	0.15	0.80	-0.04	0.23	
Alarms on medical equipment	0.10	0.33	0.78	0.31	0.24	
Cleaning equipment	0.23	-0.03	0.29	0.82	-0.08	Building systems & service sounds
HVAC	0.28	0.31	0.02	0.74	0.13	
Rolling medicine / linen carts	0.30	0.24	-0.03	0.72	0.41	
Paging System	0.21	0.09	0.24	0.30	0.75	Hospital communication, procedure sounds
Emergency procedures	0.10	0.10	0.48	-0.21	0.55	
Telephone ringing and conversation	0.40	0.30	0.37	0.38	0.50	
Patient intercom / call	0.31	0.29	0.40	0.40	0.50	

The patient and visitor’s perception of noise sources was reduced to three factors explaining 70.2% of the variance. The results are shown in Table 15. Interestingly, the three factors for the patient / visitors are quite similar to the staff factors. The first factor in Table 15 (patients and visitors) is merely a combination of the "Human activity sounds" and "Human speech, bodily sounds" derived for staff with the exception of telephone ringing and conversation. The second factor in Table 15 is essentially a combination of the "Patient monitoring" and "Building systems and service sounds" derived for staff. The third factor in Table 15 is comprised of residuals from the "Human activity" category derived for the staff.

Table 15: Results of patient and visitor noise source perception factor analysis

Questionnaire Item	Factor Number			Name of Factor
	1	2	3	
Patient sounds (e.g., coughing, snoring)	0.83	0.28	0.11	Human activity, speech, and bodily sounds
Other visitor sounds (e.g., coughing, laughing)	0.82	0.24	0.18	
Visitor Conversation	0.81	0.23	0.26	
Doors	0.75	0.36	0.11	
Telephone ringing and conversation	0.74	0.29	0.20	
Footsteps	0.64	0.30	0.44	
Staff Conversation	0.64	0.35	0.38	
Noise from nurses' station	0.62	0.48	0.30	
Falling objects	0.53	0.46	0.22	
Rolling medicine / linen carts	0.23	0.86	-0.06	Patient monitoring + Building systems & service sounds
Operational sounds of medical equipment	0.20	0.77	0.24	
HVAC	0.24	0.65	0.43	
Paging System	0.46	0.64	0.24	
Alarms on medical equipment	0.42	0.64	0.14	
Noise from bed (e.g., squeaking, air pumping)	0.49	0.61	0.20	
Cleaning equipment	0.36	0.61	0.35	
Exterior noise from outside hospital	0.19	0.22	0.86	Human activity sounds
TV	0.28	0.13	0.84	

CHAPTER 5

FUTURE RESEARCH: CRITICAL ENVIRONMENTS

The scope of this research was limited only to expanding the database of acoustic and occupant outcome data. Outside of the scope of this work are several clear aspects that need to be evaluated. These aspects include further expanding this database to represent all possible types of hospital wards, not simply a small representation, identifying the particular sources that correlate to occupant annoyance and dissatisfaction, as well as examining the transmission loss of sound and how hospital construction materials affects the transmission of sound; especially around nurses' stations and patient rooms. Another important aspect of the hospital soundscape that needs to be quantified is the tonality of the spaces measured. Once these preliminary aspects of hospitals are identified, a much more rigorous approach will be needed to fully identify the basis of annoyance and job health in these high stress environments to the particular noises and sounds that cause them. Looking at the causation effects beyond the simple correlations will require a high level understanding of this critical environment.

Additional analysis of surveys

Exposure to high noise levels in hospitals and its direct effect also needs to be analyzed. The main (direct) and interaction (indirect) effects of noise levels and job strain on self-reported job satisfaction, organizational commitment, and health need to be investigated by conducting multiple one-way ANOVA tests. The interaction effect indicates that the effect of a predictor variable on an outcome variable differs as a function of another independent variable. The presence of a statistically significant interaction is the indicator of a moderator effect within an ANOVA model (Leather, et al., 2003). In addition, ANOVA and post hoc tests can be used to assess differences in perception across occupant variables such as gender, age, job category, shift, working hours, and noise sensitivity. This can be done in numerous ways, but it is recommended that the predictor (independent) variable be used as the noise level or noise metric corresponding to the room of study, and the outcome (dependent) variable used as the perception of the occupant. Within these tests, it is the recommendation of the researchers that the future research in this area adopt the benchmark by Cohen, and Field and Hole (2003); $r = 0.1$ (small effect); $r = 0.3$ (medium effect); $r \geq 0.5$ (large effect). Several questions were asked to staff, patients and visitors on the questionnaires (Appendix C) that would be important to study for a more accurate and precise occupant evaluation. Some of these questions include speech privacy and intelligibility, job demand, and direct questions about noise sensitivity and source annoyance. Another important factor that needs to be addressed with this data set is to begin linking acoustic parameters with outcomes, and also to incorporate or include a larger database to be able to accurately and adequately determine relationships. With a larger sample size, statistically significant relationships are more likely to emerge.

In addition, research must be conducted to better determine the thresholds for maximum and peak levels in hospitals that occupants can be exposed to. This includes the effects of prolonged exposure to high maximum and peak levels, and the percentage during the day for occupant exposure. If this information is established, it will allow for an accurate depiction of what thresholds are appropriate for inclusion into guidelines.

Database expansion and source identification

It is easy to see the potential impact of expanding this database to all types of units as compared to a representation of each type of unit. Some units that need to be studied including: radiology units, operating rooms, neurology units, pediatric care units, OB/GYN units, psychiatric units among others. Although there are published papers regarding some of these types of units, key acoustic or subjective information if often missing as identified in the gap analysis of Chapter 2. Within these future studies and unit characterizations, there is a need for identification of exact noise sources and their aspects that impact patient health, visitor comfort, job health, or lead to annoyance and other negative effects inside of the work environment. This identification is extremely critical to the staff, patients and visitors as a proper identification will lead to better designed units that will ultimately lead to better patient care.

Transmission Loss and material selection in hospital soundscapes

Material selection is important for hospital design as sound transmission through walls can potentially be burdensome to patients and negatively impact patient recovery. Properly quantizing and improving upon the transmission loss will allow for major noise sources to be reduced through a focused effort of material selection and control. Then future iterations of the EBD (evidence based design) model can be attained as well as incorporated into the regular hospital design process.

Military Hospitals and Soundscapes

This study was the first time that military hospitals were specifically studied. However, no conclusions can be drawn from this research if this particular subset of hospitals needs to be defined under different categories or thresholds. Some reasons for studying these military facilities is for the unique patients and care that is required. As previously mentioned military hospitals often treat PTSD (post-traumatic stress disorder) patients, and they also likely typically treat men and women in higher physical fitness, and those exposed to viruses from countries around the world. In addition, military personnel treated at these facilities suffer combat wounds and are often in combat situations. These situations are often intense periods of short duration and extreme high level noises. Studying this particular patient population and their reactions to the hospital soundscape may prove to be insightful in further military hospital design. Another point is that civilian hospitals may have different working models, care processes, and physical designs that may impact noise levels in various units in a different way than military treatment facilities, but a specific comparison of military and civilian hospitals was beyond the scope of this thesis. Improving upon the current EBD model by researching these various issues will lead to more thorough guidelines and better patient care for hospitals.

CHAPTER 6

CONCLUSIONS

At the beginning of this thesis, the fourfold purpose of this study was established:

a. to measure and describe the acoustic environment completely and accurately using traditional and novel acoustic metrics

b. to compare the measured acoustic environment to current guidelines

c. to collect data from staff, patients, and visitors on their perception of the acoustic environment

d. to establish a rigorous methodology for describing the hospital soundscape, including both acoustics and occupant perception, as a tool that can be used for future comparisons across numerous hospitals in varying unit types and with varying subject populations.

Measuring and Describing the Acoustic Environment

Current technologies available for acoustic measurements include sound level meter (SLM) and impulse response (IR) techniques. These measurements have been previously studied with great rigor and thus were adopted in this study, and also are the most current technologies available. As previously mentioned, the hospitals in this study were described by temporal patterns, energy decay metrics, level components, and by their spectral content. A variety of traditional (e.g. LAeq) and novel (e.g. occurrence rate) metrics were used to completely and accurately describe the acoustic environment. To quickly reiterate a few key study findings, these hospitals had relatively problematic temporal pattern occurrences (LCpeak values up to 131dBC and LAmax values up to

114dBA), acceptable energy decay qualities (RT < 0.7 sec), relatively loud level component qualities (LAeq ranging from 45-66 dBA), and would likely be perceived as objectionable in terms of their spectral content (83% of RC Mark II ratings). This accurate and adequate high level description of the sound environment meets the first goal of this study.

Comparing Measured Acoustic Environment to Guidelines

The second goal of this study, to compare the measurements to current guidelines, was successfully completed. The main take-away message from that comparison was that regardless of the guideline or metric used, very few spaces meet the current criteria (44% maximum). This is problematic as it suggests that almost half of the measured units do not meet current guidelines, which reintroduces the point previously made that these guidelines might need additional investigation and revision.

Collecting Occupant Perception Data

The third goal of this study was to collect perception data from occupants in order to attempt to describe their opinion of the current sound environment. The goal of this study was achieved by administering a comprehensive survey (seen in Appendix C). In addition, some of the high level perception results were that almost 30% of patients and visitors felt that noise was disruptive or increased anxiety among patients. Furthermore, almost one third of staff perceived the unit as "moderately to quite noisy". This perception of the sound environment brings up troubling issues that need to be addressed in further detail with a larger population size.

Methodology for Describing the Hospital Soundscape

By successfully completing the first three goals of this research, the fourth goal (to develop a rigorous research tool and methodology) has been completed indirectly through the use of these other components. This goal was achieved by: a) using the best available measurement techniques to date in combining with a variety of traditional and novel acoustic metrics, b) determining an approach and methodology for the locations to be studied in each unit that allowed for comparison to the guidelines, and c) developing a survey tool which can be used for direct comparison in future studies. Through this, the goals of this study have been accomplished.

This investigation into the entirety of a hospital soundscape provided the most comprehensive set of field data to date and a more accurate view of both the acoustic environment and occupant perception in hospitals. In addition, this research has provided the largest variety of units studied and the most comprehensive acoustic and subjective testing on a large scale, including the first time that visitors have been specifically studied. Future research in this area will lead to a greater understanding of the hospital soundscape as well as lead to a more robust evidence based design model for hospital construction methods.

