SOUNDSCAPE STUDY OF FIVE HEALTHCARE ENVIRONMENTS

By

JENNIFER LEE NELSON

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN ARCHITECTURAL STUDIES

UNIVERSITY OF FLORIDA

2012

To my family who supports me through all my adventures

ACKNOWLEDGMENTS

I thank my committee chair and members who guided me throughout the completion of this thesis. I thank the healthcare professionals of Shands at the University of Florida who opened their doors to me and allowed me to observe and collect data in their facilities. I thank my family for their wholehearted encouragement throughout my graduate degree.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Master of Science in Architectural Studies

SOUNDSCAPE STUDY OF FIVE HEALTHCARE ENVIRONMENTS

By

Jennifer Lee Nelson

May 2012

Chair: Gary Siebein
Major: Architecture

This is a soundscape study in two important areas of healthcare: the operating room and the intensive care suite. These two environments are where combinations of healthcare professionals, patients, and visitors interact with one main objective, to improve the patients' health. Much of the equipment in these environments is noisy and has an impact on the healthcare professionals' communication and patients' environment.

Observations of the operating room environment and Neonatal Intensive Care Units (NICU's) at the University of Florida (UF) were made and documented. A taxonomy of sounds was created to identify the sources present in these locations. Long-term sound levels were then recorded. In the NICU's, short-term ambient measurements were recorded to identify the frequency spectra of common sources. The NICU study at UF was then compared to an earlier NICU study conducted at Tampa General Hospital by others.[1]

Through documenting the interactions in these rooms and observing the differences in the sound levels, occupants, room finishes, layout design, furniture and construction among different places and times, trends will develop to find what is most

effective in lowering noise levels. The conclusions from this study potentially will be able to be used in the design of other healthcare spaces to improve the conditions in hospitals everywhere and lead to further questions for research topics.

CHAPTER 1
INTRODUCTION

In 1898 Florence Nightingale[2] said, “Unnecessary noise, then, is the most cruel absence of care which can be inflicted either on sick or well.” Today, over one hundred years later, sound is unavoidable and louder than ever in hospitals. In fact, sound levels have been increasing steadily since.[3] It would be impossible to completely diminish all of the sound in hospitals, because some is necessary to communicate and work. Hospitals have many different sources that are important such as alarms, equipment noise, conversations between patients and staff, and family communicating with patients. Generally the word “noise” is associated with unwanted sound, and the patient can be negatively affected by such noise. Excessive sound exposure to patients in intensive care units has the possibility of affecting heart rate, respiratory changes, and neurologic responses.[4] Excessive noise exposure affects healthcare providers as well. Increases in stress levels have been documented among nurses and healthcare providers in operating rooms and patient areas. Loud background levels can also mask important alarms and conversations between doctors and nurses leading to work errors.[5] A solution needs to be found to create an environment where the patient can heal, and the hospital staff can provide for the patient with all the necessary alarms and equipment. This involves distinguishing the difference between sounds and noise in hospitals, allowing important sounds to be heard, and attenuating the noise that is not beneficial to the environment. Some research has been done already in this area, however it is still not regulated and guidelines or standards for sound levels are routinely exceeded.

In previous literature, sound level measurements have been made and compared to the World Health Organization's (WHO) and other environmental guidelines for healthcare.[3] Yet, this only gives a close-up of the problems in current healthcare soundscapes. The whole picture, including the patient, healthcare providers, visitors, and all other occupants of the individual healthcare areas need to be examined. A sound level meter will measure the sound in its' proximity. Unfortunately the distance to the source of the sound, the room's finishes, and vibration can have an effect on the measurements of the device. To fully understand the complexity of the environment and find changes that need to be made, a series of observations, measurements, and comparisons need to occur. This paper will expand upon these areas.

This is a soundscape study in just two of many important healthcare environments. Similar soundscape procedures were used to analyze the operating rooms at the Florida Surgical Center and two Neonatal Intensive Care Units (NICU's) at Shands Hospital. First, observations of the environment were conducted including the occupants and events that occur. This led to the creation of a taxonomy of the sources of sound present in each environment. Source and receiver paths were then documented in each environment to examine the importance of conversations that occur. A series of acoustical measurements in the operating room and NICUs were made. This included reverberation times and speed transmission index (STI) to evaluate the operating room, and short-term octave band measurements to record specific acoustic events in the NICUs. A series of long-term measurements were made of both a surgery in the operating room and a weeklong survey in the NICU. From these studies, conclusions were made regarding the soundscapes of the environments including sound that is important in each room, and the noise that needs to be mitigated to create a healthy space for its patients and occupants. It also defines the features of the room that create an acoustically optimized operating environment.

In addition to the NICU study at Shands Hospital, comparisons are made to a previous study of the NICUs at Tampa General Hospital. The differences in the noise levels, occupants, and construction features show what is most effective in lowering noise levels in these environments. The results will potentially be able to be used in the design of other healthcare units to improve the conditions in hospitals everywhere.

CHAPTER 2
REVIEW OF THE LITERATURE

In 2005 the work of Busch-Vishniac *et al*.[3] noted that hospital noise routinely is among the top complaints of hospital patients, visitors, and staff, however there are few reports dealing with the control of hospital noise. The studies that do exist suggest that problems are getting worse, rather than better, even in new healthcare construction.[3] When sound is present at certain levels it causes numerous effects including sleep disturbance, concentration problems, and interference with speech.[7] It is important to review the documented effects of noise as well as its presence in healthcare.

Noise Effects on Health

Noise is defined as "unwanted sound," and has been linked to interfering with sleep, concentration, communication, and recreation. It is perceived as a signal for danger, even at levels that are not harmful to human hearing. The body produces a "flight or fight" response to sound, and results in nervous, hormonal, and vascular changes to the body.[6] The control of environmental noise has been impeded by the lack of knowledge of its effects on humans, and how much noise can be experienced before its side effects are felt or noticed. Noise exposure is often higher in developing countries due to badly constructed buildings and the lack of planning.[7] In 1974, the Environmental Protection Agency (EPA) estimated that nearly 100 million Americans experienced average noise levels that were above levels thought to be safe.[6] The *Handbook of Acoustical Measurements and Noise Control*[8] and the World Health Organization[7] has outlined the effects of noise described below.

Interference with Speech Perception

In noisy environments, slight hearing impairments in the high-frequency range may cause problems with the perception of speech. People with 40 years of age have more trouble interpreting complicated, verbal messages with low linguistic redundancy than people 20 to 30 years of age. High noise levels and long reverberation times have more adverse effects on speech perception in children than young adults.[8]

Sleep Disturbance

Sleep disturbance is considered a major environmental noise effect. The primary effects are difficulty in falling asleep, alterations in stages of sleep, and a reduction in the proportion of rapid eye movement sleep (REM). Increases in blood pressure, heart rate, and finger pulse amplitude are physiological effects. Other physiological effects include changes in respiration, cardiac arrhythmia and an increase in body movements.[7]

Effects on Performance

It has been shown in both laboratory and occupational studies that noise has adverse effects on cognitive task performance. Field studies show that noise can have effects on performance and safety as well as increase the number of errors in work, however the type of noise and task being performed affects the outcome of these studies. Most affected by noise are reading, attention, problem solving, and memory activities.[7] Factors are involved such as the person's familiarity with the work, whether the use of words is related to the task, whether the task demands attention, the length of time that the task takes, and the degree of disruption of the noise. Inefficiency is often momentary. Other factors include the person's reactivity or level of arousal in response to noise. It has been found that if the noise is expected and familiar, that it will unlikely produce inefficiency effects on the person.[8]

A noise burst that lasts between 2 to 3 seconds, and sometimes as much as 30 seconds, can impair productivity on performance. Tasks that include hand and eye coordination are most affected. Intermittent noise generally acts as a distractor or can alert and arouse a person to a task.[8]

Noise Annoyance

Annoyance is defined as, "a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them." People report negative emotion often when exposed to community noise. Emotions can include anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation, or exhaustion.[8]

Noise Effects on Patients in Hospitals

The body responds to noise in ways that it responds to stress, and can have adverse effects on hearing loss, cardiovascular disturbances, sleep disturbances, and impaired wound healing.[9] Sound levels greater than 50 dB(A) has shown sleep disturbance in hospital patients. A positive correlation exists between the noise levels of the ICU and ICU delirium related to sleep deprivation. This may have potentially, negative effects on the immune system. Patient recovery can also be negatively affected and their hospital stay can be increased.[9]

Increased noise levels can have effects on communication between health care providers and patients, such as increased errors due to miscommunication and decreased concentration levels. Patient safety can also be affected in noisy environments due to delayed responses to alarms.[9]

Noise Effects on Neonates in the NICU

As premature infants reach school age, higher incidents of neurodevelopmental disorders are being discovered. There is concern that these disorders can be attributed to excessive noise exposure in the NICU.[10] Some possible effects of noise exposure are described further.

Heart Rate Response

Williams et al.[11] studied the correlation between NICU sound levels and newborns' heart rate and blood pressure during their first week of life to determine if the patients' birth weight created a difference. Thirty neonates were observed with birth weights between 401 and 1000 grams. The weekly average noise levels ranged from 55 to 60 dB(A). Lower birth rate newborns (454 to 694 g) experienced an increase in heart rate after 20 seconds of exposure to increases in noise levels. Responses to increases in NICU noise were delayed when compared to high-intensity impulse sound stimuli. Higher birth rate newborns (766 to 910g) experienced a heart rate deceleration from 25 to 60 seconds after sound levels increased, and then experienced an increase in heart rate around 175 seconds after the sound levels increased. This is termed a biphasic heart rate response.[11]

Blood Pressure Response

Williams et al.[11] also looked at the mean arterial blood pressure in correlation to high sound levels in the NICU, however there was not as strong of correlation as shown by sound levels and heart rate. The higher birth weight neonates experienced a similar biphasic blood pressure response, although it was more delayed than the results displayed by heart rate response. Lower birth weight neonates did not show a significant increase in blood pressure after exposed to NICU noise stimuli.[11]

Noise Effects on the Fetus and Newborn

Exposure to elevated noise during pregnancy can result in newborns with high-frequency hearing loss, and may be associated with premature births. Lower birth rates have also been recorded to women exposed to increased sound levels during pregnancy. One study showed high-frequency hearing loss in children 4 to 10 years of age could be linked to their birth from women exposed to occupational noise 85-95 dB during pregnancy.[12]

Studies have documented hearing loss in children cared for in the NICU, sometimes referred to as NICU graduates. Loud noises in the NICU can change behavioral and physiological responses of infants. Premature infants exposed to noise in the NICU can result in cochlear damage, and can disrupt normal growth and development.[12]

In a study conducted by Stennert *et al*.[13], it was concluded that long-lasting exposure to incubator noise could act as an additional factor in the cause of auditory damage in high-risk preterm infants connected with hypoxia, acidosis, shock, and drugs.

Noise in Hospitals

As noted by Busch-Vishniac *et al.,*[3] past studies on noise levels in hospitals are limited to overall A-weighted and linear noise levels that do not discuss the frequency, tonality, and time variance. This is a problem since most hospital alarms and machines produce transient noises. Busch-Vishniac *et al*. uncovered two important conclusions while gathering data from past hospital noise literature. First, not one published study met the guidelines set by the World Health Organization (WHO) for noise in hospitals. In fact, most studies showed that the sound levels were 20-40 dB(A) higher than recommended. Secondly, it showed hospital noise levels have risen steadily since the

1960s. The A-weighted Leq in hospitals has increased from 57 dB(A) in 1960 to 72 dB(A) today during daytime hours, and from 42 dB(A) in 1960 to 60 dB(A) today during nighttime hours. Levels were also consistent amongst all hospital units, regardless of the type of medical unit or hospital location. This suggests that hospital noise levels are consistent across many different facilities regardless of location or type.[3]

There are many different types of sound sources in hospitals that can be attributed to its noisy soundscape. Noise sources can include mechanical equipment, alarms, paging systems, telephones, computers, staff conversations, and much more. The materials used in hospitals are also generally more reflective than absorbent. Walls, ceilings, and floors are usually hard surfaces that allow for easy cleaning and sanitizing. Absorbent fabrics are not found in many places because there hasn't been an easily cleaned absorbent fabric found in the industry. The hard surfaces allow noise to propagate considerable distances and to create long reverberation times in patient areas.[14]

Many past studies characterize the existing environment in healthcare facilities, but many do not provide the reasons as to why it is noisy. It is hoped that by observing surgeries and documenting specific noisy instances it will help to understand why the operating room environment and patient areas are loud, and how to control the sound levels within these rooms to make them safe and quiet working environments.

Reducing Noise in Hospitals

Several studies have found that installing high performance sound absorbing ceiling tiles and panels can significantly decrease reverberation times and sound propagation in hospitals. This can also improve speech and intelligibility and decrease stress levels of hospital staff.[14]

Studies conducted in multi-bed rooms have found that most noises are from the presence of other patients, including additional staff, equipment, visitors, and other patient sounds. There has been additional data that show patient satisfaction can improve significantly for patients in single-bed rooms compared to those with a roommate for "noise levels in and around your room." These studies contribute to the idea that single-bed rooms can be one of the most-effective strategies for reducing noise levels in patient rooms.[14]

Overhead paging systems contribute to loud noise levels found in most hospital units. Overhead paging systems can be replaced with cell phones or wireless communication devices carried by staff.[5] Busch-Visniac *et al*.[3] noted however that while personal communication devices show large promise in reducing sounds associated with overhead paging that propagate throughout many spaces at elevated levels, the speakers on personal devices are small allowing them to be mobile, and thus reduce sound quality and intelligibility. However PICU staff in this study found this compromise sufficient in having the advantage of efficient and hand's free communication. [3]

Equipment noise and staff conversations are two other main contributors to loud noise levels in hospitals. Turning off equipment not in use and staff education programs are two easy solutions but are hard to implement and keep recurring.[14]

In Busch-Vishniac *et al*.'s[3] measurements in different hospital units they compared 24 hour sound levels in occupied patient rooms, unoccupied patient rooms, examination rooms, hallways, and nurses stations. The results showed that the hallways tended to be the loudest areas due to nurses' stations and patient rooms being very close to each other after the hallways. The quietest areas were the unoccupied patient rooms. In a

Pediatric Intensive Care Unit (PICU), only in the non-occupied rooms did the sound levels fluctuate to correspond to the time of day. Patients within an ICU need around the clock monitoring, so it is not surprising to find that the levels were consistently high at all times of the day at the nurse's station or in occupied patient areas. It should be noted, that some of the unoccupied rooms in one of the units measured did not meet the World Health Organization guidelines for sound levels due to the noise from the HVAC mechanical system.[3]

Operating Rooms

Many surgeons, anesthetists, and operating room nurses answered yes in response to a subjective questionnaire on noise in operating rooms, when asked whether there was any noise in the operating room and if they felt that noise has a negative impact on their job.[15] The differences in answers between the three groups were measured to be significant (p value < 0.050). Anesthetists were found to be most sensitive to noise, and surgeons the least. The main source of noise in the operating room was chosen as conversation, and all three groups were highly affirmative. Louder conversation, or arguments, machines being operated, external noise, and air-conditioning systems were also selected. The survey also found that the responsibility of the individual affected their answers. A head surgeon was more affected by noise than the rest of the surgical team.[15]

The type of operation, its duration, the stage of the operation, the type of equipment, the number of people in the operating room, and the operating room itself all affect the sound level during the operation. The relation of the operating room personnel to the equipment and their time of exposure influence how they perceive sound. For example an anesthetist is normally close to their equipment and this influences their noise exposure and opinion.[15]

In another study, sound pressure level measurements were obtained from the operating rooms throughout Johns Hopkins Hospital. The rooms varied in size from 272 to 733 ft^2 with an average area of 484 ft^2. All of the rooms had hard surfaces and no standard acoustical treatment.[16] During multiple surgeries occurring in Johns Hopkins Hospital, it was found that sound pressure levels averaged between 55 and 70 dB(A) with significant peak levels, some exceeding 95 dB, during surgery. The majority of the monitored surgical divisions experienced peak levels of at least 110 dB and some over 120 dB. This raised concerns for potential hearing loss and disruption to clear speech communication. The recordings for this study were taken over 24 hour periods, and surgical logs were used to identify the type of surgery and action that was going on during the recordings. WAV files were not recorded, thus not allowing the identification of transient sounds. The authors note that this limited the study because it was not possible to link specific acoustical events, such as the use of a bone saw to the observed high sound pressure levels. The study showed a tight distribution of sound pressure levels regardless of the type of hospital or geographic location, thus one may be able to apply the sound levels measured in this study of operating rooms to the general population of operating rooms.[16]

Overall, the surgeries spanned a range of Leqs from 53.0-70.5 dB(A), and the averages by category ranged from 58.0 to 67 dB(A). Peak levels were also examined by category. It was found that the surgeries with the highest peak levels (above 95 dB) were neurosurgery, orthopedics, otolaryngology, urology, cardiology, and pediatric plastic surgery. Neurosurgery procedures had the highest peak noise exceeding 95 dB over 78% of the time. The noise levels were generally sustained at this level and did not have high maximum or Lpeak levels.[16]

The conclusions to this study found that sustained sound pressure levels in the operating room were not sufficiently high to cause hearing loss, however most surgeries experienced peak levels of 110-120 dB. It was also found that the spectrum levels of the data were relatively flat over most of the frequency range, including the speech frequencies. Speech communication generally requires a 15dB signal to noise ratio, suggesting that speech levels at 70-85 dB(A) were necessary to compete with the other sound sources in the room. Normal speaking levels are roughly 55-65 dB(A).[16]