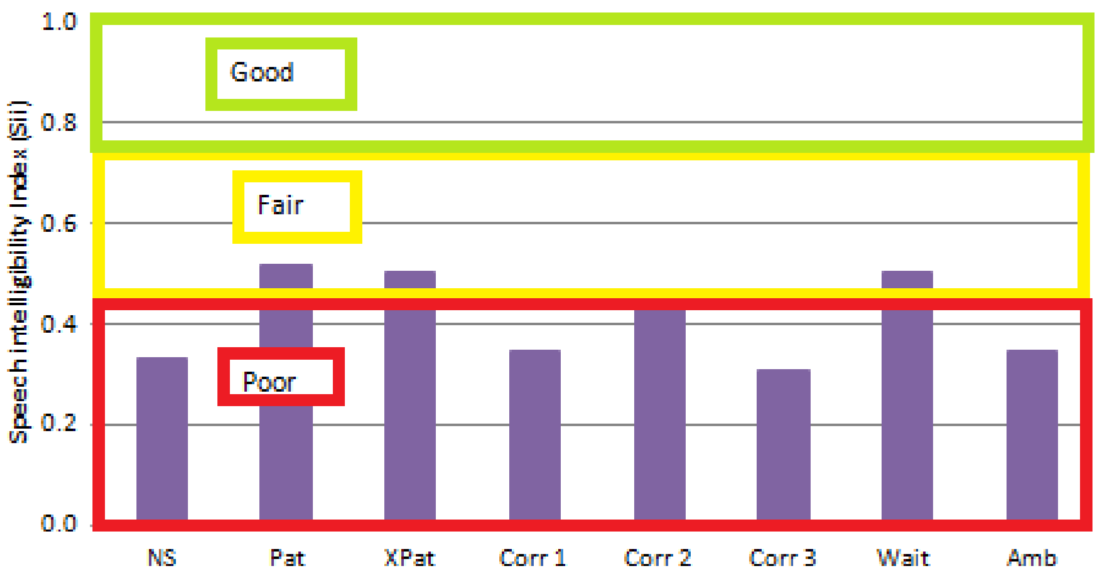
APPENDIX A

SPEECH INTELLIGIBILITY INDEX RESULTS BY HOSPITAL

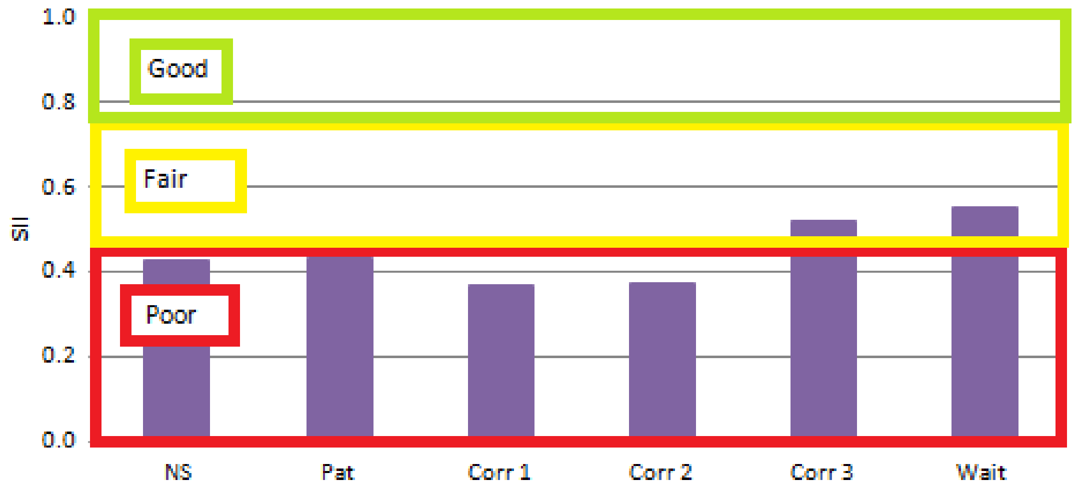
Like mentioned in the main body of this thesis, speech intelligibility is an important factor to consider. This appendix will fill in the gaps of the speech intelligibility index in all locations within the measured units that were not presented in the main body of this thesis.

Hospital 1

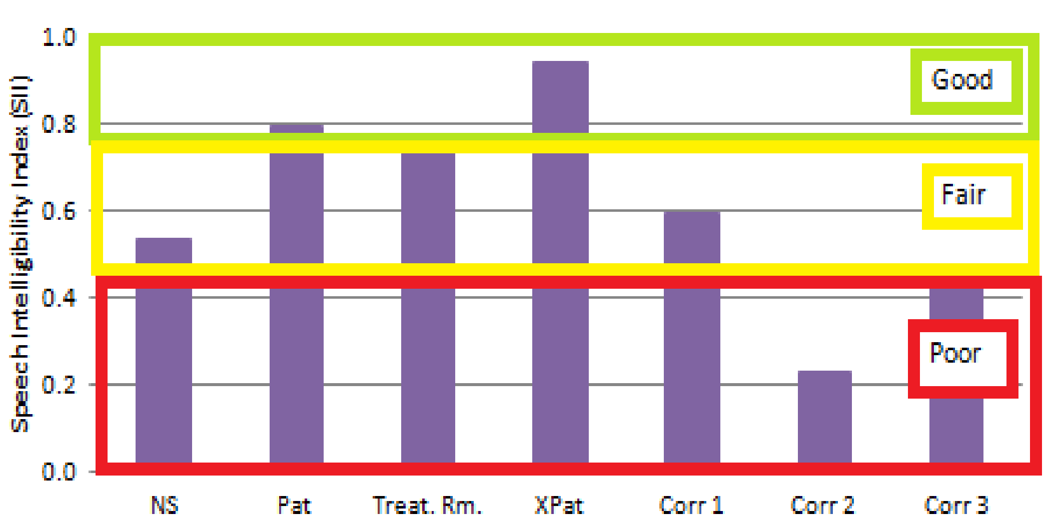
The graphs below show the SII values for Hospital 1 at the ED, ICU, IP, and SDS units.



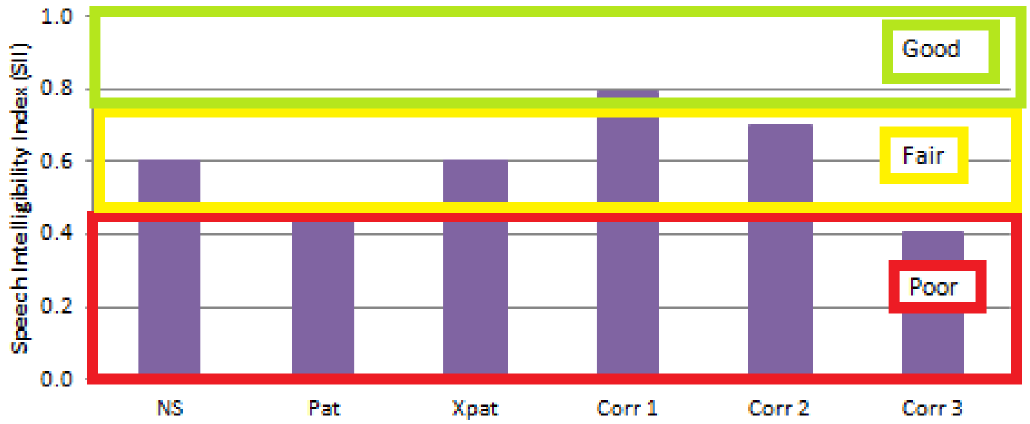
Appendix A. 1: Speech Intelligibility Index (SII) at various locations within the Hospital 1 Emergency Department. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0).



Appendix A. 2: Speech Intelligibility Index (SII) at various locations within the Hospital 1 Intensive Care Unit. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0).



Appendix A. 3: Speech Intelligibility Index (SII) at various locations within the Hospital 1 Inpatient Unit. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0).

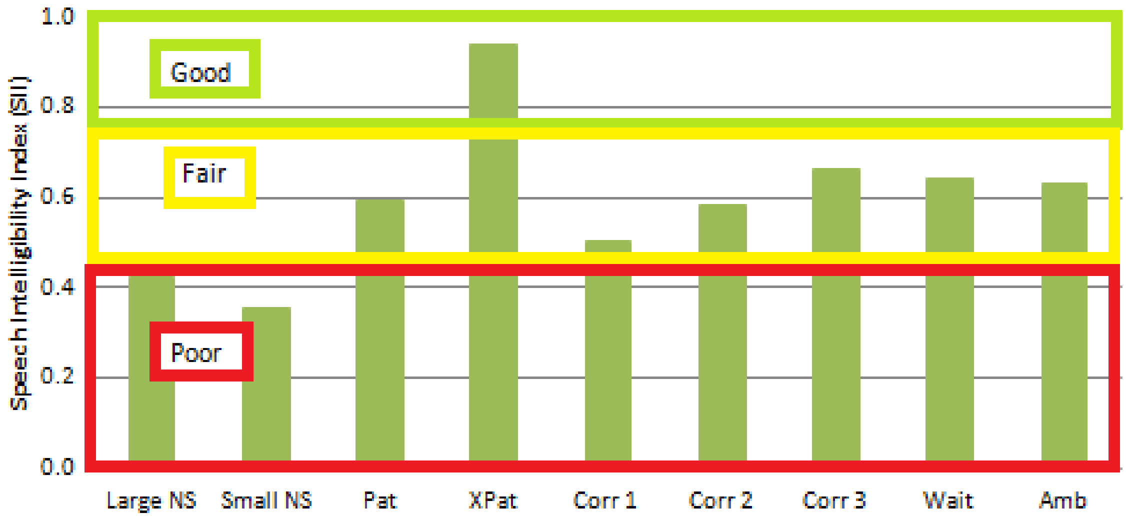


Appendix A. 4: Speech Intelligibility Index (SII) at various locations within the Hospital 1 Same Day Surgery Unit. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0).

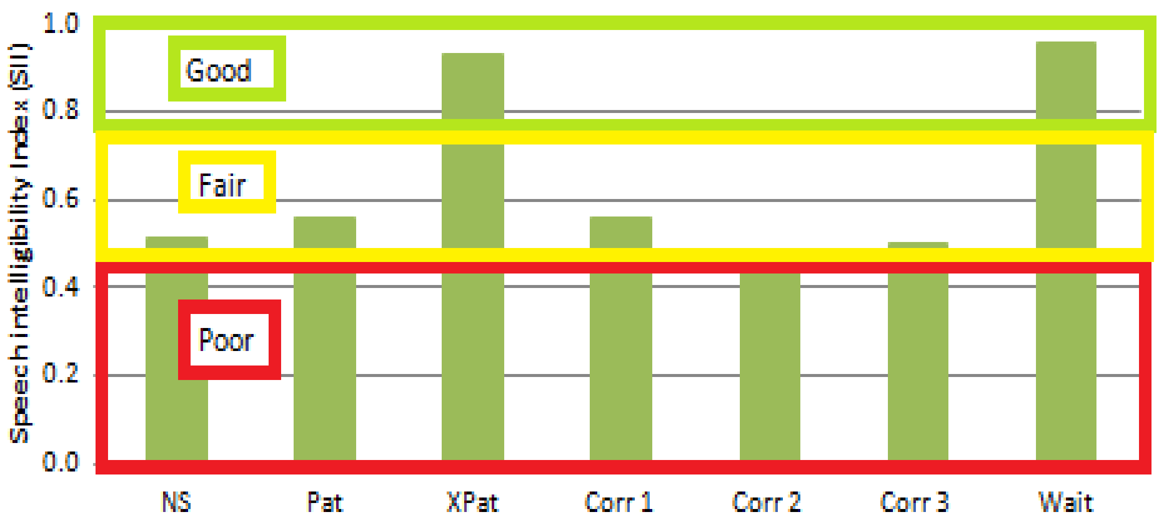
As can be seen from these previous five graphs, the overall speech intelligibility of Hospital 1 is in the marginal range (0.4-0.6) because the ICU and ED units had overall poor SII values. Amid the graphs from Hospital 1, it can be seen that 4 out of the 27 locations had a "good" SII value. Even though this is a low percentage, it still offers insight that locations within units can be designed to have good SII values, even in occupied spaces. Again, the emerging trend between lower SII values for occupied spaces and higher SII values for unoccupied spaces can be easily seen with a few exceptions.

Hospital 2

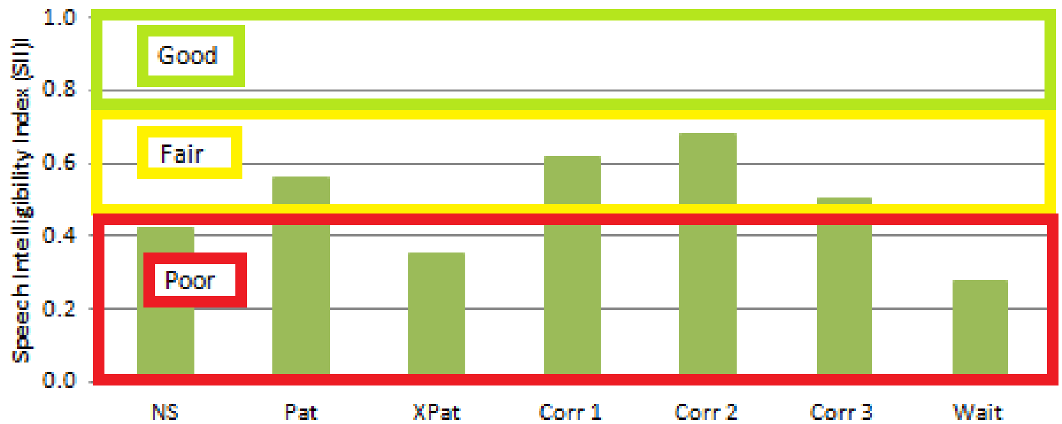
As seen in hospital 3, hospital 2 had similar trends with unoccupied spaces having the highest SII values. However, the graphs below show that there are five out of the 31 locations that have SII values in or extremely near the 0.75 "good" separation line. In the units studied at hospital 2, the unoccupied rooms and unoccupied spaces had the highest SII values, as expected.



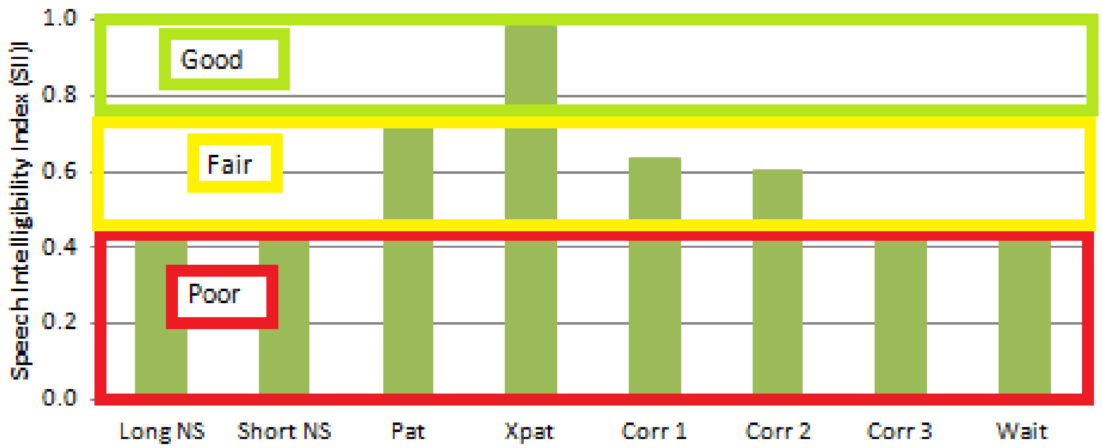
Appendix A. 5: Speech Intelligibility Index (SII) at various locations within hospital 2 Emergency Department. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0).



Appendix A. 6: Speech Intelligibility Index (SII) at various locations within hospital 2 Intensive Care Unit. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0).



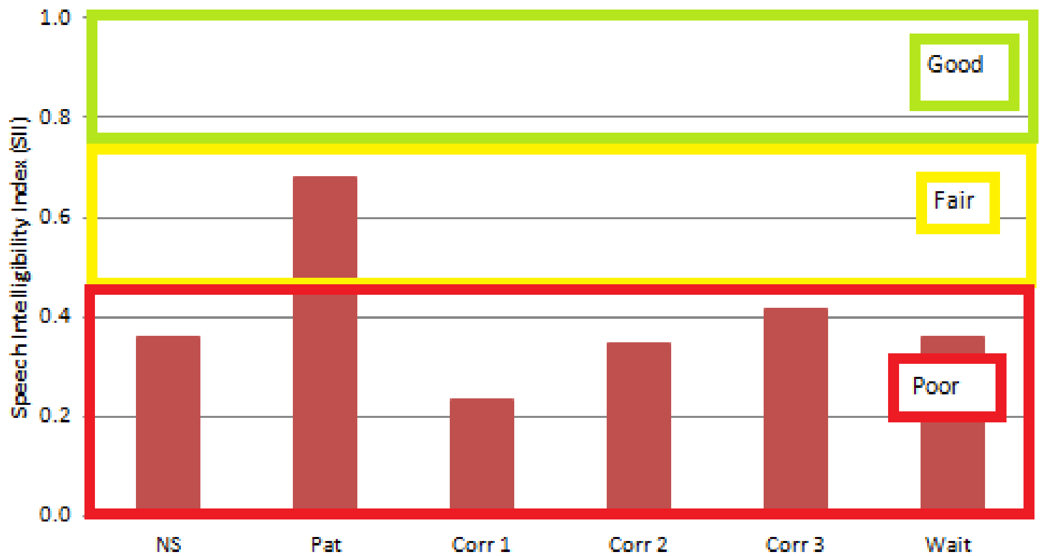
Appendix A. 7: Speech Intelligibility Index (SII) at various locations within hospital 2 Inpatient Unit 5E. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0).



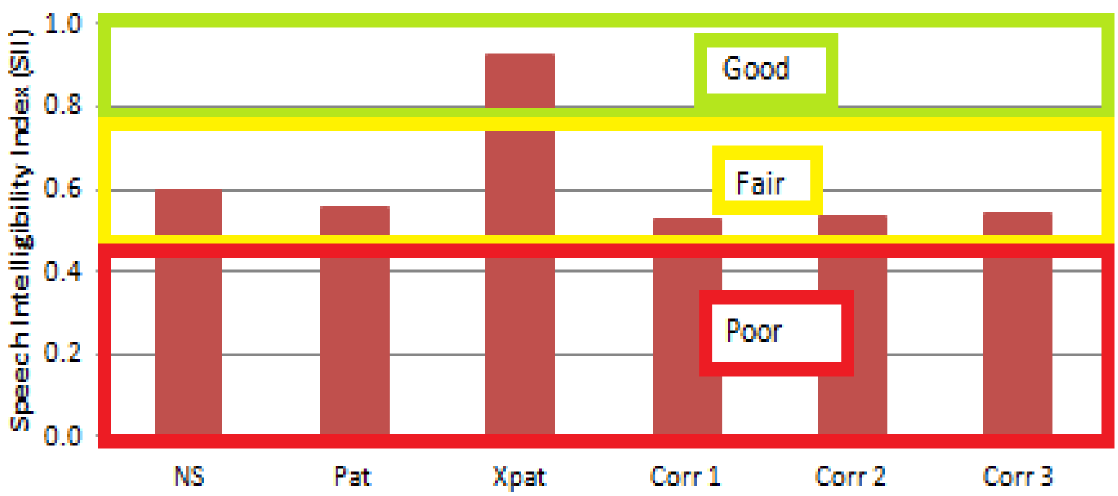
Appendix A. 8: Speech Intelligibility Index (SII) at various locations within hospital 2 Inpatient Unit 5C. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0).

One point that was interesting in the Inpatient 5E unit was that the unoccupied room had a lower SII than the occupied room. The reason for this obvious discrepancy is that during the sound level meter measurement in the occupied room, the patient fell asleep during the measurement, turned off the TV and had little to no extract noise that would make speech conditions bad. The unoccupied room was right next to the nurses' station and was also next to a large HVAC system room. From these hospital 2 graphs, it can be seen that the overall SII is close to the upper fair range (~0.6).