Wallace *et al,*[17] measured 24 operating rooms to find their background noise. All equipment except for the air handling system was turned off. Background levels ranged from 46 to 57 dB(A), with an average level of 52 dB(A).[17]

Neonatal Intensive Care Units

In *The Recommended Standards for the Newborn ICU*[18], newborn intensive care is defined as "care for medically unstable or critically ill newborns requiring constant nursing, complicated surgical procedures, continual respiratory support or other intensive interventions." Infants in the NICU are generally delivered preterm and thus their auditory system is introduced to sound earlier than normal as they are unshielded by maternal tissues that attenuate frequencies greater than 250 Hz.[19] It has been shown in studies that continuous noise exposure at or above 60 dB creates problems with sleep disturbance, stress, and hearing loss. Babies who received care in NICUs are also at risk for poor developmental outcomes. The relationship between developmental problems of preterm births and care received in the NICU has not been closely studied, but it does raise concern for the high sound levels found in the NICUs. Concerns have continued to rise in the past thirty years of the excessive levels in NICUs and these effects on patients.[19]

Williams *et al*.[20] produced a comparative study of two NICUs. One was modern and constructed with noise abatement in mind; the other was built when noise control was not of concern and had been updated recently. The NICU's were divided into isolation, Level II, and Level III units. Level II units were the step-down units, and Level III units were for the critical patients. Over a week period, 5s levels were measured in the different level units within both NICUs. The 5s Leq distribution measurements were analyzed between the units, as wells as the Lmax levels, and variability over time. The variability over time in the NICU can better predict arousal and behavioral state changes of the infant, since constant sound levels are less disruptive than changing transient sounds.[20]

It was revealed that noise levels were up to 5 dB higher during the workday 7am-7pm. Higher noise levels attributed to shift changes occurring in the NICU at 7 am and 7pm. Higher noise levels at 9am, 12pm, and 3pm were attributed to nurses recording vital signs, diaper changing, feedings, and other care.[20]

Overall sound levels were lower in the modern NICU, even though there was also more variability in the sounds that occurred. This was explained by the noise control methods used in the modern NICU, specifically its construction and isolating spaces for activities that do not directly interact with the patient, such as restocking supplies and washing hands. The use of carpeting on the floors and noise attenuating materials also contributed to containment of noise.[20]

Within both NICUs, Level II units had lower sound levels than Level III units, yet Level II units had the most variable sound levels. Level II units had less need for intensive care. However, when sound levels were loud, they were really loud. It was found that these units often required minimal care and had no visitors, while other times they were many visitors as the newborns were soon to be discharged.[20]

A separate study compared two intensive care units (ICUs) is applicable to this study even though it is not specifically a NICU. Many of the same measurement techniques and observations apply. One of the ICUs was a recently built neurological ICU and the other was a 1980s-era medical-surgical ICU. The medical-surgical ICU was perceived as louder and more annoying compared to the neurological ICU. Overall sound level measurements were conducted in both spaces and surprisingly little differences were found between the two units. It was found after detailed analysis of both spaces, that the occurrence rate of peak and maximum levels, frequency content, and speech levels were different. Mid-level transient noises were also significant in comparison to the perceived loudness and annoyance levels. This supports the theory that traditional sound measurements may be inadequate in showing the differences in perception of hospital environments. The perception of occupied spaces will likely be related to the occurrence of transient sounds.[21]

Increased sound pressure levels can also inhibit communication in the NICU. A previous study by Tzaneva showed that speech communication was severely depreciated at intensity levels of 70 – 75 dB(A). NICUs do not have continuous noise levels in this range, however the max SPL frequency exceeds 70 dB from used equipment in the NICU and can affect communication at these times.[5]

Levels of Care in the NICU

Levels of care have been defined for the NICU to assess the needs of patients. They reflect the unit's capabilities of providing complex care with proper personnel, equipment, and organization. The below definitions are provided by the journal Pediatrics, which is the official journal of the American Academy of Pediatrics.[22]

Level I

These are well-newborn nurseries that provide a basic level of care for newborn infants that are at low risk. They are able to stabilize and care for new-term infants (35-37 weeks gestation).[22]

Level II

These are specialty care nurseries that can provide newborn infants whom are moderately ill with issued that are expected to improve quickly. Patients are usually more than 32 weeks and weight more than 1500 grams at birth. Some Level II units are differentiated into IIA and IIB on whether they can provide assisted ventilation.[22]

Level III

These are subspecialty newborn nurseries that can provide continuous care to patients for as long as needed. IIIA nurseries can provide care to infants of age more than 28 weeks gestation and over 1000 grams at birth. IIIB nurseries care for infants of less than 28 weeks gestation or extremely low birth weight of less than 1000 grams at birth. Advanced respiratory care is available, such as high-frequency ventilation. IIIC nurseries can provide the most advanced care including ECMO and surgical repair of complex congenital cardiac malformations that require cardiopulmonary bypass.[22]

Guidelines

While there are several standards and guidelines listed for hospital noise criteria, The World Health Organization is the most cited and relied on the most in the literature.[3] WHO[7] notes that speech intelligibility is adversely affected by noise, it states that RT times above 1-second renders speech difficult to understand. It also suggests a signal-to-noise ratio, which is the difference between the level of speech and the level of the interfering noise, to be at least 15 dB(A) to achieve good speech clarity. The sound pressure level of normal speech is generally around 50 dB(A), which means that 35 dB(A) of background noise will begin to interfere with normal speech in smaller enclosures (24). WHO notes for hospitals that noise indoors can have critical health effects on sleep disturbance. It advises the LAeq should not exceed 30 dB(A) indoors during the night and day and at night the LAmax on Fast settings should not exceed 40 dB(A). For hospitals, treatment rooms, and indoors which could have critical health effects on interference with rest and recovery, the LAeq and LAmax is listed as being "as low as possible."[7]

The "Recommended Standards for the Newborn ICU,"[18] published in the Journal of Perinatology states that in patient rooms the background noise level should not exceed an hourly Leq of 45 dB(A) and an hourly L10 of 50 dB(A) measured with a slow response on the sound level meter. It goes on to say that transient sounds, or the Lmax shall not exceed 65 dB(A) measured with a slow response on the sound level meter. To meet these levels it states that all mechanical systems and permanent equipment should not exceed NC-25.[18]

The American Academy of Pediatrics (AAP) recommends sound levels should not exceed 45 dB(A). The Sound Study Group (SSG) recommends hourly Leq should not exceed 50 dB(A), hourly L10 should not exceed 55 dB(A), and 1s Lmaxs should not exceed 70 dB(A).[20]

Measurements

Ryherd *et al.*[23] noted that previous research on noise in hospitals has been focused on overall sound levels and has left out detailed information such as frequency distribution, and time variance. These aspects of sound have the ability to affect people's perception, annoyance and performance. Less reported criteria such as statistical exceedance levels (Ln), reverberation time (RT), speech intelligibility (SI), and frequency analysis or noise criteria indicators of spectral content would be valuable to developing an understanding of the soundscape of health care environments.[23]

The Johns Hopkins study gave background sound levels in octave bands for each OR, and typical Leq and peak levels for particular surgeries. A-weighted Leq and flat frequency analysis in octave bands from 16Hz-16Khz were obtained. Peak sound pressure levels (unweighted), Lpeak, were also found. The rooms were analyzed using both 5 and 30 min averaging intervals for the Leq. More refined time periods of 30 s and 5 min were reexamined for representative rooms. For A-weighted, the sound level meter slow setting was used. Lpeak were instantaneous limited by analog to digital converter speed.[16] This study recommends looking at L50 or STI and focus on quicker detection times (fast or impulse settings on sound level meter) that are more appropriate for speech.[16]

Okcu *et al*.[21] found in the literature that many different measurements have been used to record sound pressure levels in healthcare environments. Durations from a few minutes to 168 hours are noted, yet 24-hour measurements are the most common. Slow and fast response times are used, however WHO suggests using the fast response time (0.125s). Intervals for averaging often range from 5 s to 24 hours. In ICU studies 1 minute averaging is used most often. Measurements for day and night times are often compared to each other and weekday measurements are the most common. Nurse shifts are usually split between daytime and nighttime as 7am-7pm and 7pm-7am.[21]

CHAPTER 3
METHODS

Similar procedures were used analyze the operating rooms at the Florida Surgical Center and two Neonatal Intensive Care Units at Shands Hospital. Observations were conducted of each environment during a typical workday. The environments were documented, and a taxonomy was created to list the noise sources present. Source and receiver paths were also observed in each environment to examine the importance of conversations that occur. Acoustical measurements for each room were conducted. In the operating room this included measuring the reverberation time (RT), speech transmission index (STI), and rapid speech transmission index (RASTI) to evaluate the clarity of speech. A long-term measurement of a surgical operation was also recorded. For the NICUs, short-term octave band measurements of specific events identified as loud noise sources were recorded, as well as a series of long-term measurements to identify the sound level trends were made.

Environment Analysis

The Operating Room at Florida Surgical Center. At the Florida Surgical Center surgeries took place in operating rooms that were approximately 400 ft^2 (see fig. 3-1). Details about the room, occupants, equipment, footpaths, background noise, and specific events were documented. A taxonomy was created to identify the individual noise sources, and the source and receiving pairs were recorded.

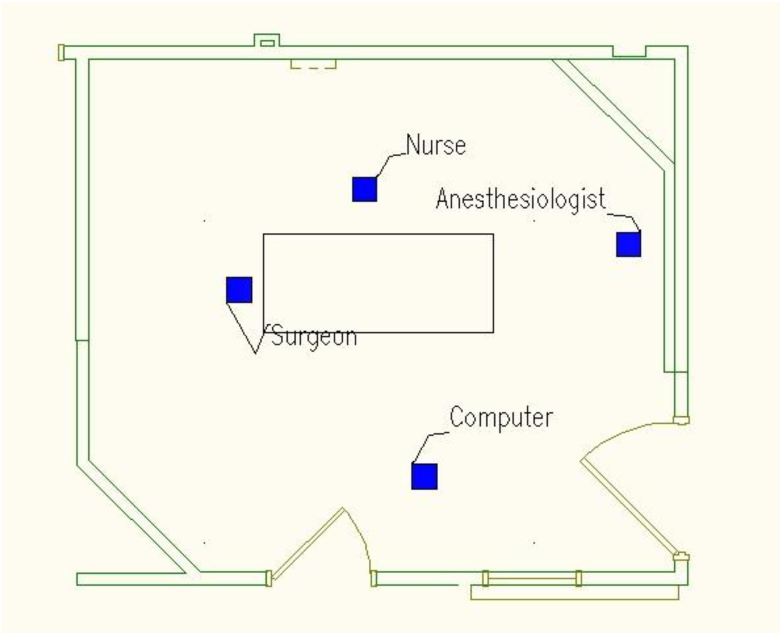


Figure 3-1. Floor plan of a typical operating room

Procedure for Florida Surgical Center

Head & Neck surgeries, specifically on the ear, were observed on three separate visits. During surgery there could be up to eight healthcare professionals in the room, however four locations were routinely occupied. Therefore, these locations were chosen for reverberation time (RT), speech transmission index (STI) and rapid speech transmission index (RASTI) measurements because of the importance of the conservations that occurred between them. WinMLS was used for RT, STI, and RASTI measurements. Four tests were conducted to represent the variation of sources and receivers. Test 1 was the source at the surgeon and the receiver at the anesthesiologist. The surgeon frequently gave instructions to the anesthesiologist. Test 2 was for the surgeon and the location at the computer in the room. The surgeon communicated events to a nurse seated at the computer, and the nurse then recorded these events. Test 3 was between the surgeon and the nurse locations. The nurse or surgical assistant prepared utensils and gave the surgeon the tools that he requested. Test 4 had the source and receiver switched from Test 1. The Anesthesiologist was the source and the surgeon was the receiver. This condition occurred when the anesthesiologist had to communicate to the surgeon on the patient's condition. Table 3-1 presents these conditions. Reverberation time, STI, and RASTI was calculated for 4 different calculations.

Table 3-1. Source and Receiver Combinations for RT, STI, and RASTI Tests in the OR

Test	Source	Receiver
1	Surgeon	Anesthesiologist
2	Surgeon	Computer
3	Surgeon	Nurse
4	Anesthesiologist	Surgeon

A RION NA-27 1/3 octave band analyzer sound level meter was used in the operating rooms to measure ambient levels and long-term surgery measurements. The microphone of the sound level meter was held at ear level of the seated surgeon. A windscreen was placed on the microphone to protect it from the environment. Before each survey, the meter was calibrated to 114 dB on location. A moderate range of 30 dB to 100 dB was set for data recording.

NICU A. NICU A is a Level III unit as classified by the American Academy of Pediatrics.[22] The open floor plan is shown in figure 3-2 above. The unit provides isolation rooms as well as Extra Corporeal Membrane Oxygenation (ECMO). It operates 24 hours a day and is available to newborn infants in need of very critical care. Visitors are allowed in to the NICU 24 hours a day except for the first 30 minutes of shift changes at 7:00 am and 7:00 pm. The unit is focused on the stabilization and critical care needs of the neonate and family. As the newest NICU in the hospital, it was designed with modern technologies and acoustics in mind. It is the preferred NICU by the hospital staff, and is perceived as quieter than NICU B based on individual conversations with staff.

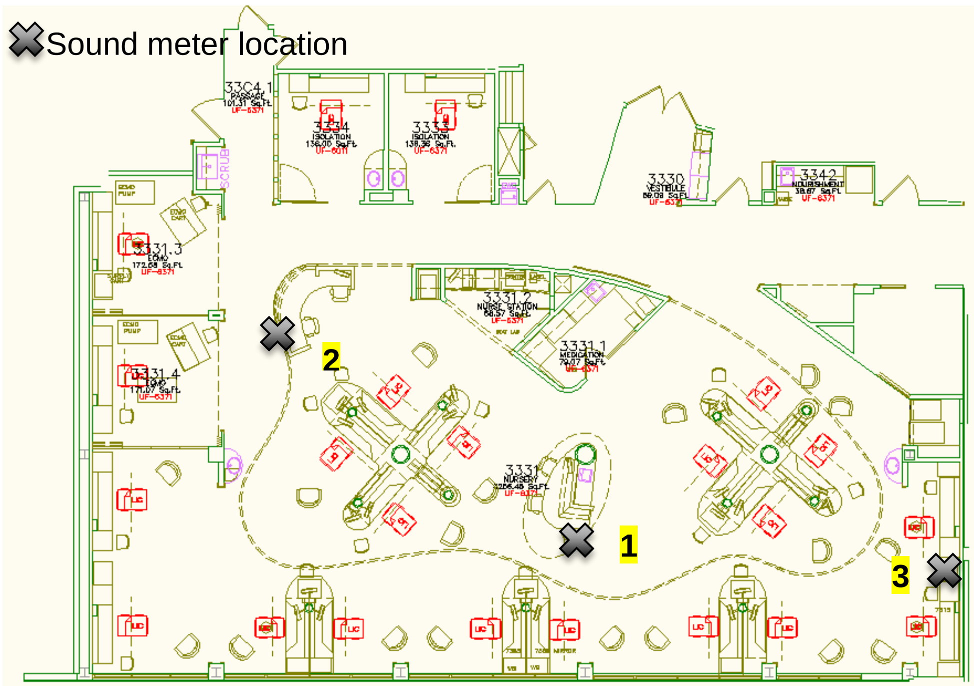


Figure 3-2. NICU A Floor Plan

NICU A is a 22-bed unit, however at times there are more than 22 beds present if needed. Each nurse is assigned to 2 patients, and sometimes 3 if a nurse calls in sick. Both NICU A and B are located on the 3rd floor of the Patient Services Building. All patients in NICU A and B have bedsides with the equipment capability to monitor heart rate, respiratory rate, blood pressure, and oxygen saturation levels.[24]

There are sound absorbent ceilings with a high NRC acoustical ceiling tile and strategically placed space dividers with sound absorbent facings to reduce the propagation of sounds to other beds in the unit. In the center of the patient area, the beds are arranged in pinwheel shaped pods to allow for sounds to be contained within the individual patient's designated space and to decrease noise overflow. On the outer edges of the room, the beds are up against the wall, however there are space dividers allowing acoustical privacy between patients. Fabric wrapped panels are also placed on these outside walls. The floors are made of a sound absorbent rubber that has less impact noise than traditional flooring.

The entrance into NICU A has partitions allowing it to be separated from the main patient floor. A sink is located in the entrance and is used by all visitors prior to entering into the NICU. The nourishment center is also located in the entrance hallway, separated from the patient floor of the NICU. The lobby area is completely separated from the entrance hallway, however a door that leads into the NICU from the receptionist's office is sometimes left open and creates an area for nurse's to converse with each other. A pneumatic tube transporter is inside the receptionist office to eliminate its noise from the patient area.

NICU B. As shown in figure 3-3, NICU B also has an open plan, however it does not provide much acoustical separation between individual patients. There are 3 rows of beds with only 1 divider below adult eye level that is between the front 2 rows. NICU B is a Level II unit as classified by the American Academy of Pediatrics.[22] It operates 24 hours a day. Visitors are allowed in to the NICU 24 hours a day except for the first 30 minutes of shift changes at 7:00 am and 7:00 pm. NICU B is the inpatient sister unit of NICU A. Patients are transferred between NICU A and NICU B based on their acuity. NICU B is focused on the intermediate or recovery phase of the neonate's care. The patients are banded with security devices that will alarm if the device is breached.[24] This is called a "HUG" alarm and will sound a very loud alarm that signifies lock down.

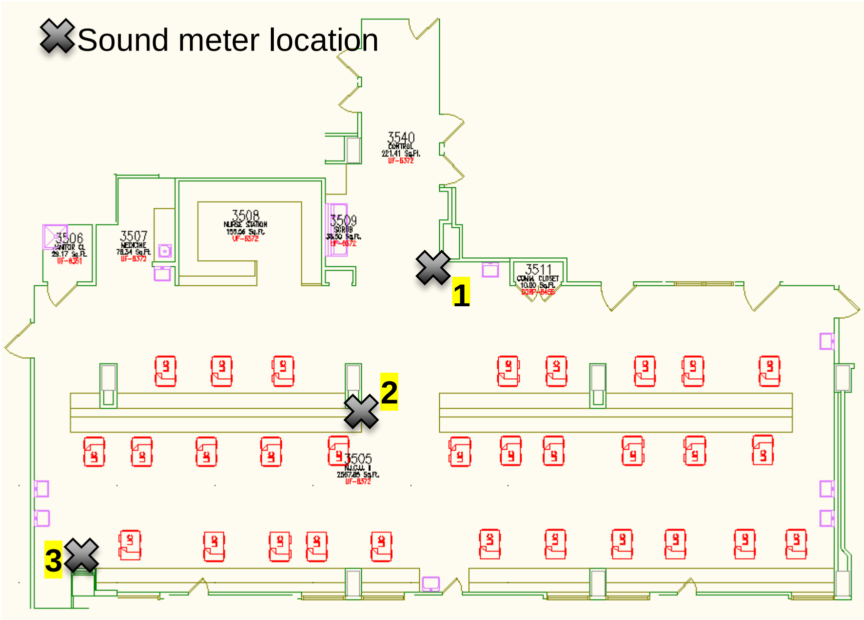


Figure 3-3. NICU B Floor Plan

NICU B is a 30-bed unit, however there are sometimes up to 32 patients. Each nurse is assigned to 3 or 4 patients. The main hallway that leads into NICU B is at the first row of patients. The nurses' station, medication room, visitors' sink, and pneumatic tube transporter are all located on the entrance hallway and are within 10 feet of the first row of patients.

The walls were painted gypsum board, and the floor was wood. There were windows on the back wall of the room, and no acoustical walls were installed. Acoustical ceiling tile was installed in the ceiling, and cabinets and doors were mounted in the room.

A study previously conducted in 2008 at the Tampa General Hospital Neonatal Intensive Care Unit is also compared to the NICUs at Shands Hospital. The unit existing at that time was divided between the 4th and 5th floor creating two separate units. The 4th Floor NICU will be referred to as NICU C and the 5th Floor NICU will be referred to as NICU D.

NICU C. NICU C (see fig. 3-4) is capable of providing Level II and Level III care as classified by the American Academy of Pediatrics.[22] The unit also provides Extra Corporeal Membrane Oxygenation (ECMO). NICU C has approximately 35-40 patient beds, two isolation rooms and one room dedicated to ECMO. The unit has hard, sound reflecting surfaces. It is divided into three aisles with aisles 1 and 2 being Level II care and aisle 3 as Level III care. Aisle 1 has a plexi-glass divider to separate it from the rest of the unit and it is capable of reducing the amount of sound that is propagated to aisles 2 and 3. Aisles 2 and 3 do not utilize a plexi-glass divider, and thus sounds are transmitted between the aisles, resulting in higher sound levels.

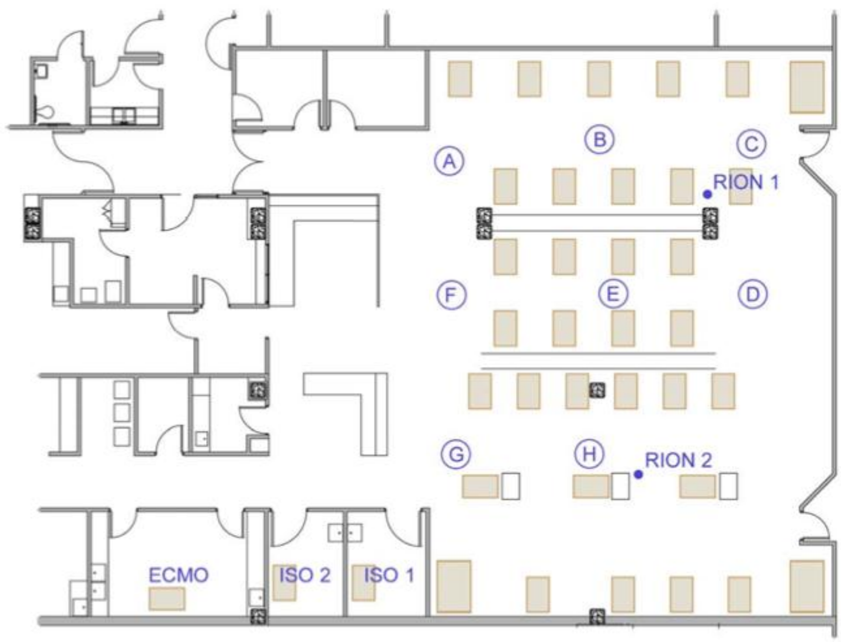


Figure 3-4. NICU C Floor Plan

NICU C had loud mechanical systems that contributed to the background noise levels. This noise consists of several components: low frequency “rumble” from mechanical equipment, duct generated noise due to high velocity air moving through ducts; a “hissing” noise as air passes through supply diffusers; and various “rattling” sounds from loose hardware, etc. Ambient noise levels were thus approximately 55 to 60 dB(A) and resulted in medical staff speaking louder to communicate with one another. The volumes of alarms are thus set higher and general communication is inhibited.

NICU D. NICU D (see fig. 3-5) is a Level II unit as classified by the American Academy of Pediatrics.[22] There are approximately 9-12 patient beds. There is a central corridor that connects three groups of patient rooms with three to four beds in each. In addition, there are two nursing stations and a private Sleeping Room on this floor. In each patient room there is equipment that consists of incubators/basins, cardiac and respiratory monitors, ventilators, and various pumps.

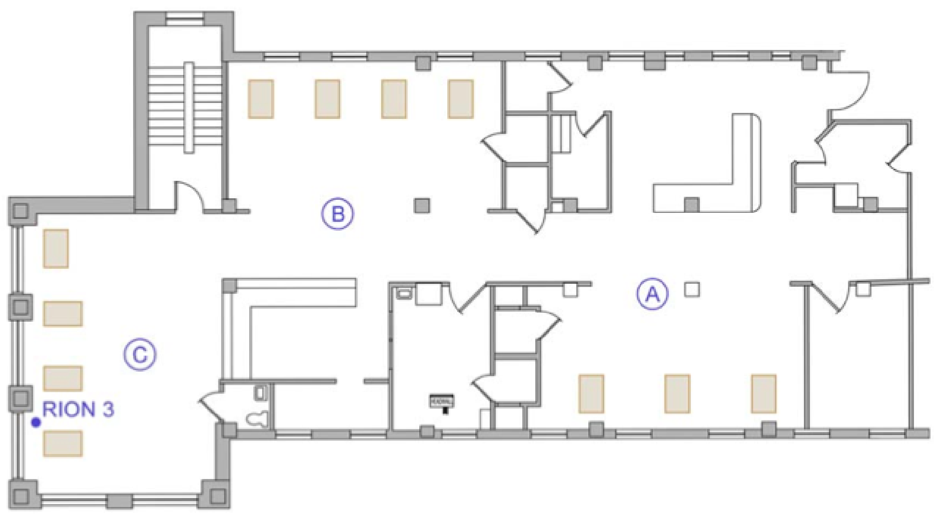


Figure 3-5. NICU D Floor Plan

Each separate area of patients in NICU D contains significantly fewer patients than NICUs A, B and C. Therefore, NICU D has lower ambient noise levels due to the reduction of patient equipment, caregivers, and other equipment.

Procedure for NICU A and B Study

Prior to setting up the week surveys, several site visits to observe activities conducted in the rooms occurred in NICUs A and B.   This allowed many of the noise sources in both of the rooms to be identified and categorized. A taxonomy of the noise sources was created. Individual noise sources were recorded by spot measurements to capture their overall A-weighted octave band sound pressure levels. Important communication was also observed between doctors, nurses, visitors, patients and other occupants of the environment. An importance factor of these conversations was noted and provides insight into the soundscape. Foot traffic was also noted in both NICU A and B as their bed arrangement requires different ways circulation paths for movement through the NICUs.

Observations made in both NICUs allowed noise maps to be created to show potential loud areas, and construction features that prevented noise build-up. The locations allowable for the sound level meters were limited and were chosen based on the noise levels in those areas and the requirement that the meters remain unobtrusive to the pathways for doctors, nurses, patients, and visitors. Three RION NL-32 integrating sound level meters were used in each NICU. The RION NL-32 meets ANSI requirements for type I sound level meters. The microphone for each sound level meter was placed on a tripod with an extension cable attached to the microphone that allowed the sound level meter to be placed in a pelican case that was located on the floor beside the tripod. A windscreen was placed on the microphone to protect it from the environment. Before each survey, the meter was calibrated to 114 dB prior to arriving on location. A moderate range of 20 dB to 110 dB was set for data recording. The sound level measurements were averaged over a 10 second interval.

The sound level meters recorded long-term sound levels in NICU A and B for a period of 4-6 days. The 10 s data was averaged into 1-Hour LAeq levels so that the hour levels could be compared across the days and across all of the NICUs in the study. LAmax data was also analyzed; The percentage of LAmax levels surpassing 70 dB(A) was calculated for each sound level meter to compare different locations and to compare between NICUs A and B.

In NICU A, one tripod was located at each of the two nurses' stations within the patient area. One of the nurses' stations is near the center of the patient area, and the other is located on the edge of the patient area next to an isolation room. The ideal height of the receiver would be at the height of the neonate's head in the incubator, however it was more important to have the meter located away from reflective surfaces. In most locations the tripod was secured to the side of a desk. This allowed the tripod be kept out of the way of moving traffic and to protect it from being hit by carts and people. A sign was attached to the tripod to notify people in the NICU that it was for a sound test and their voices would not be recorded. The locations of the sound level meters are explained below and are shown on the floor map of NICU A in figure 3-2.

Meter #1 (Fig. 3-6) was placed at nurses' station (1) in the Northwest corner of NICU A. Its location was chosen due to it being one of the louder spaces of NICU A. It is located next to the hallway into the NICU A patient area and beside the isolation rooms. The microphone was placed at 54" from the floor. Measurements were recorded from November 30, 2011 at 13:51:08 to December 6, 2011 at 13:47:38.

Figure 3-6. NICU A Sound Level Meter #1.

Meter #2 (Fig 3-7) was placed at nurses' station (2) towards the center of the NICU A. This location was chosen due to it being one of the louder spaces in the NICU A. It is located towards the South wall of the patient area. The microphone was placed at 54" from the floor. Measurements were recorded from November 30, 2011 at 13:55:06 to December 4, 2011 at 18:36:16.

Figure 3-7. NICU A Sound Level Meter #2

Meter #3 (Fig. 3-8) was placed in a patient area in the Southeast corner of the room. This location was chosen due to it being one of the quieter spaces in the NICU

A. The microphone was placed at 58” above the floor so that the wall behind it would be a fabric wrapped panel and not a reflective surface. Measurements were recorded from November 30, 2011 at 14:00:04 to December 6, 2011 at 13:56:54.

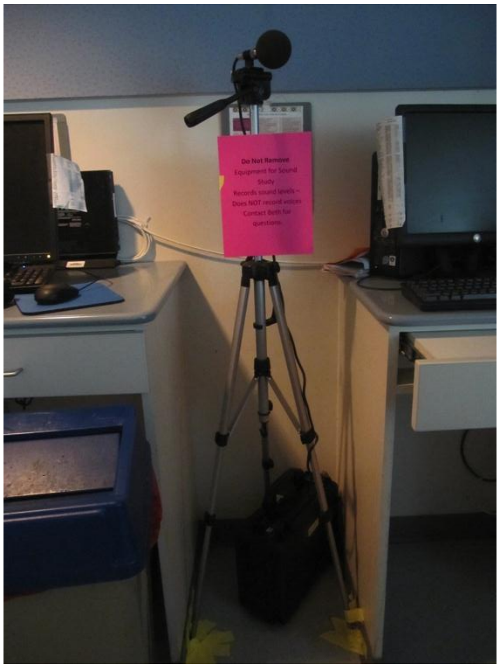


Figure 3-8. NICU A Sound Level Meter #3

In NICU B, one tripod was located in a patient area, one was in the central walkway in the patient area, and the other was at the intersection of the visitors’ entrance into the NICU and the front walkway of the patient area. In most locations the tripod was secured to the side of a desk. This allowed the tripod be kept out of the way of moving traffic and to protect it from being hit by carts and people. A sign was attached to the tripod to notify people in the NICU that it was for a sound test and their voices would not be recorded. See figure 3-3 for a floor map of NICU B with locations of the sound level meters.

Meter #1 (Fig. 3-9) was placed across from the visitors’ sink at the entrance into NICU B. This location was chosen due to it being one of the louder spaces in the NICU B. It is located across from the patient area. Nurses converse with visitors as they prepare to enter the patient area. Due to its location away from the patients, many conversations take place here, even though their noise drifts to the patient area. The microphone was placed at 58” from the floor due to its proximity near a vent. Measurements were recorded from January 4, 2012 at 12:52:38 to January 8, 2012 at 10:28:18.

Figure 3-9. NICU B Sound Level Meter #1

Meter #2 (Fig. 3-10) was placed in the middle of the patient area in NICU B. Its location was to the side of the center aisle. This location was chosen because of its central location in the NICU and that it did not disturb foot traffic. The microphone was placed at 60” from the floor to avoid reflective surfaces. Measurements were recorded from January 4, 2012 at 12:56:26 to January 10, 2012 at 16:33:16.

Figure 3-10. NICU B Sound Level Meter #2

Meter #3 (Fig. 3-11) was placed in the Southwest corner of NICU B. Its proximity to a patient's bedside makes it a great place to measure what a typical neonate experiences in NICU B. This location is one of the quieter spaces in NICU B because the only foot traffic it receives is from those going to this specific corner. Due to its location near the patient, the conversations that take place here are from the nurses conversing with each other about the specific patient and the visitors talking to the patient or each other. The microphone was placed at 58" from the floor to be close to the height of the other meters in NICU B. Measurements were recorded from January 4, 2012 at 13:00:40 pm to January 10, 2012 at 16:39:00 pm.

Figure 3-11. NICU B Sound Level Meter #3

Measurements in NICU C and D

The 3 RION NL-32 sound level meters were also used to record long-term ambient sound levels in both NICU C and D. The RION NL-32 meets ANSI requirements for type I sound level meters. The microphone was covered with a windscreen and positioned on a tripod approximately 4 ft. from the ground, the height of an infant at crib height. The floor plans for NICUs C and D shown above in figures 3-4 and 3-5 respectively, indicate the locations of the sound level meters, marked RION 1, 2, and 3.

Long-term, ambient sound measurements were recorded on December 23, 2008 from approximately 12:30 PM to 3:00 PM and on January 21, 2009 from approximately 6:50 PM to January 22, 2009 at approximately 12:45 PM. Locations of the meter remained the same during both site visits as shown in figures 3-4 and 3-5.

Short-term Acoustical Measurements of Specific Acoustic Events

In addition to the long-term measurements in NICU A and B, short-term octave-band measurements were also made to provide sound level measurements of transient noise. This included ambient noise, which is the room's background noise with sound such as HVAC and patient equipment running. However the ambients were measured without alarms and specific acoustical events present. Other transient noises included alarms, paper towel dispensers, and patient noise, such as crying at the patient's bedside. Figures 3-12 and 3-13 show where the ambient levels were measured in NICU A and NICU B respectively.

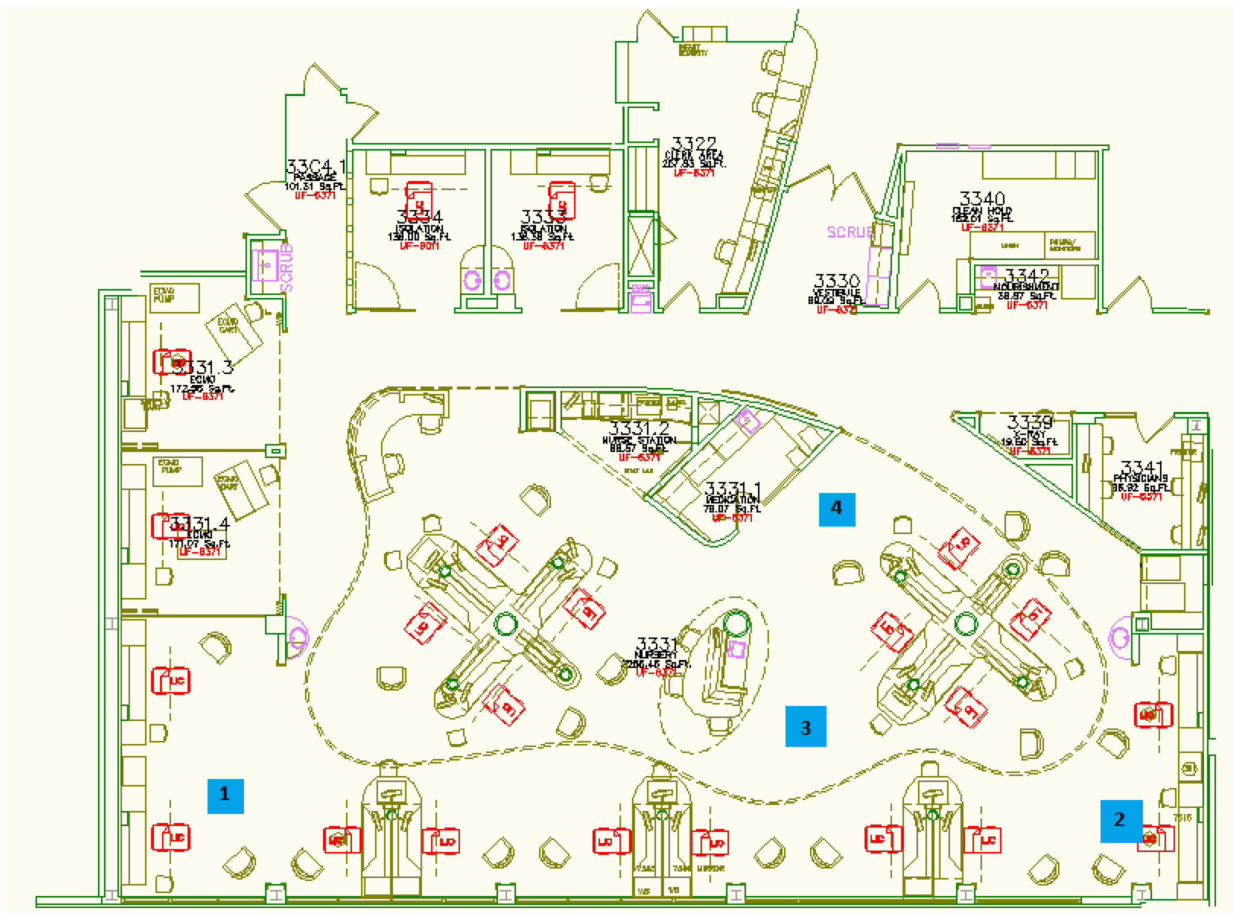


Figure 3-12. The ambient measurement locations in NICU A.