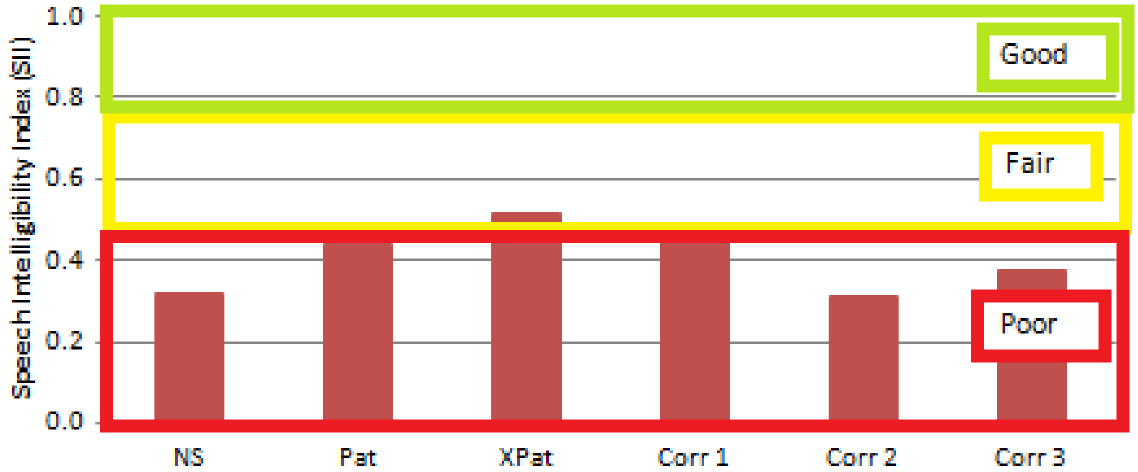
Hospital 3



Appendix A. 9: Speech Intelligibility Index (SII) at various locations within hospital 3 Emergency Department. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0).



Appendix A. 10: Speech Intelligibility Index (SII) at various locations within hospital 3 Intensive Care Unit. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0).



Appendix A. 11: Speech Intelligibility Index (SII) at various locations within hospital 3 Inpatient Unit. Shown here are the ranges of SII: "poor" (0-0.45), "fair" (0.45-0.75) and "good" (0.75-1.0).

Upon analyzing the SII in the hospital 3 units, it can be seen that there are several trends that occur, in a similar manner to those mentioned above. The unoccupied rooms have the highest SII values and that the worst locations for speech communication (lowest SII) are in the nurses' stations and corridors. However, the more noteworthy piece of information in these graphs is that only one out of the 18 measured locations had a good SII value. This is extremely concerning in any hospitals where differences between drugs and dosages can have a significant impact on the care provided to patients.

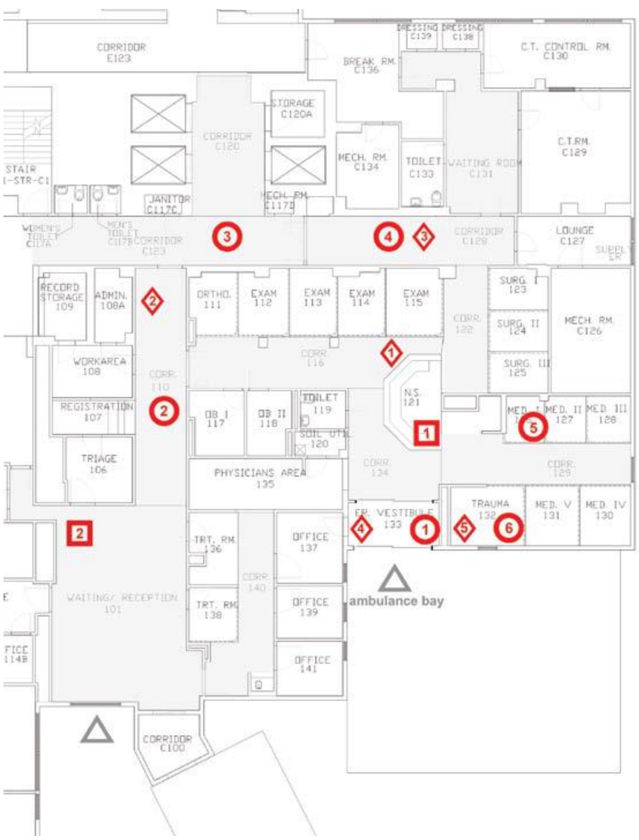
APPENDIX B: SOUNDSCAPE MEASUREMENT LOCATIONS AND UNIT LAYOUTS

Legend:

(□=Long term measurement, ○=short term measurement, ◊=impulse)

(Hospital 1, Hospital 2, Hospital 3)

Hospital 1 ED



□ 1 Nurses' station
2 Waiting Room

◊ 1 Nurses' station
2 Corridor location A
3 Corridor location B
4 Ambulance bay
5 Treatment room A

○ 1 Ambulance bay
2 Corridor location A
3 Corridor location B
4 Corridor location C
5 Treatment room A
6 Treatment room B

As can be seen in the figure above, six-30 minute sound level meter (SLM) measurements, two-24 hour SLM measurements and 5 impulse response measurements were taken in the Hospital 1 ED. The exact location and specific type of measurements are indicated in the key next to the figure. These measurements characterize the acoustic footprint of this unit.

Hospital 1 ICU

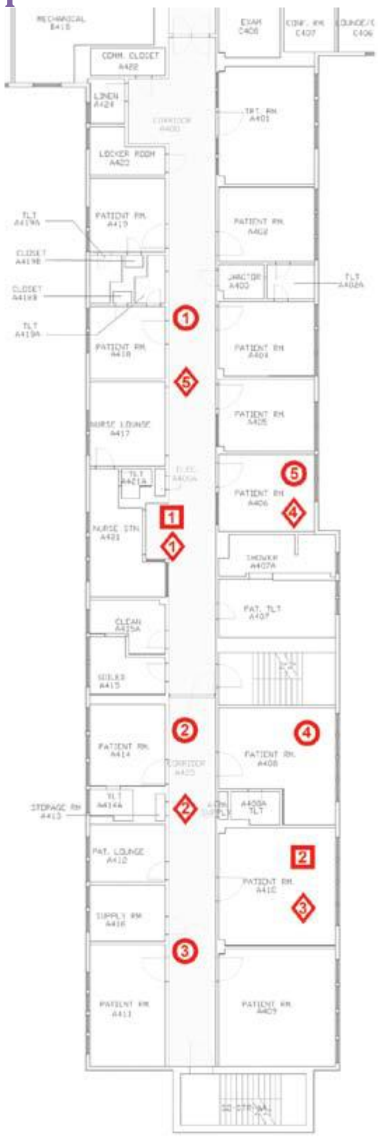
☐ 1 Unoccupied patient room
2 Nurses' station

◊ 1 Corridor location A
2 Corridor location B
3 Corridor location C
4 Occupied patient room
5 Nurses' station
6 Unoccupied patient room

○ 1 Corridor location A
2 Corridor location B
3 Corridor location C
4 Occupied patient room

As can be seen in the figure above, four-30 minute sound level meter (SLM) measurements, two-24 hour SLM measurements and 6 impulse response measurements were taken in the Hospital 1 Intensive Care Unit. The exact location and specific type of measurements are indicated in the key next to the figure.

Hospital 1 IP



□ 1 Nurses' station
2 Unoccupied patient room

◊ 1 Nurses' station
2 Corridor location A
3 Unoccupied patient room
4 Treatment room
5 Corridor location B

○ 1 Corridor location A
2 Corridor location B
3 Corridor location C
4 Occupied patient room
5 Treatment room

In the Hospital 1 IP unit, five-30 minute sound level meter (SLM) measurements, two-24 hour SLM measurements and five impulse response measurements were taken. The exact location and specific type of measurements are indicated in the figure.

Hospital 1 MB

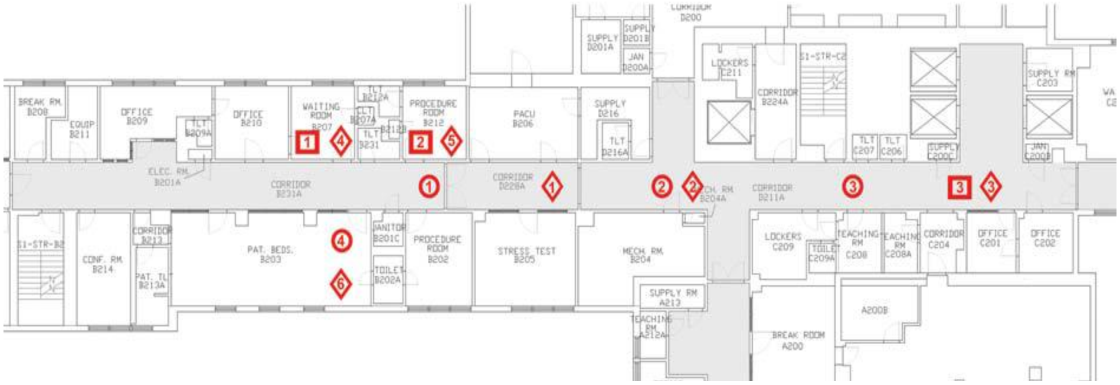
☐ 1 Nurses' Station
2 Unoccupied patient room

◊ 1 Corridor location A
2 Corridor location B
3 Corridor location C
4 Nurses' station
5 Unoccupied patient room
6 Nursery
7 Occupied patient room

○ 1 Corridor location A
2 Corridor location B
3 Corridor location C
4 Nurses' station
5 Nursery A
6 Nursery B
7 Occupied patient room

In the Hospital 1 MB, seven-30 minute sound level meter (SLM) measurements, two-24 hour SLM measurements and seven impulse response measurements were taken. The exact location and specific type of measurements are indicated in the figure. All locations are occupied unless otherwise specified.

Hospital 1 SDS



□ 1 Waiting Room
2 Procedure Room
3 Corridor location A

◊ 1 Corridor location A
2 Corridor location B
3 Corridor location C
4 Waiting room
5 Procedure room
6 Occupied patient room

○ 1 Corridor location A
2 Corridor location B
3 Corridor location C
4 Occupied patient room

In the Hospital 1 SDS unit, four-30 minute sound level meter (SLM) measurements, three-24 hour SLM measurements and six impulse response measurements were taken. The exact location and specific type of measurements are indicated in the figure.

Hospital 2 ED

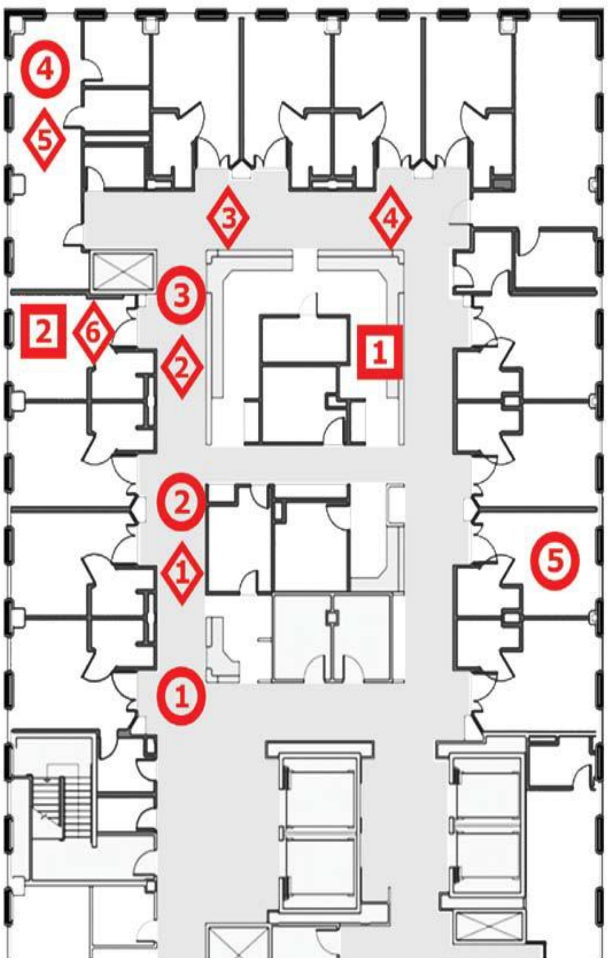
□ 1 Nurses' station
2 Unoccupied treatment room

◊ 1 Ambulance bay
2 Corridor location A
3 Corridor location B
4 Nurses' station
5 Unoccupied treatment room
6 Waiting area

○ 1 Ambulance bay
2 Corridor location A
3 Corridor location B
4 Corridor location C
5 Nurses' work area
6 Occupied treatment room
7 Waiting area

In the hospital 2 ED, seven-30 minute sound level meter (SLM) measurements, two-24 hour SLM measurements and six impulse response measurements were taken. The exact location and specific type of measurements are indicated. All spaces are occupied unless otherwise specified.

Hospital 2 ICU



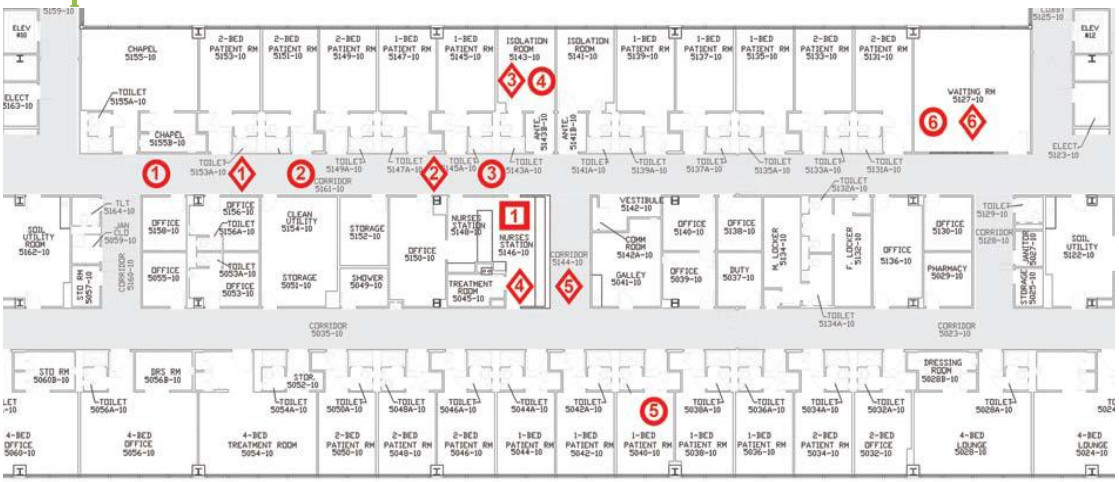
□ 1 Nurses' station
2 Unoccupied treatment room

◊ 1 Corridor location A
2 Corridor location B
3 Corridor location C
4 Nurses' station
5 Occupied treatment room
6 Unoccupied patient room

○ 1 Corridor location A
2 Corridor location B
3 Corridor location C
4 Occupied patient room
5 Unoccupied patient room

In the hospital 2 ICU, five-30 minute sound level meter (SLM) measurements, two-24 hour SLM measurements and six impulse response measurements were taken. These measurements characterize the acoustic footprint of the new ICU. All spaces are occupied unless otherwise specified.

Hospital 2 IP



☐ 1 Nurses' station

◊ 1 Corridor location A
2 Corridor location B
3 Unoccupied patient room
4 Nurses' station
5 Corridor location C
6 Waiting area

○ 1 Corridor location A
2 Corridor location B
3 Corridor location C
4 Unoccupied patient room
5 Occupied patient room
6 Waiting area

In the hospital 2 Inpatient Unit, five-30 minute sound level meter (SLM) measurements, one-24 hour SLM measurement, and six impulse response measurements were taken. The short term SLM measurement taken in the unoccupied room (SLM legend-number 4) lasted for 4 hours. All spaces are occupied unless otherwise specified.

Hospital 2 MB

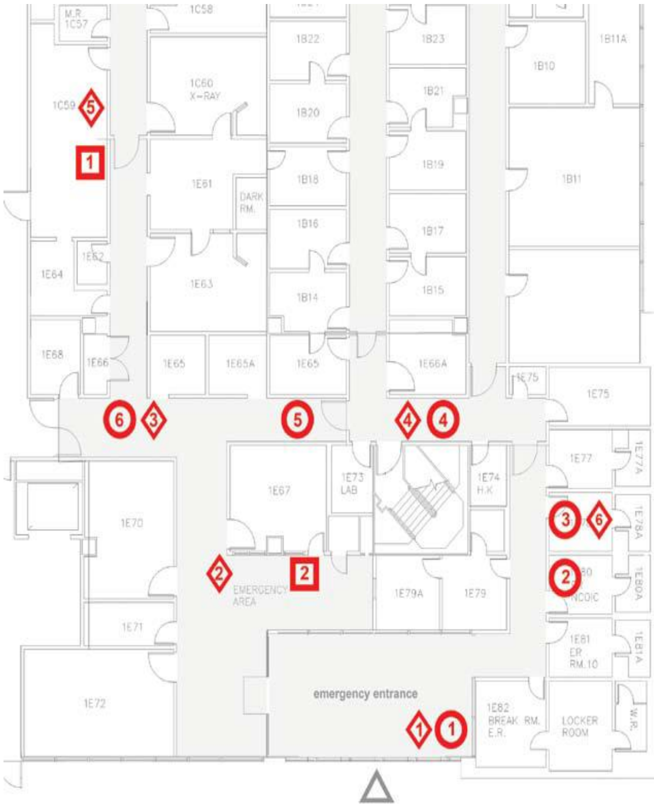
1 Unoccupied patient room
2 Nurses' station

◊ 1 Corridor location A
2 Corridor location B
3 Nurses' station
4 Waiting area
5 Unoccupied patient room

○ 1 Corridor location A
2 Corridor location B
3 Corridor location C
4 Waiting area
5 Occupied patient room

As can be seen in the figure above, five-30 minute sound level meter (SLM) measurements, two-24 hour SLM measurements and five impulse response measurements were taken in the hospital 2 MB unit. The exact location and specific type of measurements are indicated in the key next to the figure.

Hospital 3 ED



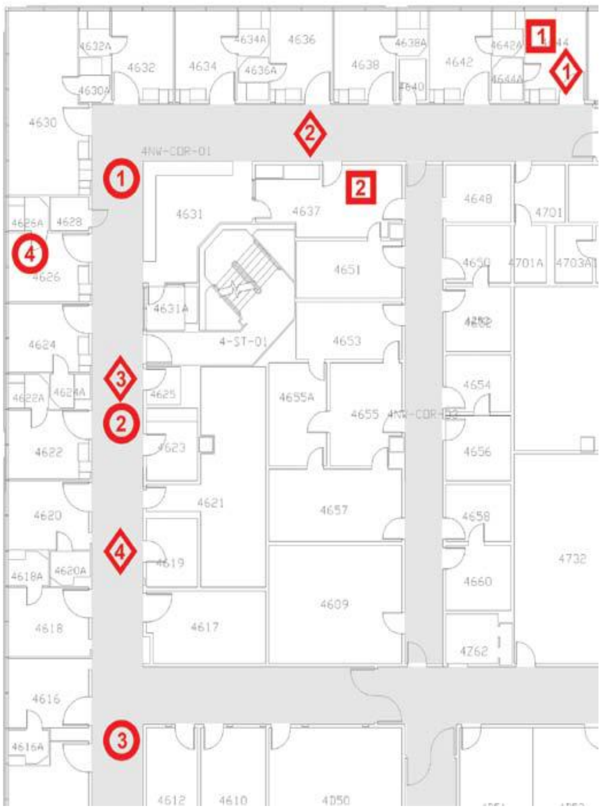
□ 1 Waiting room
2 Nurses' station

◊ 1 Ambulance bay
2 Nurses' station
3 Corridor location A
4 Corridor location B
5 Waiting room
6 Unoccupied patient room

○ 1 Ambulance bay
2 Occupied patient room
3 Unoccupied patient room
4 Corridor location A
5 Corridor location B
6 Corridor location C

As can be seen in the figure above, six-30 minute sound level meter (SLM) measurements, two-24 hour SLM measurements and six impulse response measurements were taken in the hospital 3 ED. The exact location and specific type of measurements are indicated in the key next to the figure. These measurements characterize the acoustic footprint of this unit.