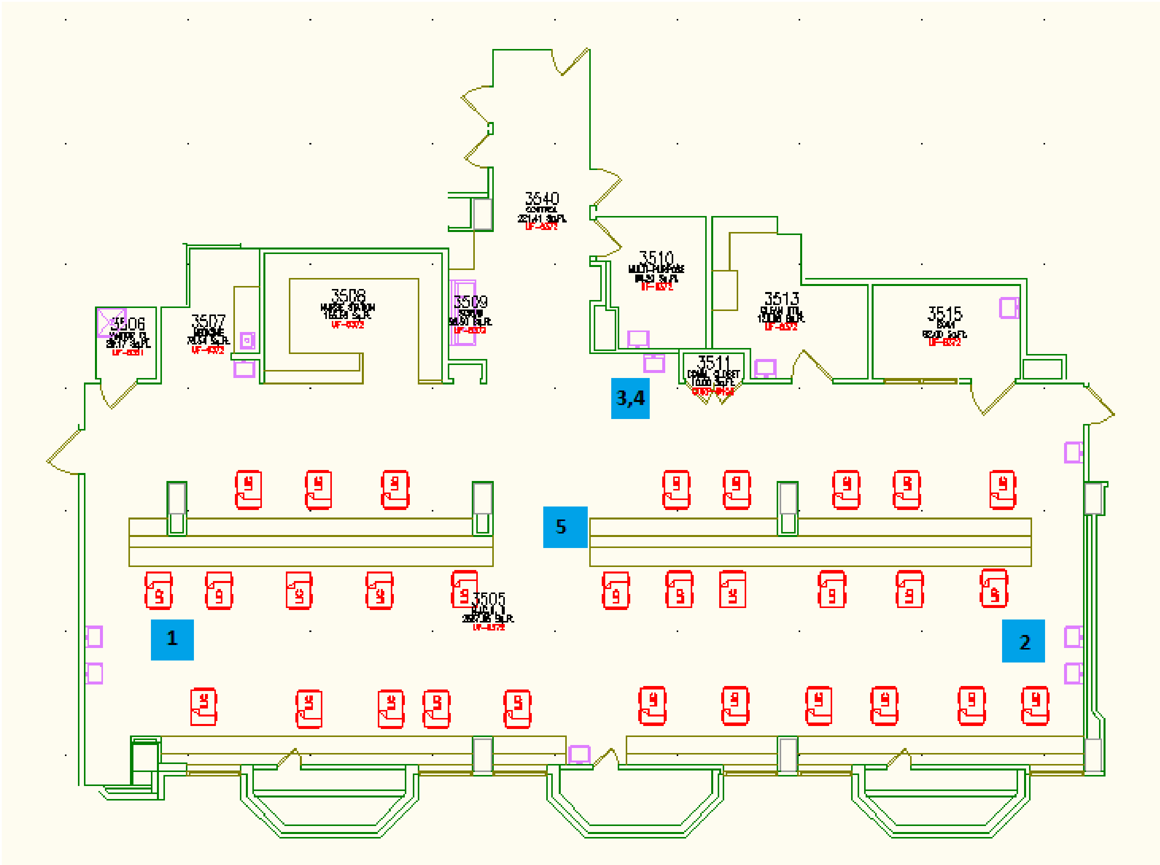


Figure 3-13. The ambient level locations in NICU B.

Acoustical Criteria

The Methods Chapter mentioned acoustical tests including reverberation time, speech transmission index, and rapid speech transmission index. The definitions for these tests are given below. They are defined in Harris's *Handbook of Acoustical Measurements and Noise Control*.[8]

Reverberation Time (RT). In an enclosure with a sound presented at a given frequency or frequency band, it is the time required for the sound pressure level in the enclosure to decrease by 60 dB after the source has stopped.[8]

Speech Transmission Index (STI). STI takes both noise and reverberation effects on speech intelligibility. First a modulated noise signal affected by reverberation is measured. The spectrum of the noise signal is equal to the long-term speech spectrum. The reduction in the depth of the modulation is used to look at the effects reverberation has on intelligibility. This reduction in depth of modulation is measured over a range of frequencies from .63 to 12.5 Hz in one-third octave-band steps for octave bands ranging from 125-8k Hz. The average reduction in depth of modulation is measured in each of the seven octave bands. Then the equivalent background noise is computed that would produce this same reduction in depth of modulation. If background noise is present in the signal, the two noise sources are added and then the speech-to-noise ratio is computed for each octave band. The STI is derived from this equivalent speech-to-noise ratio.[8]

$$STI = \sum_{i=1}^{7} W_i(\frac{S}{N_i} + 15)/30$$

W_i= weight associated with octave band i

S/N_i= equivalent speech-to-noise ratio for octave band i

i = index that identifies the seven octave bands from 125 to 8000 Hz

Rapid Speech Transmission Index (RASTI). RASTI is computed in much the same way as the STI, but the complexity is reduced. The reduction in depth of modulation is measured for only two octave bands, 500 and 2k Hz, and for only four frequencies in the lower octave band, 1,2,4, and 8 Hz, and five modulation frequencies in the higher octave band (0.7, 1.4, 2.8, 5.6, and 11.2 Hz). The RASTI is then computed in the same way as the STI.[8]

CHAPTER 4
DATA ANALYSIS

Observations

Florida Surgical Center

At the Florida Surgical Center, surgeries took place in operating rooms (OR's) that were approximately 265-415 ft^2. There were always at least four people in the room including the surgeon, anesthesiologist, nurse, and surgical technician. At most there were eight people in the room. This could include the surgeon, resident surgeon, anesthesiologist, two or more nurses, and two or more surgical assistants. People would come and go, sometimes they would come in for only a few minutes to have a discussion during the surgery. Depending on the choice of the surgeon, there was sometimes music playing in the room from two small bookshelf speakers above the computer. At any time there were one to four conversations taking place. These conversations could be between the surgeon in the surgical assistant over the patient, the surgeon and the anesthesiologist to discuss the patient or to move the position of the bed, the surgeon and the nurse taking notes about the surgery, or the surgical assistants as they prepared the instruments for the surgeon. Facial masks were worn over the mouths of all the healthcare professionals in the room.

Some of the communication that took place during the surgery was not about the surgery itself. Healthcare professionals discussed typical things between themselves that you would expect in an office environment, such as weekend plans, current events, and movies. The surgeon regularly spoke to the resident surgeon during operations. They were generally seated right next to each other, however they were also closest to the loudest equipment in the room, including lasers, drills, and tools used during operations. Communication included instructions and guidelines on how to perform procedures; this could range from levels of whispering to yelling depending on the situation.

Other communication included directives from the surgeon to the nurse or surgical assistant when certain tools were needed or the bed needed to be moved. The surgeon occasionally spoke to a nurse seated at the computer when major events needed to be recorded, such as first incision or a device implanted. The first notable conversation during surgery was between the surgeon and everyone in the room. The surgeon confirmed the patient's name and the complete operation that would take place that day, including which ear (left or right) would be worked on that day. Many times there were two nurses or surgical assistants providing the surgeon with the tools he requested. The nurses often communicated to one another, usually in quieter voices to not disturb the surgeon.

The soundscape of the room was made up of transient noise from the drills, machines, suction devices, anesthesiologist's equipment, background music, doors opening and closing, and the conversations of the healthcare professionals. A taxonomy of sounds heard in the room is shown in figure 4-1. Through discussions with the head surgeon it was noted that the length of the surgery and of the overall use of equipment was dependent on the surgeon's personal experience. An inexperienced surgeon will take a much greater time performing the same task than an experienced surgeon.

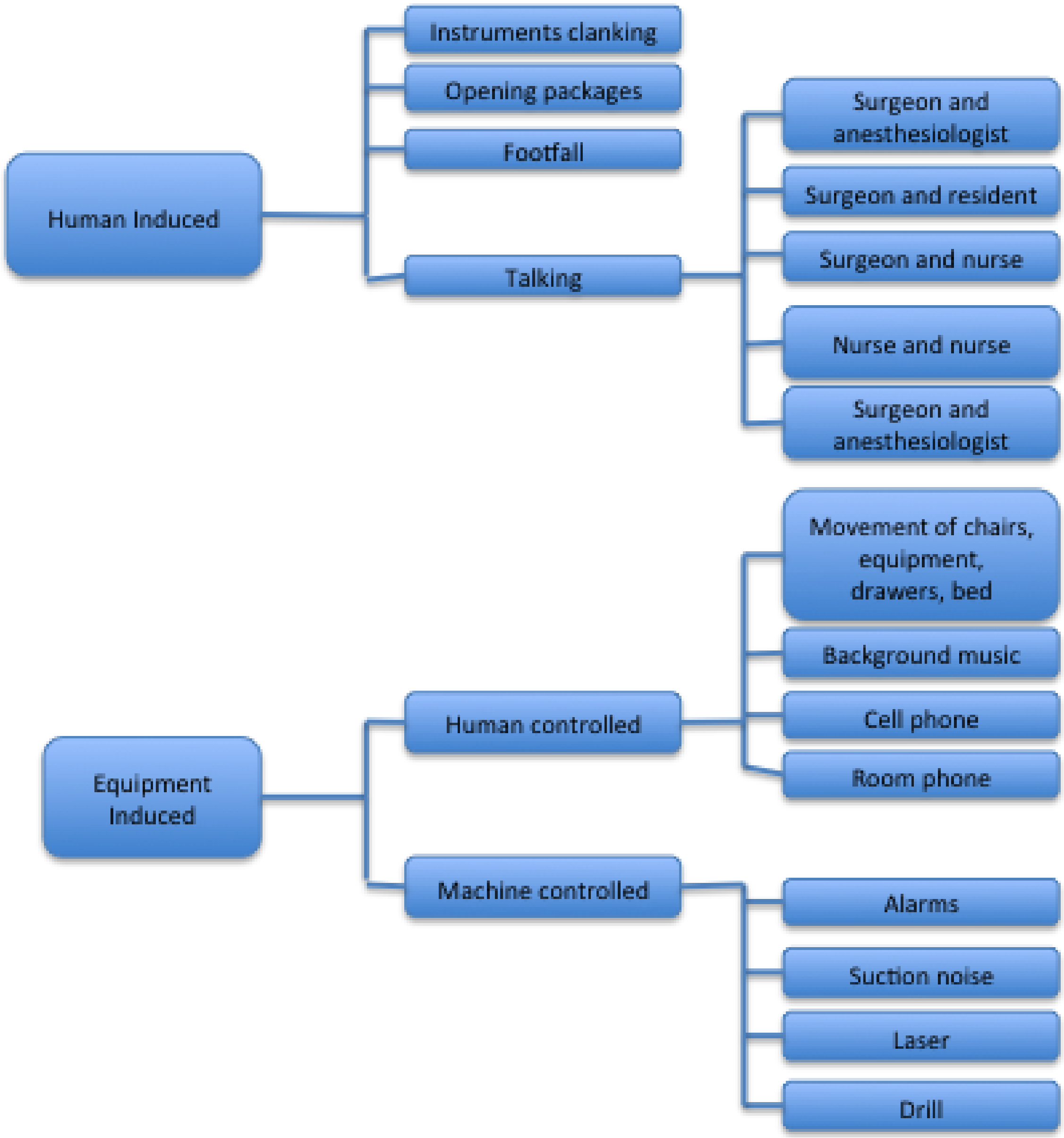


Figure 4-1. A taxonomy of sounds heard in the operating room during surgical procedures.

The sounds shown in figure 4-1 from the operating room environment can be categorized into two main groups: human induced or equipment induced. Human induced sounds include instruments clanking, opening packages, footfall, and talking. The sounds due to conversation were of personal and work nature. If the environment was too noisy, this would be the most controllable source. Equipment induced sounds are divided into two groups, those controlled by human or machines. Human controlled sounds were from the movement of equipment in the room, music sources, cell phones, and room phones. The movement of equipment is necessary in the operating room environment so this source will not be discussed, however if they are considered distracting, the cell phone and room phone noise can be reduced by setting to vibrate or using a light source to gain attention. Music noise can be used as a stress-reliever, however its volume is controllable and can be changed accordingly if distracting to the occupants of the room. The machine controlled sound sources are alarms, suction noise, lasers and drills. These items are necessary in the operating room environment; however their noise can be distracting. The alarms must be heard to complete the job function, so the overall noise levels in the room need to be low enough to accommodate this task.

The ambient sound level measured in the operating room environment is shown in figure 4-2. The room had HVAC, computers, and several machines turned on. There were no occupants or operating equipment on in the room. The LAeq measured in the room was 50 dB(A) at noise criteria curve of NC-45. This is high considering there are up to eight occupants in the room during a surgery and there is noisy equipment running during surgery. The room was built principally of sound reflecting surfaces that add to the overall sound level in the room and cause a noise build-up of reverberant noise in the room making it a difficult environment to communicate. Further testing results are shown in figures 4-2 to 4-5.

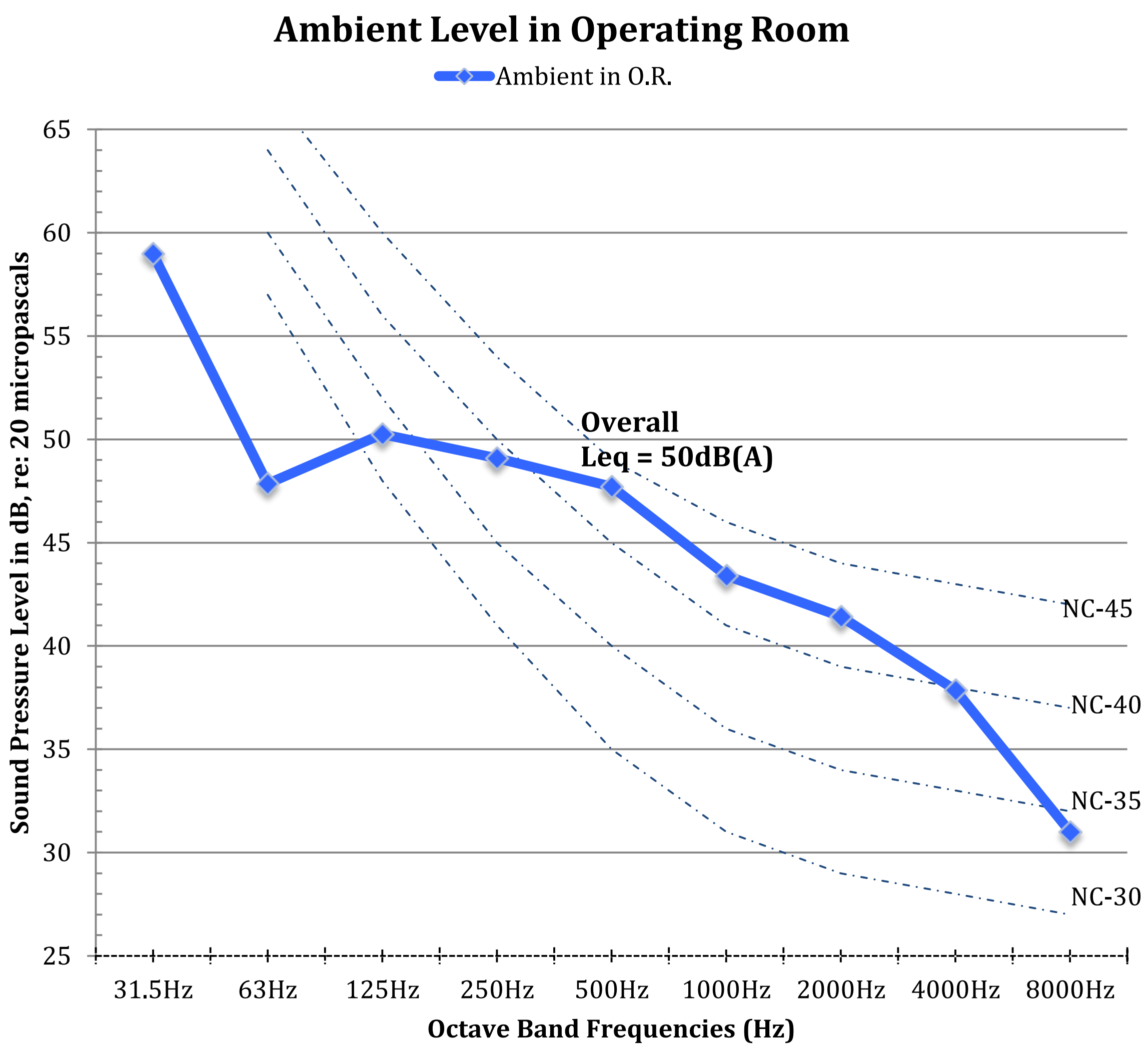


Figure 4-2. The ambient sound level in the operating room.