Hospital 3 ICU



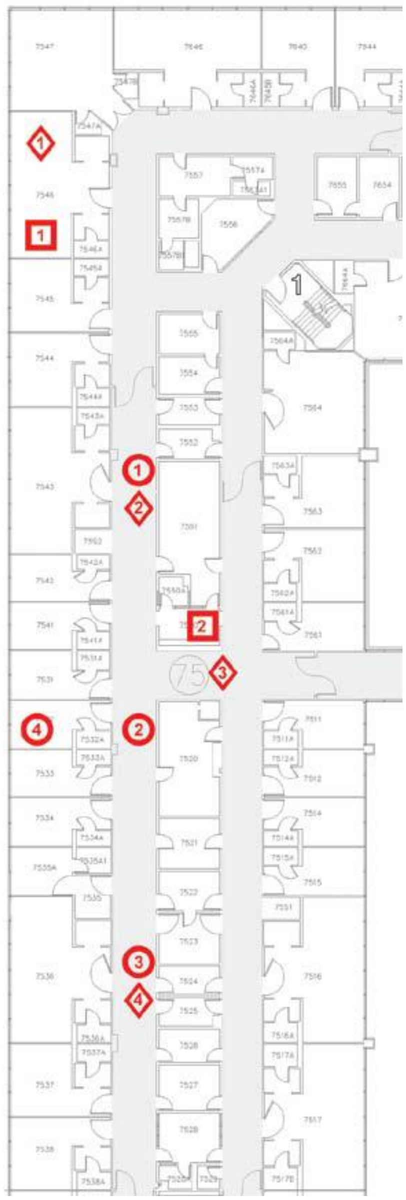
□ 1 Unoccupied patient room
2 Nurses' station

◊ 1 Unoccupied patient room
2 Nurses' station
3 Corridor location A
4 Corridor location B

○ 1 Corridor location A
2 Corridor location B
3 Corridor location C
4 Occupied patient room

As can be seen in the figure above, four-30 minute sound level meter (SLM) measurements, two-24 hour SLM measurements and four impulse response measurements were taken in the hospital 3 ICU. The exact location and specific type of measurements are indicated in the key next to the figure. These measurements characterize the acoustic footprint of this unit.

Hospital 3 IP



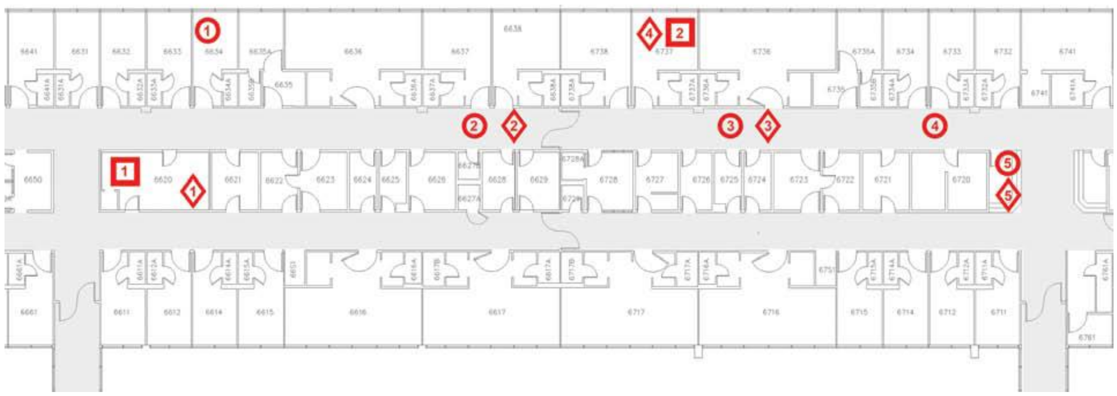
□ 1 Unoccupied patient room
2 Nurses' station

◊ 1 Unoccupied patient room
2 Corridor location A
3 Nurses' station
4 Corridor location B

○ 1 Corridor location A
2 Corridor location B
3 Corridor location C
4 Occupied patient room

In hospital 3's IP unit, four-30 minute sound level meter (SLM) measurements, two-24 hour SLM measurements and four impulse response measurements were taken. The exact location and specific type of measurements are indicated.

Hospital 3 SDS



☐ 1 Nurses' station
2 Unoccupied patient room

◊ 1 Nurses' station
2 Corridor location A
3 Corridor location B
4 Unoccupied patient room
5 Waiting room

○ 1 Occupied patient room
2 Corridor location A
3 Corridor location B
4 Corridor location C
5 Waiting room

In hospital 3's SDS unit, five-30 minute sound level meter (SLM) measurements, two-24 hour SLM measurements and five impulse response measurements were taken. The exact location and specific type of measurements are indicated on the figure and in the key.

APPENDIX C

STAFF, PATIENT, AND VISITOR SURVEYS ADMINISTERED

STAFF INTRODUCTORY LETTER
Georgia Institute of Technology
Protocol Title: Soundscape Evaluations in MHS Hospitals
Investigators: Dr. Erica Ryherd (erica.ryherd@me.gatech.edu); Craig Zimring (craig.zimring@coa.gatech.edu);

Research Introductory Letter

Dear Caregiver,
You are being asked to volunteer in a research study.

Purpose:
The purpose of this study is:
This study will examine how various characteristics of the hospital sound environment impact the perceptions of staff members about the qualities of their current job. Previous research has indicated that various aspects of the built environment, including acoustics, can impact occupant perception. The purpose of this research is to measure acoustical conditions alongside patient, staff, and visitor outcomes via questionnaires in military hospitals. Data is being collected in multiple hospitals around the U.S., including Military Health Systems (MHS) facilities This survey, a portion of the above mentioned study, is being distributed to staff in the unit in which you work. The results will be used to help improve sound environment in hospitals.

Procedures:
If you decide to be in this study, your part will involve:
You will be asked to fill out a paper based survey about your perception of your current job and various aspects of the sound environment at your workplace. The survey will take approximately 20 minutes to complete, and you should plan to fill out the entire survey in one sitting. It does not necessarily need to be filled out while you are at work; however, you may complete this survey at work if you so choose.

Risks/Discomforts:
The following risks/discomforts may occur as a result of your participation in this study:
The risks involved are no greater than those involved in your daily tasks.

Benefits:
The following benefits to you are possible as a result of being in this study:
There are no direct benefits to you from participating in the study. But we hope that this study may benefit society if the results lead to a better understanding of the sound environment in hospitals.

Compensation to You:
You will receive no compensation for participating. You may complete the survey during working hours, but will not receive additional compensation for your participation.

Confidentiality

The following procedures will be followed to keep your personal information confidential in this study:

The data that is collected about you will be kept private to the extent allowed by law. To protect your privacy, your records will be kept under a code number rather than by name. Your records will be kept in locked files and only study staff will be allowed to look at them. Your name will not be collected in this survey, and any other fact that might point to you will not appear when results of this study are presented or published.

For online surveys, include the following:{You should be aware, however, that the experiment is not being run from a "secure" https server of the kind typically used to handle credit card transactions, so there is a small possibility that responses could be viewed by unauthorized third parties (e.g., computer hackers). Also, in general the web page software will log as header lines the IP address of the machine you use to access this page, e.g.,102.403.506.807, but otherwise no other information will be stored unless you explicitly enter it.]

To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology Review Board also look at study records. The Office of Human Research Protections may also look at study records. All of these people are required to keep your identity confidential.

Costs to You:

There are no costs to you for participating in this study, except for your time.

Subject Rights:

- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
- You have the right to change your mind and leave the study at any time without giving any reason, and without penalty.
- Any new information that may make you change your mind about being in this study will be given to you.
- You may print a copy of this introductory letter to keep.
- You do not waive any of your legal rights by completing the survey.

Questions about the Study or Your Rights as a Research Subject

- If you have any questions about the study, you may contact Dr. Erica Ryherd at telephone (404) 385-3276 or at erica.ryherd@me.gatech.edu
- If you have any questions about your rights as a research subject or feel that you have been unfairly treated, please contact Ms. Kelly Winn, Georgia Institute of Technology IRB at (404) 385-2175.

By completing this survey, you have indicated your consent to volunteer in this study.

The assigned Report Control Symbol is
DD-HA(AS)2263
with an approval expiration date of
April 30, 2014.

Dear Participant,

You are being asked to volunteer in a performance improvement study.

This study will examine how various characteristics of the hospital sound environment are perceived by staff, patients, and visitors. This survey is being distributed to Military-DoD employee (DEERS registered) nurses in the unit in which you work.

If you decide to participate, you will be asked to fill out a survey about your perception of various aspects of your workplace, including the sound environment. The survey will take approximately 20 minutes to complete, and you should plan to fill out the entire survey in one sitting. It does not necessarily need to be filled out while you are at work; however, you may complete this survey at work if you so choose. You may decide to complete the survey during working hours, but you will not receive additional compensation for your participation.

Please return your survey to the drop box located at the central nurse station in your unit.

We would appreciate it if you could complete the survey by July 2011.

Thank you!

Healthcare Environments-Baseline Assessment of Safety and Quality (HE-BASQ) Study to Evaluate the Soundscape in NCR Hospitals

Staff Survey

Please fill in the bubbles completely.

The information you provide will be used to measure acoustical conditions in multiple hospitals around the U.S., including Military Health Systems (MHS) facilities and examine how various characteristics of the hospital sound environment impact the perceptions of staff members about the qualities of their current job. Your responses to this survey will be de-identified (coded with a sequential respondent number), remain confidential, and will not be used in a manner that could identify you in the future. Your name will not be collected in this survey and any other fact that might point to you will not appear when results of this study are presented or published.

1. Gender

○ Male ○ Female

2. What is your age?

○ 18-29 ○ 30-39 ○ 40-49

○ 50-59 ○ 60-69 ○ 70 years or older

3. Which job category best describes you?

○ Full-time nurse ○ Part-time nurse

○ Clerk ○ If other, please describe: ______________________

4. When are your normal working hours?

○ Mostly Mornings ○ Mostly Afternoons

○ Mostly Nights ○ Combination of morning, afternoon and night

5. In an ordinary week, how many total hours do you spend at work?

○ 0 – 20 hours ○ 20 – 39 hours

○ 40 hours ○ 40 + hours

6. To which department are you primarily assigned?

- ○ Intensive Care (ICU)
- ○ Med/Surg Nursing
- ○ Emergency (ED)
- ○ Ambulatory Care
- ○ Labor & Delivery
- ○ Other, please describe:

7. In an ordinary week, how many total hours do you spend in your primary department?

- ○ 0 – 20 hours
- ○ 20 – 39 hours
- ○ 40 hours
- ○ 40 + hours

8. How many years have you worked in your primary department at this MTF?

- ○ Less than 1 year
- ○ 1 to 5 years
- ○ 6 to 10 years
- ○ 11 or more years

9. How many years have you worked in the kind of department to which you are now primarily assigned during your entire career?

- ○ Less than 1 year
- ○ 1 to 5 years
- ○ 6 to 10 years
- ○ 11 or more years

10. Overall, how noisy is your primary department?

A little noisy	A little noisy	Moderately noisy	Quite noisy	Extremely noisy
○	○	○	○	○

11. Please indicate how annoyed (if at all) you typically are with the overall sound environment in the following locations in your primary department:

	Not at all annoyed	A little annoyed	Moderately annoyed	Quite annoyed	Extremely annoyed
... Physician / nurse work areas	○	○	○	○	○

11. Please indicate how annoyed (if at all) you typically are with the overall sound environment in the following locations in your primary department:

	Not at all annoyed	A little annoyed	Moderately annoyed	Quite annoyed	Extremely annoyed
... Unoccupied patient rooms	○	○	○	○	○
... Occupied patient rooms	○	○	○	○	○
... Corridors	○	○	○	○	○

Please rate your level of agreement with the following statements, describing how you typically experience the sound environment in the following locations in your primary department:

12. I have to raise my voice in order to communicate with others in the...

	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5
... Physician / nurse work areas	○	○	○	○	○
... Occupied patient rooms	○	○	○	○	○
... Corridors	○	○	○	○	○

13. I have trouble communicating with other staff because of the sound environment in the...

	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5
... Physician / nurse work areas	○	○	○	○	○
... Occupied patient rooms	○	○	○	○	○
... Corridors	○	○	○	○	○

14. I have trouble communicating with the patients because of the sound environment in the...

	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5
... Physician / nurse work areas	○	○	○	○	○

14. I have trouble communicating with the patients because of the sound environment in the…					
	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5
… Occupied patient rooms	○	○	○	○	○
… Corridors	○	○	○	○	○

15. The background noise helps keep my conversations from being overheard by others in the…					
	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5
… Physician / nurse work areas	○	○	○	○	○
… Occupied patient rooms	○	○	○	○	○
… Corridors	○	○	○	○	○

16. Please indicate how much the following noise sources typically disturb your work concentration in your department:					
	Not at all annoyin g 1	A little bit annoying 2	Moderatel y annoying 3	Quite a bit annoying 4	Extremel y annoying 5
Staff conversation noise	○	○	○	○	○
Visitor conversation noise	○	○	○	○	○
Other visitor sounds (e.g., footfall, coughing, laughing)	○	○	○	○	○
Patient sounds (e.g., coughing, snoring)	○	○	○	○	○
Emergency procedures (e.g., cardiac arrest)	○	○	○	○	○
Operational sounds of medical equipment used for patients (e.g., breathing machines, suction)	○	○	○	○	○
Beeping patient monitoring devices	○	○	○	○	○
Alarms on medical equipment	○	○	○	○	○
Patient intercom and call lights	○	○	○	○	○
Paging system	○	○	○	○	○
Telephone ringing and conversation	○	○	○	○	○
Noise from rolling medicine/linen carts	○	○	○	○	○
Noise from bed (e.g., squeaking, air pumping)	○	○	○	○	○

16. Please indicate how much the following noise sources typically disturb your work concentration in your department:					
	Not at all annoying 1	A little bit annoying 2	Moderately annoying 3	Quite a bit annoying 4	Extremely annoying 5
Ventilation and air conditioning system	○	○	○	○	○
Cleaning equipment (e.g., vacuum cleaners)	○	○	○	○	○
Door opening, closing, slamming	○	○	○	○	○
Falling objects	○	○	○	○	○
Toilets flushing	○	○	○	○	○
Television	○	○	○	○	○
Footsteps	○	○	○	○	○
Exterior noise from outside of hospital	○	○	○	○	○
If other, please describe:	○	○	○	○	○

17. Please indicate how much you agree with each of the following statements.					
	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5
My job requires that I learn new things	○	○	○	○	○
My job requires me to be creative	○	○	○	○	○

17. Please indicate how much you agree with each of the following statements.

	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5
My job requires a high level of skill	○	○	○	○	○
I get to do a variety of different things in my job	○	○	○	○	○
I have an opportunity to develop my own abilities	○	○	○	○	○
My job involves a lot of repetitive work	○	○	○	○	○
My job allows me to make a lot of decisions on my own	○	○	○	○	○
I have a lot to say about what happens on my job	○	○	○	○	○
On my job, I have very little freedom to decide how I do my work	○	○	○	○	○
My job requires working very fast	○	○	○	○	○
My job requires working very hard	○	○	○	○	○
I am not asked to do an excessive amount of work	○	○	○	○	○
I have enough time to get the job done	○	○	○	○	○
I am free from conflicting demands that others make	○	○	○	○	○

18. Taking everything into consideration, how are you satisfied with your job as a whole?

Extremely Satisfied	Satisfied	Neutral	Dissatisfied	Extremely dissatisfied
○	○	○	○	○

19. Overall, what is your level of commitment to your present job?			
Not at all committed	Slightly committed	Moderately committed	Fully committed
○	○	○	○

The following questions ask for your views about your health. This information will help keep track of how you feel and how well you are able to do your usual activities. For each of the following questions, please fill in the bubble that best describes your answer.

20. In general, would you say your health is:				
Excellent	Very good	Good	Fair	Poor
○	○	○	○	○

21. The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?	Yes, limited a lot	Yes, limited a little	No, not limited at all
Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf	○	○	○
Climbing several flights of stairs	○	○	○

22. During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of your physical health?	All of the time	Most of the time	Some of the time	A little of the time	None of the time
Accomplished less than you would like	○	○	○	○	○
Were limited in the kind of work or other activities	○	○	○	○	○

23. During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?	All of the time	Most of the time	Some of the time	A little of the time	None of the time
Accomplished less than you would like	○	○	○	○	○

23. During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
Did work or other activities less carefully than usual	○	○	○	○	○

24. During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)?

Not at all	A little bit	Moderately	Quite a bit	Extremely
○	○	○	○	○

25. These questions are about how you feel and how things have been with you during the past 4 weeks. For each question, please give the one answer that comes closest to the way you have been feeling. How much of the time during the past 4 weeks …

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
Have you felt calm and peaceful?	○	○	○	○	○
Have you had a lot of energy?	○	○	○	○	○
Have you felt depressed?	○	○	○	○	○

26. During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting friends, relatives, etc.)?

All of the time	Most of the time	Some of the time	A little of the time	None of the time
○	○	○	○	○

27. Do you have any hearing impairments?

○ **Yes** ○ **No** ○ **I don't know**

If yes, what type?

28. In everyday life, do you have difficulties understanding speech in an environment where there are several others talking at the same time?

○ **Yes** ○ **No**

29. How do you think your hearing is?

Very good	Good	Normal	Poor	Very Poor
○	○	○	○	○

30. In general, how sensitive are you to noise?

Not at all	A little bit	Moderately	Quite a bit	Extremely
○	○	○	○	○

THANK YOU VERY MUCH FOR YOUR TIME AND INPUT

PATIENT INTRODUCTORY LETTER
Georgia Institute of Technology
Protocol Title: Soundscape Evaluations in MHS Hospitals
Investigators: Dr. Erica Ryherd (erica.ryherd@me.gatech.edu; Craig Zimring (craig.zimring@coa.gatech.edu);
Consent title:

<u>Research Introductory Letter</u>

Dear Patient,
You are being asked to volunteer in a research study.

<u>Purpose</u>:
This study will examine how various characteristics of the hospital sound environment impact the perceptions of patients. Previous research has indicated that various aspects of the built environment, including acoustics, can impact occupant perception. The purpose of this research is to measure acoustical conditions alongside patient, staff, and visitor outcomes via questionnaires in military hospitals. Data is being collected in multiple hospitals around the U.S., including Military Health Systems (MHS) facilities This survey, a portion of the above mentioned study, is being distributed to patients. The results will be used to help improve sound environment in hospitals.

Procedures:
If you decide to be in this study, your part will involve:
You will be asked to fill out a paper survey about your perception of the sound environment in this hospital. The survey will take approximately 10 minutes to complete.

Risks/Discomforts:
The following risks/discomforts may occur as a result of your participation in this study:
The risks involved are no greater than those involved in typical daily activities.

Benefits:
The following benefits to you are possible as a result of being in this study:
There are no direct benefits to you from participating in the study. But we hope that this study may benefit society if the results lead to a better understanding of the sound environment in hospitals.

Compensation to You:
You will receive no compensation for participating.

Confidentiality
The following procedures will be followed to keep your personal information confidential in this study:
The data that is collected about you will be kept private to the extent allowed by law. To protect your privacy, your records will be kept under a code number rather than by name. Your records will be kept in locked files and only study staff will be allowed to look at them. Your name will not be collected in the survey, and any other fact that might point to you will not appear when results of this study are presented or published.

To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology Institutional Review Board also look at study records. The Office of Human Research Protections may also look at study records. All of these people are required to keep your identity confidential.

Costs to You:
There are no costs to you for participating in this study, except for your time.

Subject Rights:
- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
- You have the right to change your mind and leave the study at any time without giving any reason, and without penalty.
- Any new information that may make you change your mind about being in this study will be given to you.
- You may have a copy of this introductory letter to keep.
- You do not waive any of your legal rights by completing the survey.

Questions about the Study or Your Rights as a Research Subject

- If you have any questions about the study, you may contact Dr. Erica Ryherd at telephone (404) 385-3276 or at erica.ryherd@me.gatech.edu
- If you have any questions about your rights as a research subject or feel that you have been unfairly treated, please contact Ms. Kelly Winn, Georgia Institute of Technology IRB at (404) 385-2175.

By completing this survey, you have indicated your consent to volunteer in this study.

The assigned Report Control Symbol is
DD-HA(AS)2263
with an approval expiration date of
April 30, 2014.

Dear Participant,

You are being asked to volunteer in a performance improvement study.

This study will examine how various characteristics of the hospital sound environment are perceived by staff, patients and visitors.

If you decide to participate, you will be asked to fill out a paper survey about your perception of various aspects of the sound environment. The survey will take approximately 10 minutes to complete.

We would appreciate it if you could complete the survey by July 2011.

Thank you!

Healthcare Environments-Baseline Assessment of Safety and Quality (HE-BASQ) Study to Evaluate the Soundscape in NCR Hospitals

Patient Survey

Please fill in the bubbles completely.

The information you provide will be used to measure acoustical conditions in multiple hospitals around the U.S., including Military Health Systems (MHS) facilities and examine how various characteristics of the hospital sound environment impact the perceptions of patients. Your responses to this survey will be de-identified (coded with a sequential respondent number), remain confidential, and will not be used in a manner that could identify you in the future. Your name will not be collected in this survey and any other fact that might point to you will not appear when results of this study are presented or published.