The reverberation times measured in the operating room are shown in figure 4-3. The average RT for the 4 locations at 500 Hz was 0.63 sec. and at 1000 Hz was 0.71 sec. This room was 265 ft^2 compared to the room where the sound level measurements were taken during surgery which was 414 ft^2. The RT's for the larger O.R. are likely to be longer because of the room's increased volume. A longer RT will result in reduced STI and RASTI indexes.

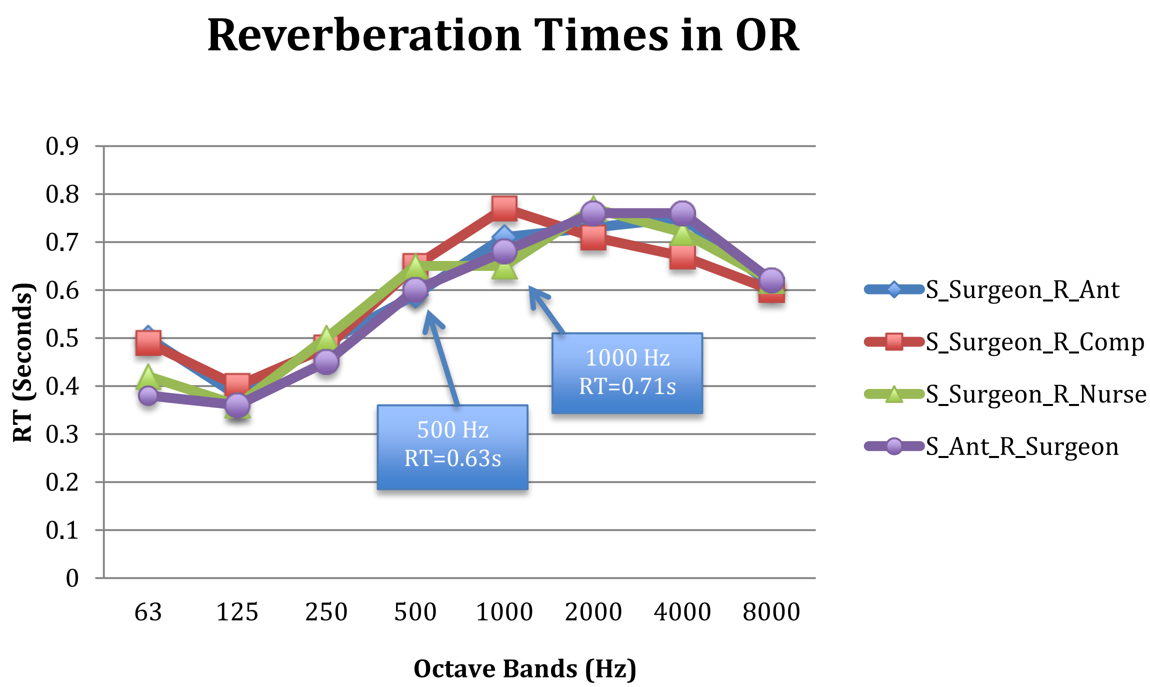


Figure 4-3. Reverberation times measured in the operating room.

When a signal is transmitted from a source to a receiver, the environment impacts the signal in a way that can result in a loss of speech intelligibility. The speech transmission index (STI) and rapid speech transmission index (RASTI) are two factors used to measure the speech intelligibility between the source and receivers in a room due to the environment. RASTI is an approximation of the STI. A score of 0.45-0.6 is rated as fair and a score of 0.75-1.0 is rated as excellent for speech transmission.[25]

In figure 4-4 the STI index measured in the operating room is shown for the four pairs of sources and receivers. The measurements at the four locations range between an index of 0.73–0.76. This is not a significant difference, probably due to the small size of the room the test was conducted in. This is on the low end of "excellent" for speech transmission. The RASTI index (fig. 4-5) gave similar results of 0.71–0.74 also on the low end of "excellent". The short distance between source and receiver paths allow for easy communication between the Surgeon, nurses (“Nurse and Comp”), and anesthesiologist (“Ant”).

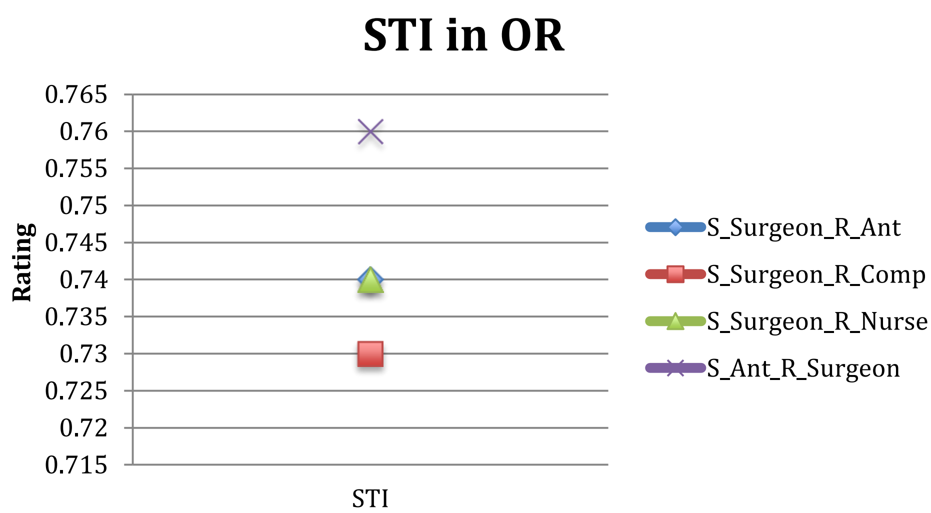


Figure 4-4. Speech transmission index measured in the operating room.

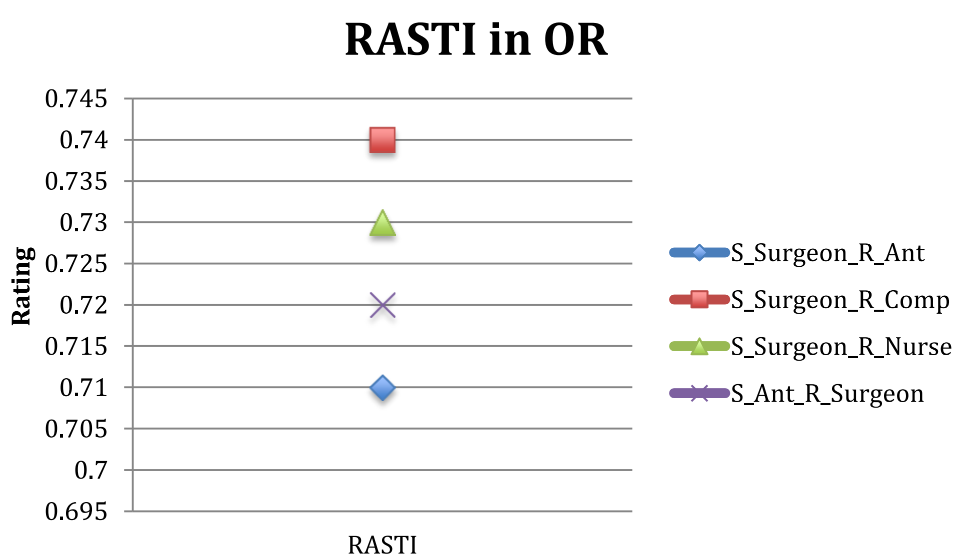


Figure 4-5. Rapid speech transmission index measured in the operating room.

Figure 4-6 shows LCeq measurements recorded in 10 s increments by a RION sound level meter. The LCeq measurements range from 63 to 77 dB(C) during the 2 hour and 36 minute surgery; Fourteen decibels is a wide range of variance for these sound measurements. Detailed notes were taken during observation of the surgery to identify what occurred. Some points and trends are shown on the graph to see what events occurred at specific instances.

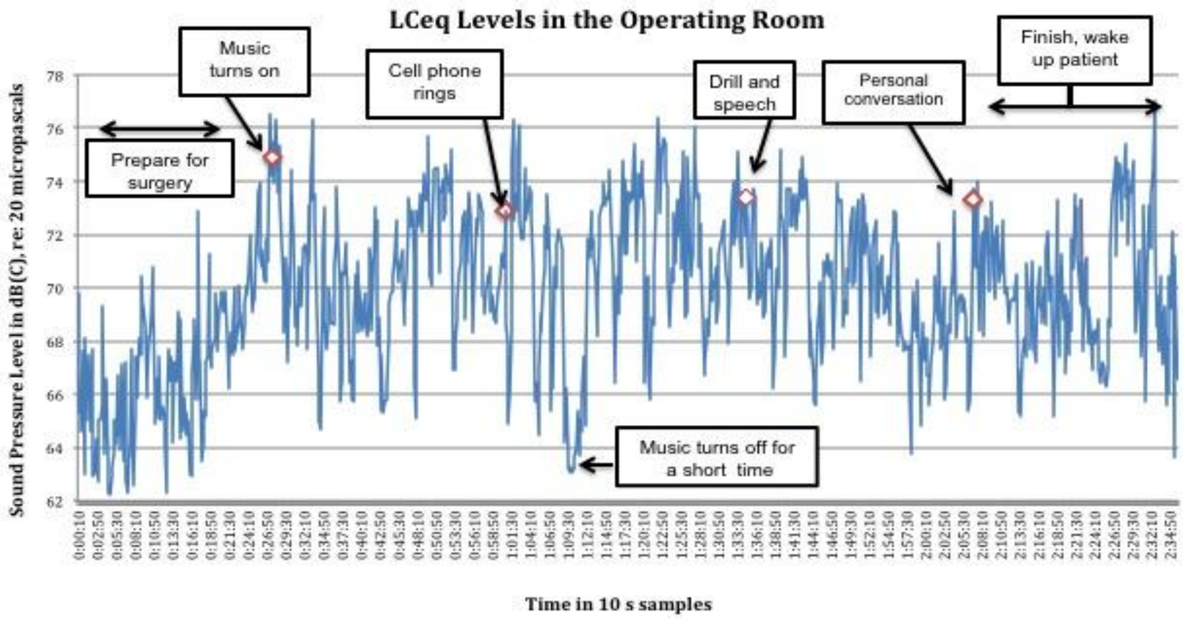


Figure 4-6. LCeq levels in the operating room during surgery.

The Neonatal Intensive Care Units at Shands Hospital

Much of the sounds present in the NICU environment are caused by equipment that is vital to the physical survival of the patients. Thomas and Martin[5] note that the high-frequency oscillatory ventilation creates twice as much noise as the conventional mechanical ventilation. This is a type of ventilation used on critical patients for breathing. It is seen more in Level III NICUs and was present in NICU A at Shands on several occasions. With noise criteria set at 25-35 curves for hospital wards, the equipment present in these environments is louder than the acoustic criteria.

Figures 4-7 to 4-9 show photographs of some of the equipment found in NICU B that generates unwanted noise. The visitors' sink (see fig. 4-7) is often a source of complaints by the nurses because it is very loud and clumsy. One must use their body to hit the front panels to allow soap and water to be released by the system. The medicine area shown in figure 4-8 is a room where nurses go to prepare medicine for the patients. It is offset from the main patient area in NICU B, however it does not have an acoustical separation such as a door.

Figure 4-7. A visitors’ sink in NICU B.

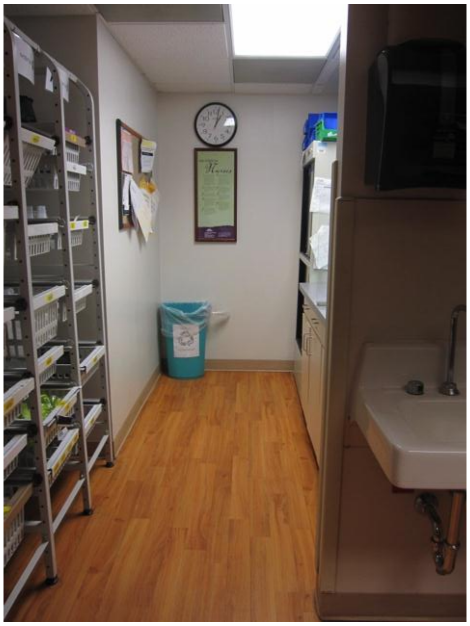


Figure 4-8. The medicine area in NICU B.

Figure 4-9. A pneumatic tube system in NICU B.

The pneumatic tube system shown in figure 4-9 is used to transport medicine and supplies from another location in the hospital into NICU B. Conversations with staff and visitors reveal that it is used very frequently during the day and causes a loud disturbing noise when it drops. The three things mentioned here are acoustically separated from the patient area in NICU A. The visitor's sink is away from the patient area down the main hallway, but still close enough to hear it if one is near the front of the room. The medicine area is enclosed within glass walls near the front of NICU A, and the pneumatic tube system is located in the receptionist's area, completely separated from the NICU patient area. This controls disturbing noise while still being able to serve the patient area appropriately.

Observations made in both NICU's allowed sound maps to be created to show potential loud areas, and construction features that prevent sound build-up. The taxonomy of sounds heard in the NICU is shown in figure 4-10.

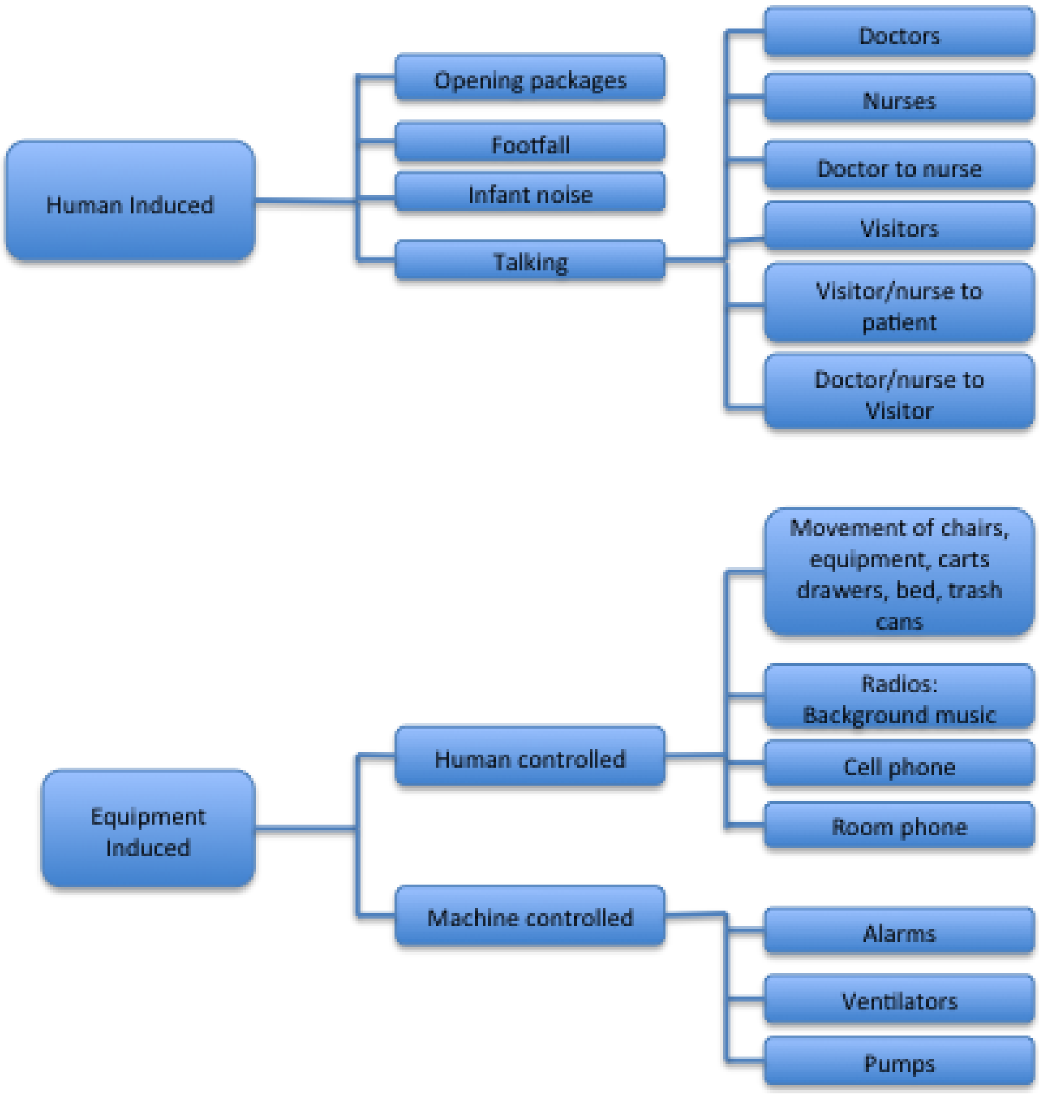


Figure 4-10. A taxonomy of the sounds heard in the NICU.