1. What department are you in?

- ○ Intensive Care (ICU)
- ○ Med/Surg Nursing
- ○ Emergency (ED)
- ○ Ambulatory Care
- ○ Labor & Delivery
- ○ Other, please describe:

2. How many days have you been in the hospital?

- ○ 1 day
- ○ 2 -3 days
- ○ 4+ days

3. What is your age?

- ○ 18-29
- ○ 30-39
- ○ 40-49
- ○ 50-59
- ○ 60-69
- ○ 70 years or older

4. What is your gender?

- ○ Male
- ○ Female

5. How much do you agree or disagree with the following statement?

	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly Agree 5
The noise in my room increases my anxiety level	○	○	○	○	○

6.a. How much do you agree or disagree with the following statement?					
	Strongly disagree 1	**Disagree 2**	**Neutral 3**	**Agree 4**	**Strongly Agree 5**
The noise in my room disrupts my sleep	○	○	○	○	○

6.b. Please list any noise sources you feel are disrupting your sleep at this hospital:

7. How easily can you hear visitors and caregivers when they speak to you?				
Very easy to hear	**Easy to hear**	**Somewhat easy to hear**	**Difficult to hear**	**Very difficult to hear**
○	○	○	○	○

8. What degree of speech privacy do you expect when staying at this hospital? In other words, to what degree should people <u>outside</u> of your room be able to hear and understand conversations between you and your doctor/family/etc.?

○	**Minimal**	Individual words and phrases can be occasionally understood (e.g., every few minutes)
○	**Low**	Individual words and phrases can be occasionally understood with some effort (e.g., a few times an hour)
○	**Standard**	Individual words can rarely be understood (e.g., once every few hours) and loud speech can be occasionally heard (e.g., a few times an hour)
○	**High**	Individual words and phrases very difficult to understand (e.g., once a day) and loud speech can be heard with some effort (e.g., a few times an hour)
○	**Very High**	Loud speech cannot be heard

9. Please rate how annoying (if at all) you find the following noises to be during your stay in this room.					
	Not at all annoying 1	A little bit annoying 2	Moderately annoying 3	Quite a bit annoying 4	Extremely annoying 5
Staff conversation noise	○	○	○	○	○
Visitor conversation noise	○	○	○	○	○
Other visitor sounds (e.g., footfall, coughing, laughing)	○	○	○	○	○
Noise from nurse station	○	○	○	○	○
Physiological sounds from other patients (e.g., coughing, snoring)	○	○	○	○	○
Medical equipment noise	○	○	○	○	○
Alarms	○	○	○	○	○
Noise from bed (e.g. squeaking, air pumping)	○	○	○	○	○
Hospital paging system	○	○	○	○	○
Air conditioning / Heating system	○	○	○	○	○
Noise from rolling carts	○	○	○	○	○
Cleaning equipment	○	○	○	○	○
Telephone ringing and conversation	○	○	○	○	○
Door opening, closing, slamming	○	○	○	○	○

9. Please rate how annoying (if at all) you find the following noises to be during your stay in this room.					
	Not at all annoying 1	A little bit annoying 2	Moderately annoying 3	Quite a bit annoying 4	Extremely annoying 5
Falling objects	○	○	○	○	○
Television	○	○	○	○	○
Footsteps	○	○	○	○	○
Exterior noise from outside of hospital	○	○	○	○	○
If other, please describe	○	○	○	○	○

THANK YOU VERY MUCH FOR YOUR TIME AND INPUT

VISITOR INTRODUCTORY LETTER

Georgia Institute of Technology
Protocol Title: Soundscape Evaluations in MHS Hospitals
Investigators: Dr. Erica Ryherd (erica.ryherd@me.gatech.edu); Craig Zimring (craig.zimring@coa.gatech.edu);
Consent title: Main 03/10/2010v1

Research Introductory Letter

Dear Visitor,
You are being asked to volunteer in a research study.

Purpose:
The purpose of this study is:

This study will examine how various characteristics of the hospital sound environment impact the perceptions of visitors. Previous research has indicated that various aspects of the built environment, including acoustics, can impact occupant perception. The purpose of this research is to measure acoustical conditions alongside patient, staff, and visitor outcomes via questionnaires in military hospitals. Data is being collected in multiple hospitals around the U.S., including Military Health Systems (MHS) facilities This survey, a portion of the above mentioned study, is being distributed to visitors. The results will be used to help improve sound environment in hospitals.

Procedures:
If you decide to be in this study, your part will involve:
You will be asked to fill out a paper survey about your perception of the sound environment in this hospital. The survey will take approximately 10 minutes to complete.

Risks/Discomforts:
The following risks/discomforts may occur as a result of your participation in this study:
The risks involved are no greater than those involved in typical daily activities.

Benefits:
The following benefits to you are possible as a result of being in this study:
There are no direct benefits to you from participating in the study. But we hope that this study may benefit society if the results lead to a better understanding of the sound environment in hospitals.

Compensation to You:
You will receive no compensation for participating.

Confidentiality
The following procedures will be followed to keep your personal information confidential in this study:
The data that is collected about you will be kept private to the extent allowed by law. To protect your privacy, your records will be kept under a code number rather than by name. Your records will be kept in locked files and only study staff will be allowed to look at them. Your name will not be collected in the survey, and any other fact that might point to you will not appear when results of this study are presented or published.

To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology Institutional Review Board also look at study records. The Office of Human Research Protections may also look at study records. All of these people are required to keep your identity confidential.

Costs to You:
There are no costs to you for participating in this study, except for your time.

Subject Rights:
- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.

- You have the right to change your mind and leave the study at any time without giving any reason, and without penalty.
- Any new information that may make you change your mind about being in this study will be given to you.
- You may have a copy of this introductory letter to keep.
- You do not waive any of your legal rights by completing the survey.

<u>Questions about the Study or Your Rights as a Research Subject</u>

- If you have any questions about the study, you may contact Dr. Erica Ryherd at telephone (404) 385-3276) or at erica.ryherd@me.gatech.edu
- If you have any questions about your rights as a research subject or feel that you have been unfairly treated, please contact Ms. Kelly Winn, Georgia Institute of Technology IRB at (404) 385-2175.

By completing this survey, you have indicated your consent to volunteer in this study.

The assigned Report Control Symbol is
DD-HA(AS)2263
with an approval expiration date of
April 30, 2014.

Dear Participant,

Are you employed by the DOD or the family member of someone in active duty?

If so,

You are being asked to volunteer in a performance improvement study.

This study will examine how various characteristics of the hospital sound environment are perceived by staff, patients and visitors.

If you decide to participate, you will be asked to fill out a paper survey about your perception of various aspects of the sound environment. The survey will take approximately 10 minutes to complete.

We would appreciate it if you could complete the survey by July 2011.

Thank you!

Healthcare Environments-Baseline Assessment of Safety and Quality (HE-BASQ) Study to Evaluate the Soundscape in NCR Hospitals

Visitor Survey

Please fill in the bubbles completely.

The information you provide will be used to measure acoustical conditions in multiple hospitals around the U.S., including Military Health Systems (MHS) facilities and examine how various characteristics of the hospital sound impact the perceptions of visitors. Your responses to this survey will be de-identified (coded with a sequential respondent number), remain confidential, and will not be used in a manner that could identify you in the future. Your name will not be collected in this survey and any other fact that might point to you will not appear when results of this study are presented or published.

1. What department is the patient being visited in or accompanied to?

○ Intensive Care (ICU)
○ Med/Surg Nursing
○ Emergency (ED)
○ Ambulatory Care
○ Labor & Delivery
○ Other, please describe:

2. How many days have you visited or accompanied the patient in this unit?

○ 1 day
○ 2 -3 days
○ 4+ days

3. What is your age?

○ 18-29
○ 30-39
○ 40-49
○ 50-59
○ 60-69
○ 70 years or older

4. Your gender

○ Male
○ Female

5. Are you…

○ Staying overnight
○ An occasional visitor

Please answer the following questions, based on your experiences in the room where the patient that you are visiting is staying.

6. How much do you agree or disagree with the following statement?

	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly Agree 5
The noise in the room increases my anxiety level.	○	○	○	○	○

7.a. How much do you agree or disagree with the following statement?

	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly Agree 5
The noise in the room disrupts the patient's sleep.	○	○	○	○	○

7.b. Please list any noise sources you feel disrupt the patient's sleep:

8. How easily can you hear the patient and caregivers when they speak to you?

Very easy to hear	Easy to hear	Somewhat easy to hear	Difficult to hear	Very difficult to hear
○	○	○	○	○

9. What degree of speech privacy do you think patients should expect when staying at this hospital? In other words, to what degree should people <u>outside</u> of a patient's room be able to hear and understand conversations between the patient and their doctor/family/etc.?

○	**Minimal**	Individual words and phrases can be occasionally understood (e.g., every few minutes)
○	**Low**	Individual words and phrases can be occasionally understood with some effort (e.g., a few times an hour)
○	**Standard**	Individual words can rarely be understood (e.g., once every few hours) and loud speech can be occasionally heard (e.g., a few times an hour)

○	**High**	Individual words and phrases very difficult to understand (e.g., once a day) and loud speech can be heard with some effort (e.g., a few times an hour)
○	**Very High**	Loud speech cannot be heard

10. Please rate how annoying (if at all) you find the following noises to be during your stay in this room.

	Not at all annoying 1	A little bit annoying 2	Moderately annoying 3	Quite a bit annoying 4	Extremely annoying 5
Staff conversation noise	○	○	○	○	○
Visitor conversation noise	○	○	○	○	○
Other visitor sounds (e.g., footfall, coughing, laughing)	○	○	○	○	○
Noise from nurse station	○	○	○	○	○
Physiological sounds from other patients (e.g., coughing, snoring)	○	○	○	○	○
Medical equipment noise	○	○	○	○	○
Alarms	○	○	○	○	○
Noise from bed (e.g. squeaking, air pumping)	○	○	○	○	○
Hospital paging system	○	○	○	○	○
Air conditioning / Heating system	○	○	○	○	○
Noise from rolling carts	○	○	○	○	○

10. Please rate how annoying (if at all) you find the following noises to be during your stay in this room.					
	Not at all annoyin g 1	A little bit annoying 2	Moderatel y annoying 3	Quite a bit annoying 4	Extremel y annoying 5
Cleaning equipment	○	○	○	○	○
Telephone ringing and conversation	○	○	○	○	○
Door opening, closing, slamming	○	○	○	○	○
Falling objects	○	○	○	○	○
Television	○	○	○	○	○
Footsteps	○	○	○	○	○
Exterior noise from outside of hospital	○	○	○	○	○
If other, please describe	○	○	○	○	○

THANK YOU VERY MUCH FOR YOUR TIME AND INPUT

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