Figure 4-10 includes general sounds in the NICU that are classified into human induced and equipment induced groups. Human induced sounds include opening packages, footfall, infant noise, and conversations. Conversations include those from and between doctors, nurses, visitors, and other occupants of the NICU. Conversations are necessary in this environment to exchange information from the doctors to the parents of patients and between healthcare professionals. However these conversations can be designated to a place outside the patient environment to not disturb the patient. In the literature it is beneficial for the parents to speak to the patient, and thus should be encouraged to do so. A more private environment where less beds and foot traffic is present would encourage this behavior.

Figures 4-11 and 4-12 are the sound maps created for NICU A and B respectively; Areas observed that tend to have increased sound levels are shown in red. Areas that are designed to control noise are shown in blue.

NICU A

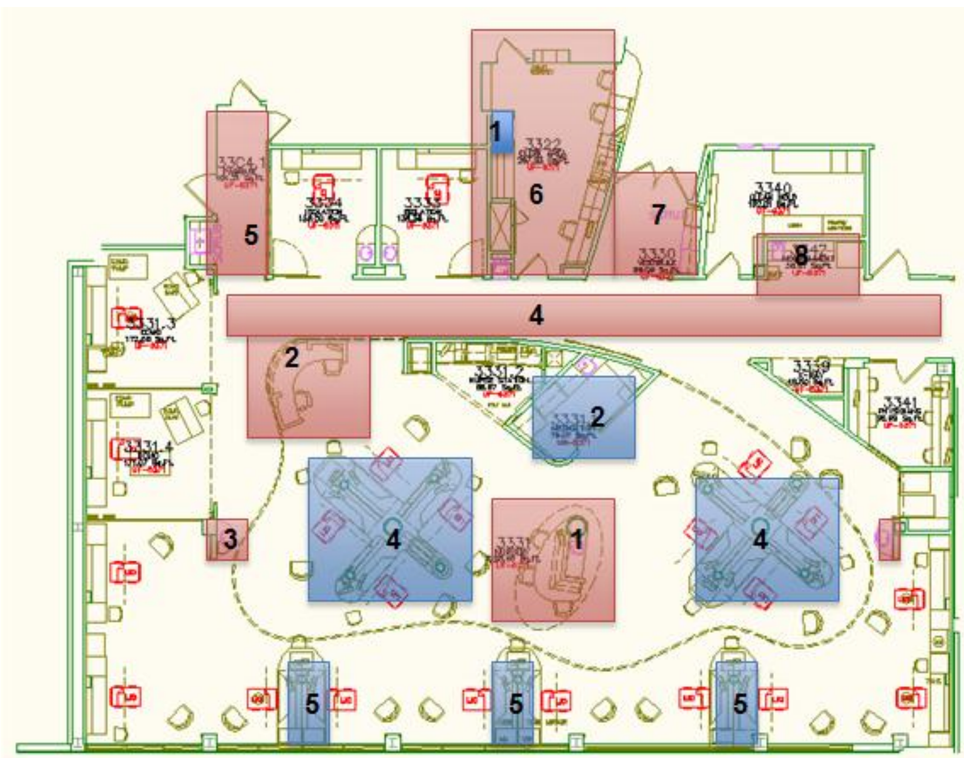


Figure 4-11. The sound map of NICU A; Red areas: Higher noise level areas in NICU A 1) Nurses' Station 2) Nurses' Station 3) Sinks and electronic paper towel dispensers in patient areas 4) Entrance hallway into patient areas 5) Entrance hallway for staff into NICU, offices and a break room are at the end 6) Receptionist area, door is left opened many times and conversations take place in doorway 7) Visitor's wash area 8) Feeding area with fridges. Blue areas: Noise Control Areas: 1) Pneumatic tube for delivery located in receptionist office 2) Medicine area in separated glass room with door 3) Quiet sign that illuminates when noise levels are too high (currently is on all the time) 4) Beds arranged in pods on main floor 5) Beds have isolation dividers separating them.

NICU B

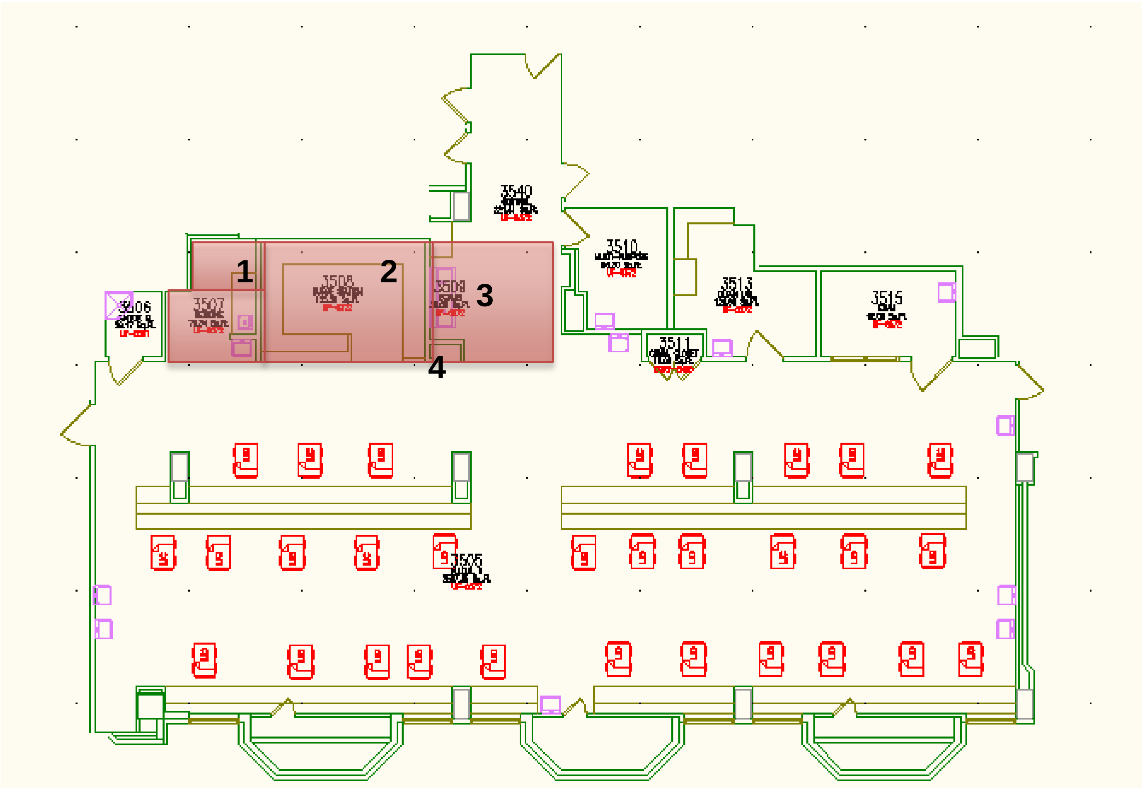


Figure 4-12. The sound map of NICU B; Red areas: Higher noise level areas in NICU B 1) Medicine area 2) Receptionist's office open into NICU 3) Visitor entrance with wash area 4) Pneumatic tube system open into NICU.

Long Term Measurements in the NICU's

The 1-Hour LAeq data from sound level meters #1, 2, and 3 from NICUs A and B is discussed below. The sound levels in a particular hour when compared across different days can have a high range of variability. This is because the NICU has a extensive range of events that can happen at any hour on an individual day, such as the people working, visitors, operations within the NICU, emergency situations, new patients, intercom calls, and discharging of patients. However, the hour LAeq data is useful to see trends during the day. This allows one to infer the acoustic calendar of the NICU.

NICU A

The graph in figure 4-13 shows the 1-Hour LAeq's for the data from sound level meter #1 in NICU A. The hours shown are from 2:00 pm on 11/30/11 to 6:00 pm on 12/4/11. The sound level meter turned off earlier than meters #2 and #3. In table A-1, a chart lists the hour LAeq calculations and the arithmetic average for the individual hour LAeq's from the different days recorded. This shows the average loudest (red) and quietest (blue) hours in NICU A at this location. The loudest hours at location #1 were at 6:00 pm, 7:00 am, and 9:00 am. The average LAeq at these hours was 57 dB(A). The hours of 7:00 am and 7:00pm correspond to the nurse shift changes in the NICU A. Nurses work a regular 12-hour shift. The quietest hours in NICU A are 1:00 am and 2:00 am. The average LAeq at these hours was 51 dB(A). Overall the hours from 11:00pm to 5:00 am are the quietest at 51-53 dB(A).

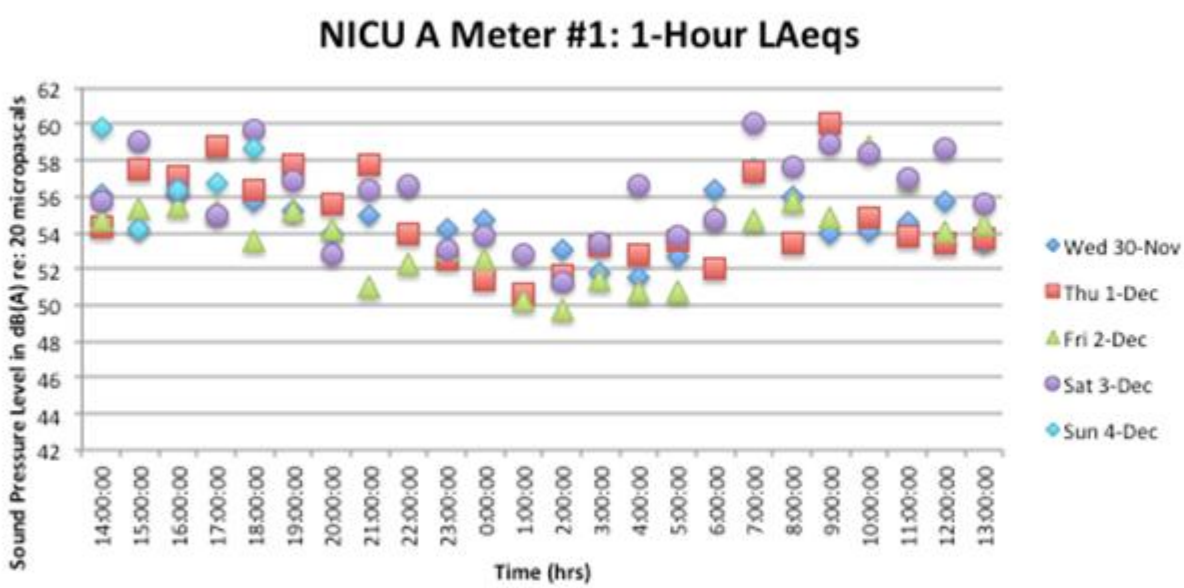


Figure 4-13. The 1-Hour LAeq's for sound level meter #1 in NICU A.

Figure 4-14 shows the 1-Hour Leq's for sound level meter #2. The hours shown are from 2:00 pm on 11/30/11 to 12:00 pm on 12/6/11. Table A-2 has a chart that lists the 1-Hour LAeq's for sound level meter #2. The far right column is the arithmetic average of the individual 1-Hour Leq's for the 6 days recorded. This shows the average loudest (red) and quietest (blue) hours in NICU A at this location. The loudest hours at sound level meter # 2 were at 7:00 pm and 7:00 am at 58 dB(A) and at 11:00 am at 57 dB(A). The hours of 7:00 am and 7:00 pm correspond to the nurse shift changes in the NICU A. The quietest hours in NICU A are 2:00 am and 3:00 am. The average of the Leqs at these hours was 51 dB(A). Overall the hours from 9:00pm to 5:00 am are the quietest with 1-Hour LAeq's varying between 51-53 dB(A).

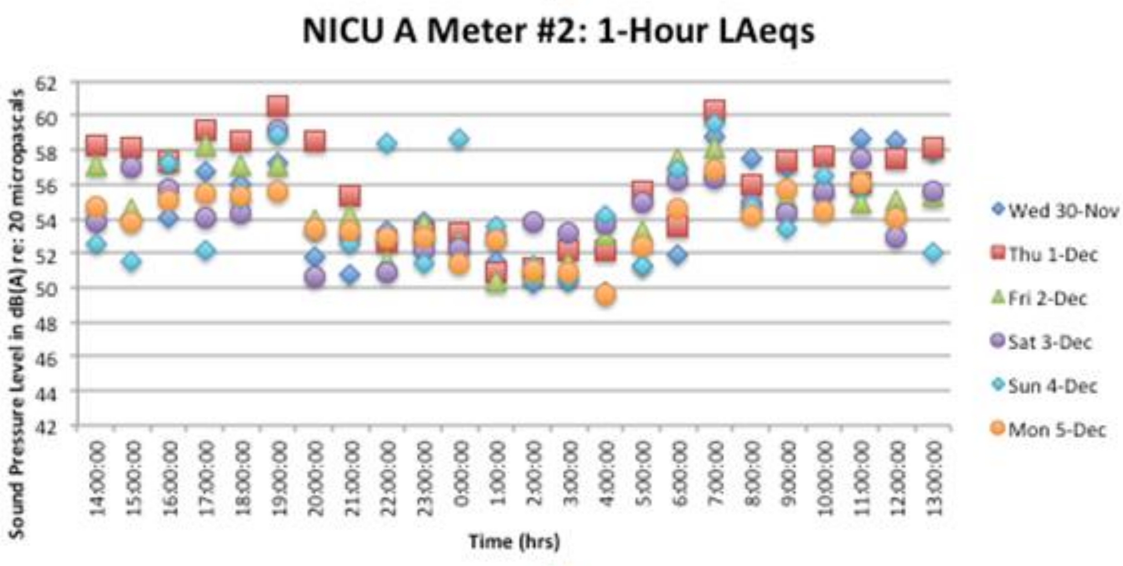


Figure 4-14. The 1-Hour LAeq's for sound level meter #2 in NICU A.

In figure 4-15, the 1-Hour LAeq's are shown for the data from sound level meter #3. The hours shown are from 2:00 pm on 11/30/2011 to 1:00 pm on 12/6/11. In table A-3 a chart lists the hour LAeqs for sound level meter #2. The far right column is the arithmetic average of the individual hour Leqs for the 6 days recorded. This shows the average loudest (red) and quietest (blue) hours in the NICU A at this location. The loudest hours at location #3 were at 12:00 pm, 1:00 pm, 2:00 pm, 4:00 pm, 7:00 pm, and 7:00 am. The average LAeq at these hours was 52 dB(A). 7:00 am and 7:00pm correspond to the nurse shift changes in the NICU A. The quietest hour in NICU A was at 3:00 am with a 1-Hour LAeq of 47 dB(A). Overall the hours from 11:00am to 5:00 am are the quietest hours with 1-Hour LAeq's varying between 47-49 dB(A).

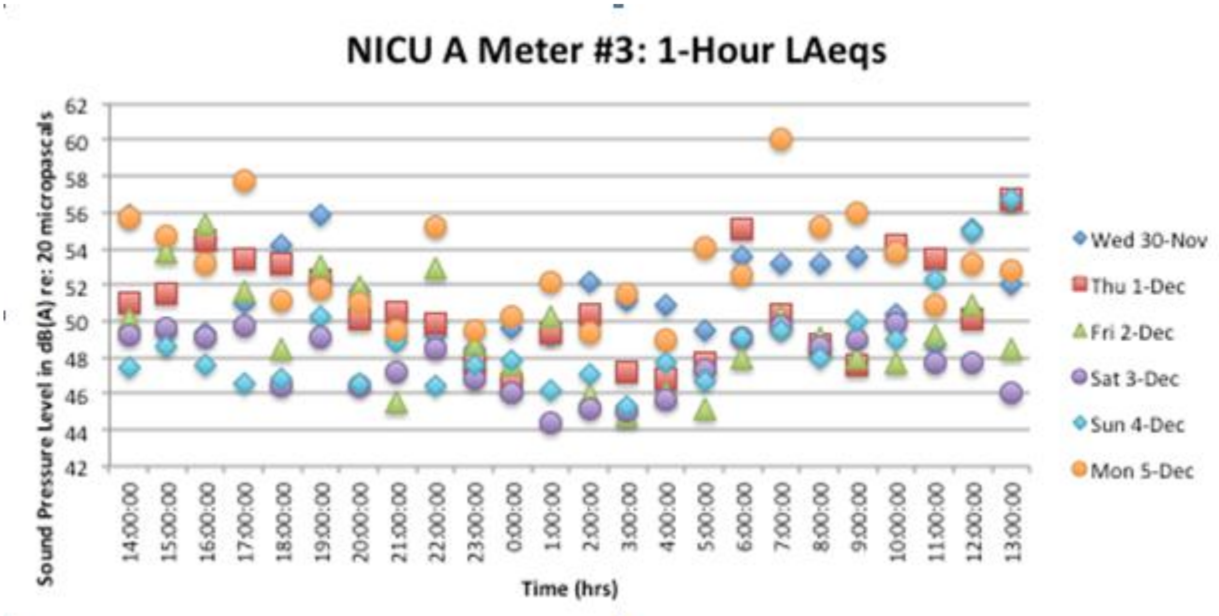


Figure 4-15. The 1-Hour LAeq's for sound level meter #3 in NICU A.

In figure 4-16 a comparison is shown for the arithmetic averaged 1-Hour LAeq's from sound level meters #1, #2, and #3 in NICU A. It is possible to see how sound levels in NICU A tend to decrease around 8:00 pm. They stay low until 5:00 am in this figure.

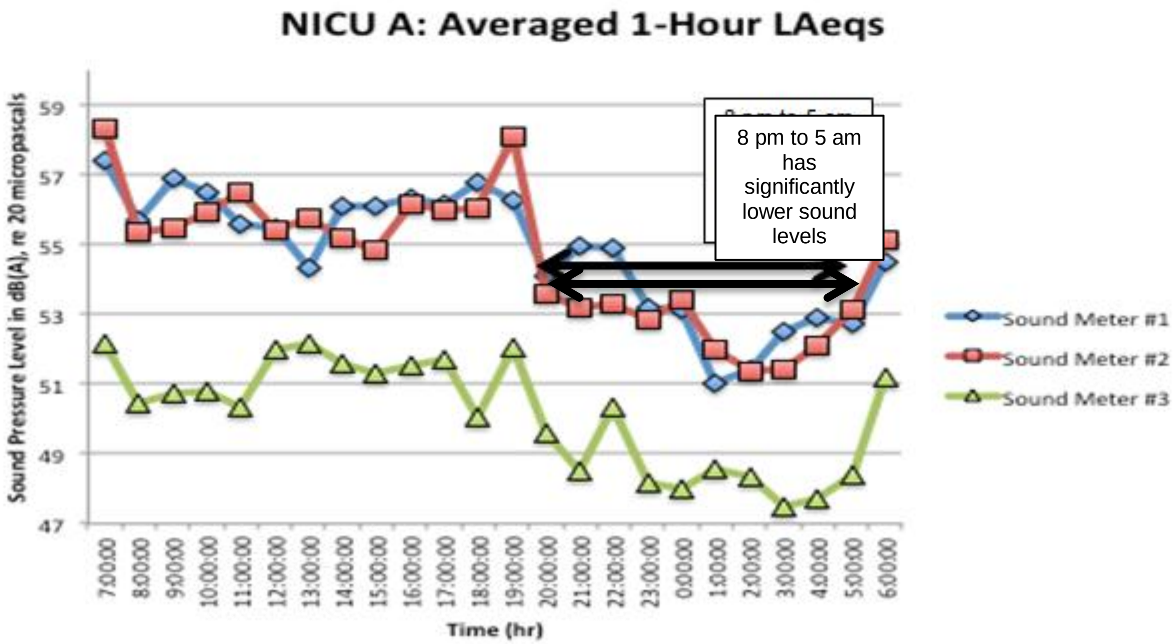


Figure 4-16. The average 1-Hour LAeq's for sound level meters #1,2,3 in NICU A.

Sound level meter #1 and #2 are both at nurses' stations in the patient area. They follow the same trend line within 2 dB(A) of each other. This shows that foot traffic, patient noise, and conversation levels are comparable at both locations. Sound level meter #3 measured considerably lower sound levels than meters #1 and #2. Some hours, as much as 7 dB(A) separates the averages between meter #3 and meter #1. It is significant, because all the patient areas have the potential to be as quiet as that at meter #3. The sources that are causing the higher sound levels at meters #1 and 2 are avoidable. Sound level meter #3 represents the minimum background noise level in NICU A because the only noise the meter picks up is that of the patient's equipment, alarms, and conversations that take place in this corner, presumably between the nurses and visitors. All locations in NICU A have the potential to be at this level.

It also can be assumed that sound does not travel very far in the patient areas in NICU A. The walls have fabric wrapped panels applied to them, ACT ceiling is installed, and the layout of the patient area has pods that attempt to separate the patients. Since these meters are concurrently measuring levels in the NICU, we can see that the NICU has very good attenuation effects from one location to the other. For example, sound level meter #3 is within eyesight of sound level meter #2, however the levels are significantly lower at meter #3 away from the nurses' station.

NICU B

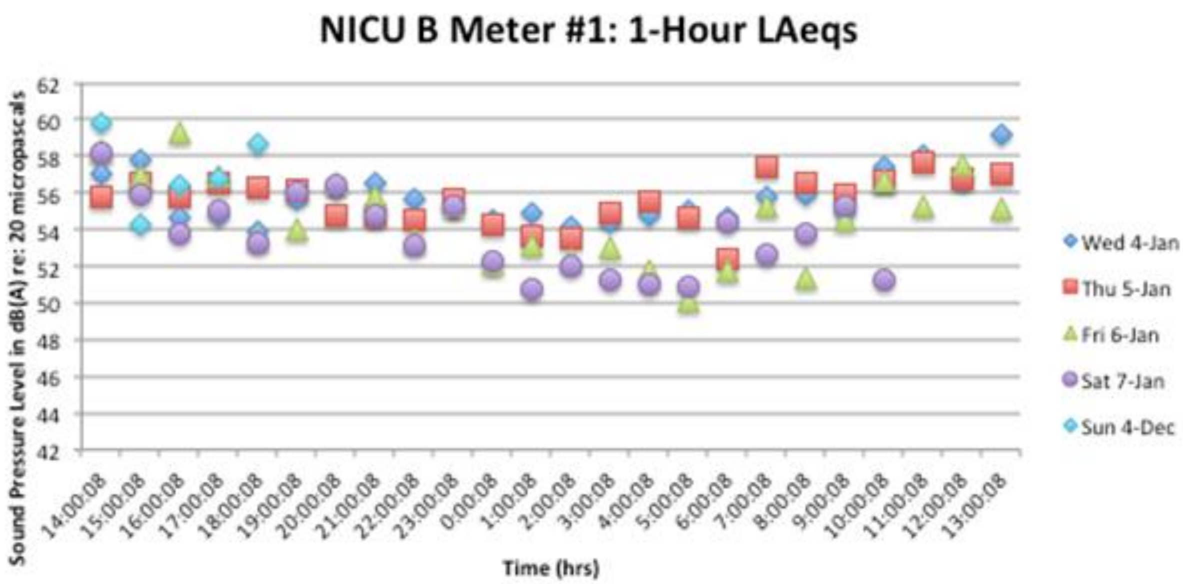


Figure 4-17. The 1-Hour LAeq's for sound level meter #1 in NICU B.

In figure 4-17, the 1-Hour LAeq's for the data from sound level meter #1 in NICU B. The measurements were recorded from the hours of 2:00 pm on 1/4/12 to 10:00 am on 1/8/12. The sound level meter turned off earlier than meters #2 and #3. In table A-4 the 1-Hour LAeq's of figure 4-17 are listed in a chart. The far right column shows the arithmetic average from individual 1-Hour LAeq's for the 3 or 4 days recorded. This chart shows the average loudest (red) and quietest (blue) hours in NICU B at this location. The loudest hours at location #1 were from the hours of 11:00 am – 3:00 pm at 57 dB(A). The quietest were from the hours of 12:00 am – 6:00 am. The average

LAeq at these hours was 53 dB(A). These levels correspond to the ingress and egress of visitors to the patients. This hallway where the sound level meter is located is the visitor entrance and exit and is where the visitors' sink is located. The loudest hours are between 11:00 am – 3:00 pm when this entrance is presumably most utilized.

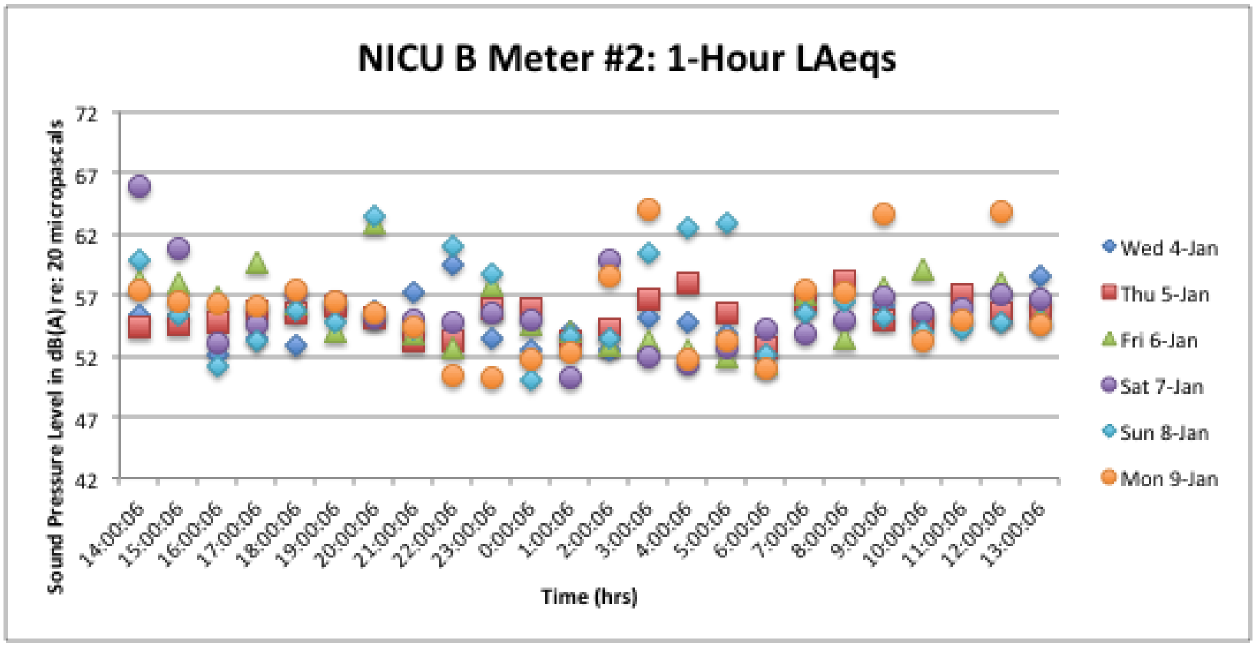


Figure 4-18. The 1-Hour LAeq's for sound level meter #2 in NICU B.

In figure 4-18 the hour LAeq's for sound level meter #2 in NICU B are shown. The recordings were from 2:00 pm. on 1/4/12 to 1:00 pm on 1/10/12. Table A-5 has a chart that lists the hour LAeq's from figure 4-18. The far right column is the arithmetic average from the individual hour LAeq's for the 6 days recorded. This shows the average loudest (red) and quietest (blue) hours in the NICU B at this location. The loudest hours at meter # 2 were at 2:00 pm and 8:00 pm with a 1-Hour LAeq of 58 dB(A). The quietest hours at meter #2 were at 12:00, 1:00, and 6:00 am. The average of the 1-Hour LAeq's at these hours was between 52 – 53 dB(A). The hours between 11:00 – 6:00 am were the quietest, with the averaged

1-Hour LAeq's between 53 – 55 dB(A).

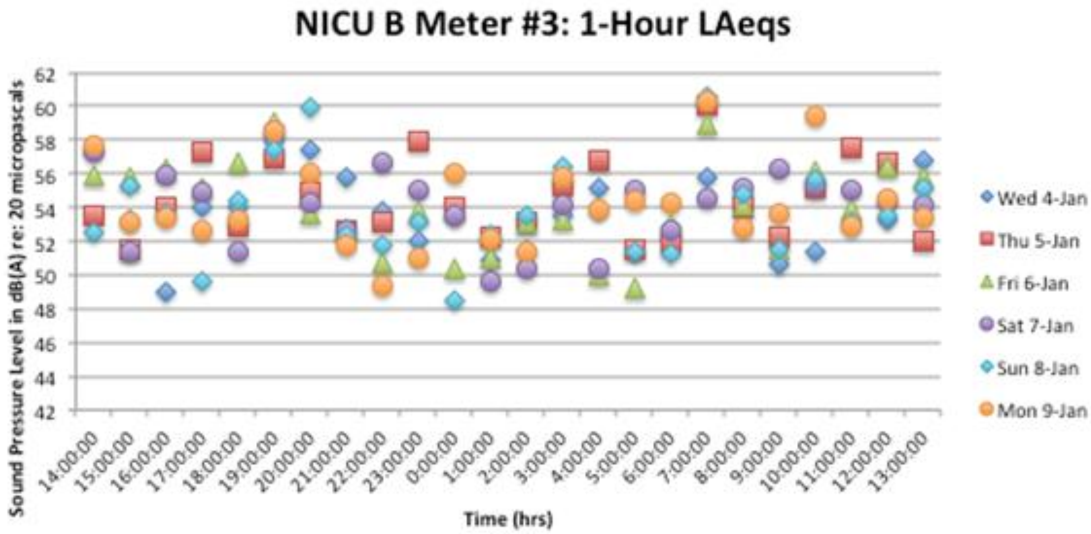


Figure 4-19. The 1-Hour LAeq's for sound level meter #3 in NICU B.

In Figure 4-19 the 1-Hour LAeq's for sound level meter #3 in NICU B. The hours shown are from 2:00 pm. on 1/4/12 to 1:00 pm on 1/10/12. The 1-Hour LAeq's for figure 4-19 are listed in a chart in table A-6. The far right column is the arithmetic average of the 1-Hour LAeq's for the 6 days recorded. This shows the average loudest (red) and quietest (blue) hours in the NICU B at this location. The loudest hour at sound level meter # 2 was 7:00 am with a 1-Hour LAeq of 59 dB(A). The quietest hours at sound level meter #3 were from 9:00 – 10:00 pm and 1:00 – 2:00 am, with the averaged 1-Hour LAeq's between 51 – 52 dB(A).

In figure 4-20 a comparison is shown of the 1-Hour LAeq's from sound level meters #1, #2, and #3. Just as in NICU A, there is a definite decrease in sound levels during the evening hours. The sound levels in NICU B tend to decrease around 9:00 pm and stay low until 6:00 am.

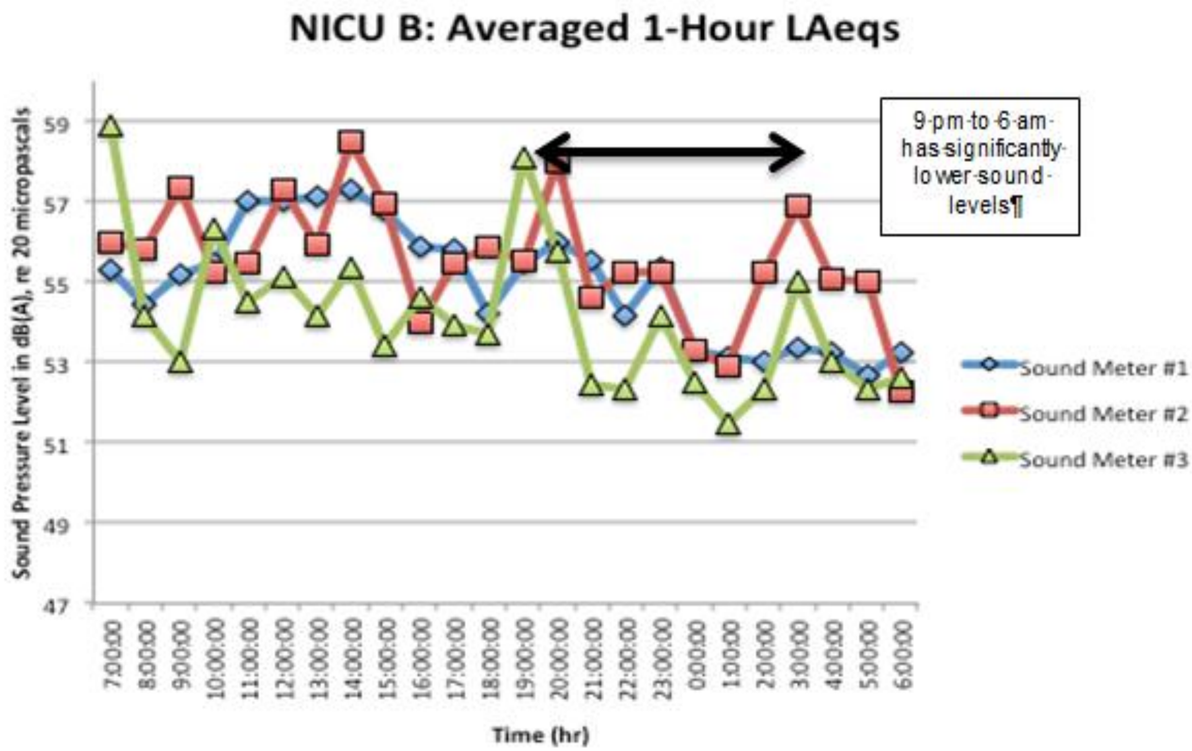


Figure 4-20. The average 1-Hour LAeq's for sound level meters #1,2,3 in NICU B.

Sound level meter #1 was placed near the visitor's pathway into NICU B. There is a consistency among the sound levels at this location during daytime hours 10:00 am – 11:00 pm. This is presumably from visitors washing their hands and foot traffic near this meter's location.

Sound level meter #2 was placed in the central location of the patient area. This location is a good overall estimate of the noise levels you would expect in the NICU. It will pick up foot traffic and several patients' noise and their equipment's alarms. This meter also shows us that the NICU is loud even during the middle hours of the night with an averaged 1-Hour LAeq of 57 dB(A) at 3:00 am.

Sound level meter #3 was placed in the Southwest patient corner in NICU B, which is an area that you would expect to see less foot traffic. However, the 1-Hour

LAeq’s are consistently within 4 dB(A) of each other. This meter also measured higher levels at 7:00 am and 7:00 pm comparatively to the other sound level meters. This is presumed to be from the microphone’s receiver placed closely to the infant and the station’s computer that human voice was significantly picked up at these times from the nurses during the shift changes.

In figure 4-21 the averaged 1-Hour LAeq’s for both NICUs A and B are shown. The 1-Hour LAeq’s for figure 4-21 are listed table A-7. The various orange shapes represent the different meter locations in NICU A, while the various turquoise shapes represent the different meter locations in NICU B. From the graph, we can see that overall the quietest location in both NICUs is the Southeast corner of the patient area in NICU A. It is here that there is little foot traffic, it is tucked away in a corner, and distanced from the nurses’ stations. Little conversation occurs at this location besides the conversations of nurses during a shift change when the nurse explains the patient’s condition during their shift, or the whispers of a visitor or nurse to the patient as they care and comfort them. All of the same equipment is located here that is in other patient stations. Therefore, this is a good estimate for the background noise level of NICU A. This includes machine beeps and alarms, HVAC, and occupational and personal conversations.

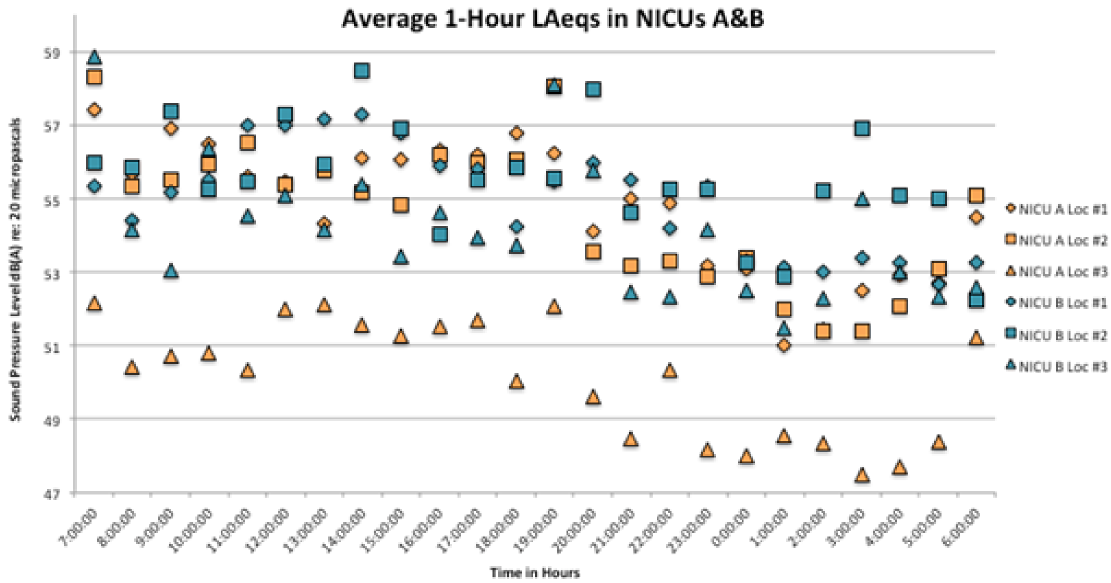


Figure 4-21. The averaged 1-Hour LAeq's for sound level meters #1,2,3 in NICUs A and B.

It is also notable that there is not a significant difference in NICU A's overall sound levels than NICU B. This is noteworthy because during multiple conversations with staff it is recognized that NICU B is perceived louder than NICU A. As you can see here, some locations in NICU A are louder overall during particular hours than in the locations measured in NICU B.

Comparisons of Acoustical Measurements

The 1-Hour LAeq's show trends in the acoustic calendar of the NICU. These are time periods in the NICU when one can expect louder or quieter sound levels due to the time of day. For a closer analysis it is beneficial to look at individual samples of the 10 s data as opposed to the averaged hour LAeq's. LAeq and LAmin measurements from NICU A meter #1 for December 1, 2011 and December 3, 2011 from 7:00:06-7:59:56 are shown in figure 4-22 below. These days were chosen randomly to show a good sample of the measurements of meter #1. There is not a significant difference between the levels when comparing December 1 and December 3. The LAmin mostly stays between 44 and 50 dB(A), however the LAeq is everywhere between 48 and 71 dB(A). This confirms that peak or maximum sound levels associated with short term transient noises are contributing to the background level in NICU A.

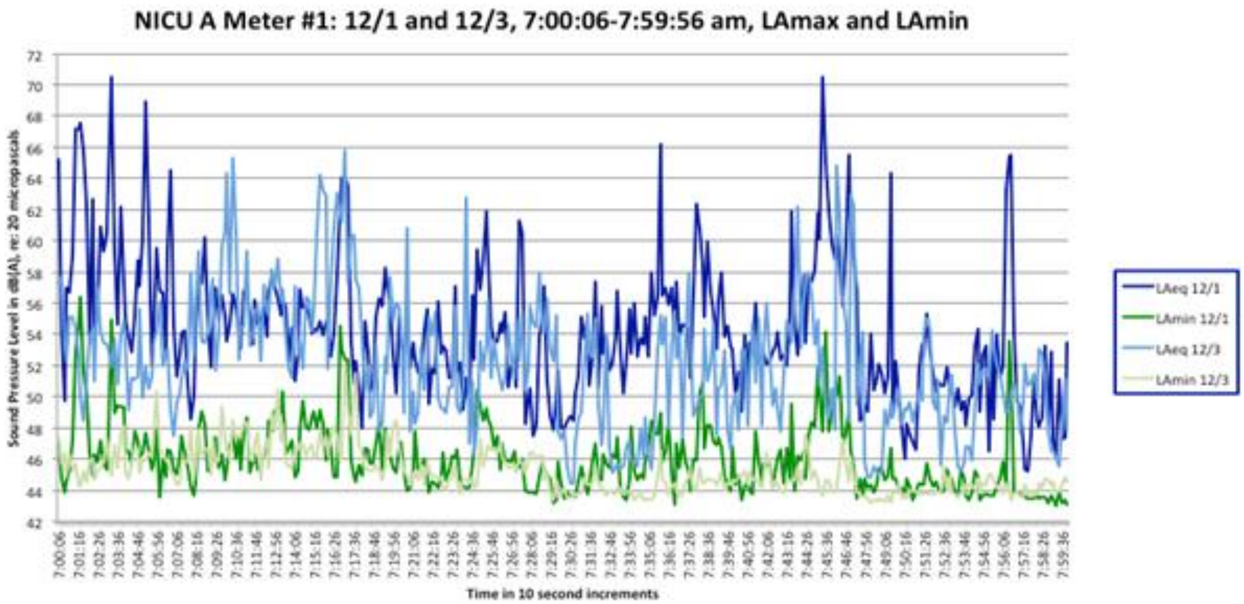


Figure 4-22. The 10-second LAeq and LAmin levels from NICU A Meter #1

The next three figures (4-23,4-24, and 4-25) show the LAmax, LAeq, and LAmin levels for three different two hour time periods in NICU A at meter #1 on December 3, 2011. By showing the LAmax for these time periods in conjunction with LAeq and LAmin levels it is obvious that there are significantly more LAmax levels at a greater intensity during 7:00:06 - 7:59:06 and 15:00:06 – 16:59:06 than from 1:00:06 – 2:59:56. This is presumably due to less visitors, doctors, and activity going on during the nighttime hours. The same machines and patients are in NICU A during the night and day time hours, with the same alarms and beeps being produced by the machines, however the levels are significantly lower and there is less intensity in the LAmax levels.

This concludes that the noise sources contributing to the high daytime levels can be controlled and avoided by limiting the sources that influence the LAmax levels.

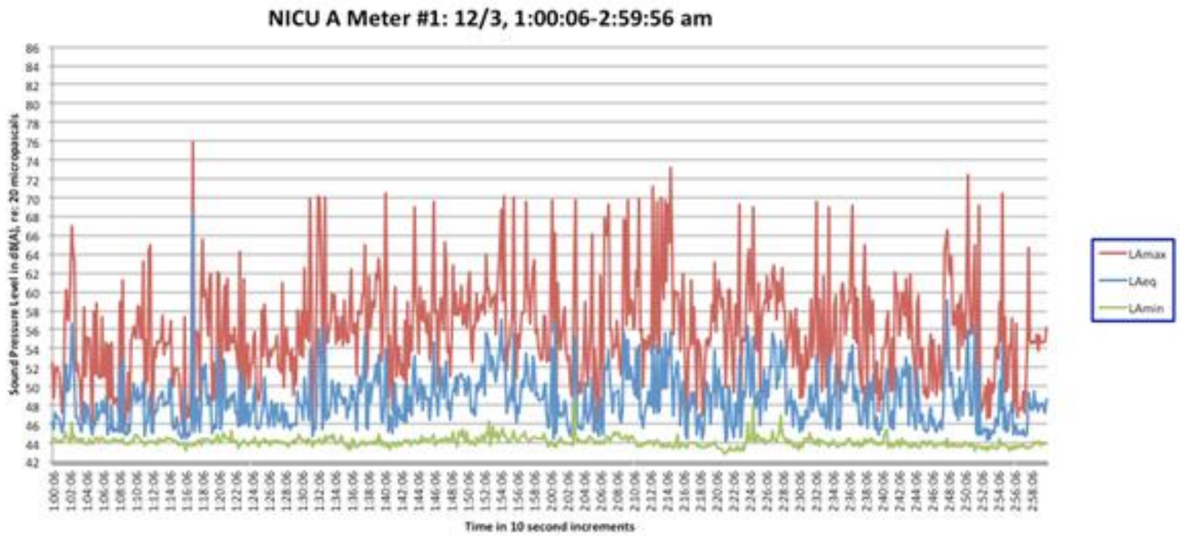


Figure 4-23. NICU A Meter #1, 12/3/11, 1:00:06 - 2:59:56 am.

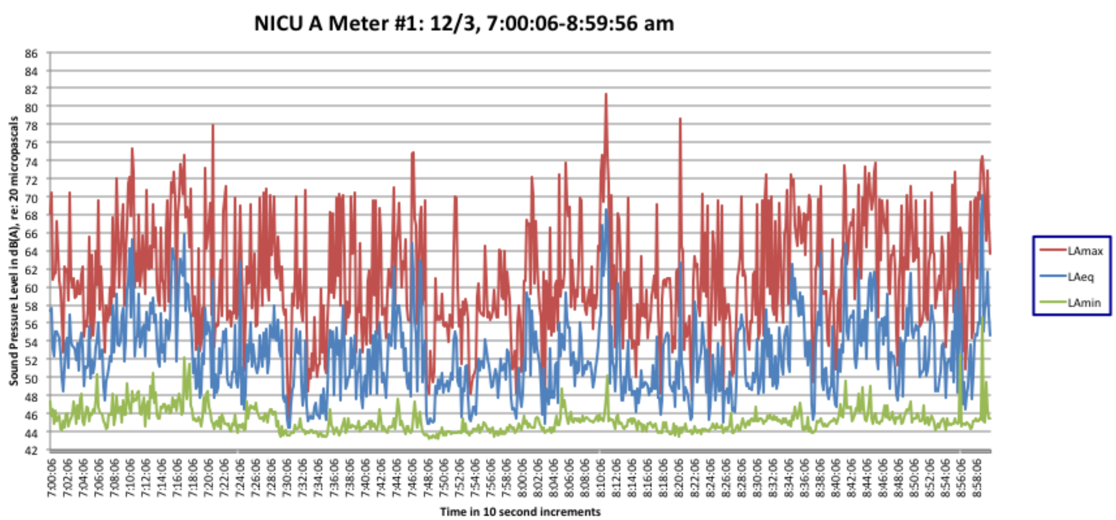


Figure 4-24. NICU A Meter #1, 12/3/11, 7:00:06 – 8:59:56 am.

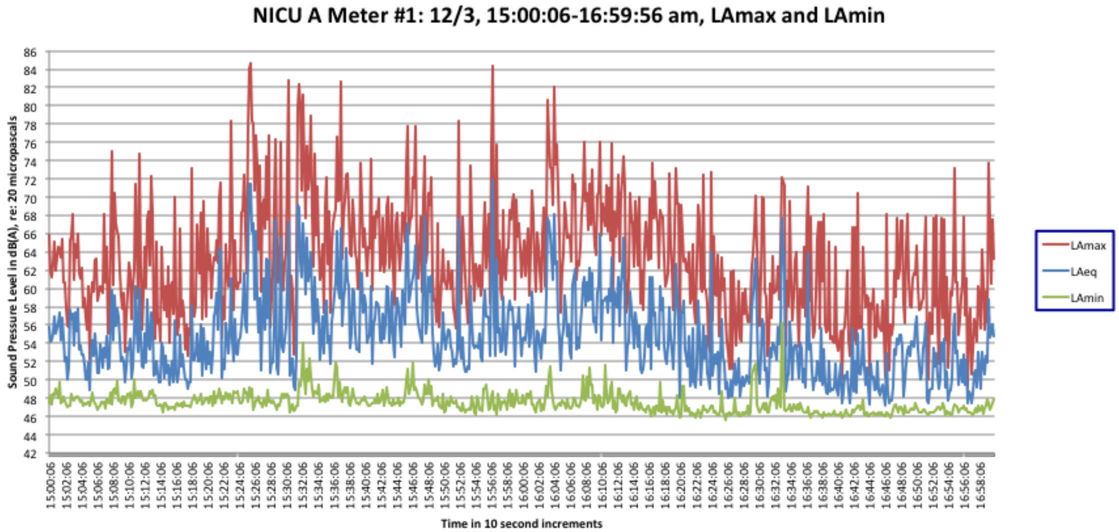


Figure 4-25. NICU A Meter #1, 12/3/11, 15:00:06 – 16:59:56 pm.

Figure B-1 shows the comparison of LAmax and LAmin levels at two different sound level meter locations in NICU A from 7:00-8:00 am, which is one of the louder hours in NICU A. Meter #2 is at a nurses' station, and meter #3 is located in a patient area. This comparison is important because the variability of the LAmax levels is much higher in the patient area. This shows that sound levels produced in the patient area can be just as loud as those at the nurses' station but less frequently and for a very short time such as when two nurses at the patient's bedside speaking about the patient's care for that day as they conduct the shift change or if several alarms go off as they tend to the patient. At the nurses' station the LAmax levels are normally high compared to those in the patient area and have a low range of variability. Therefore the LAmax levels in the nurses' station are consistent, with many more events that cause high sound levels such as nurses congregating and communicating, phones, printers, or computer noise. The LAmin level comparisons show the residual noise at meter locations #2 and #3. In the patient area the LAmin levels are generally lower than those at the nurses' station and have a much lower range of variability. Therefore, LAmin levels in the patient area are generally low and if they do increase, it is for a very short time due to transient sound sources. LAmin levels at the nurses' station are higher and have a wider range of variability. Therefore the nurses' area is one of the louder, noise generating areas of the NICU and the levels fluctuate more frequently due to louder sound sources. Figures B-2 through B-4 show the LAmax and LAmin levels in NICU A and B at two different hours of the day.

LAMax Samples

In figure 4-26 below, The LAmax samples from NICU A sound level meter #1 are shown from 7:00:06 – 8:59:06 (blue) and 1:00:06 – 2:59:06 (red) on December 3, 2011. The LAmax samples in blue are frequently greater in intensity than the samples in red as this is a busier and more eventful time in NICU A. This led to an investigation of finding the percentage of LAmax samples that surpass the highest LAmax recommended in healthcare guidelines.

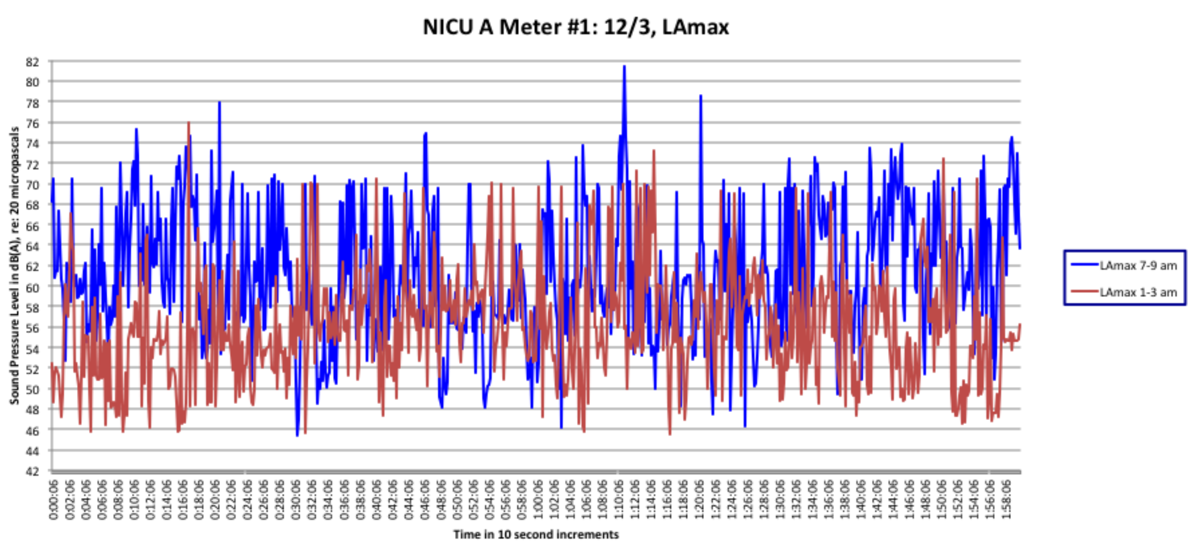


Figure 4-26. NICU A Meter #1, LAmax samples between 7:00-9:00 am and 1:00-3:00 am.

The long-term surveys measured sounds in increments of 10 s. In each 10 s sample the loudest dB(A) level was recorded as the LAmax, regardless of duration. LAmax's greater than 70 dB(A) are examined below, because the guidelines for the American Academy of Pediatrics (AAP) recommend that the Lmax should not exceed 70 dB(A). However, this is a guideline for any 1 s, and because we are looking at 10 s intervals, the guidelines could be surpassed more than shown below. Each hour has 360 ten-second samples, while each day has 8640 ten-second samples. Therefore the percentages below are calculated by adding how many samples of the 360 for each hour exceeded 70 dB(A), divided by 360 and multiplied by 100. For each day there were 8640 samples and the same process was used to show at each meter in NICU A and B how many samples exceeded 70 dB(A) per day. This was done to also see how loud sounds affect the overall LAeq's previously discussed. The first four charts are NICU A's Meters #2 and #3 and NICU B's Meters #2 and #3. Sound level meters #2 and #3 were examined, and not meter #1, because these meters have the most daily data for 5 days from 12:00 am-12:00 pm, and meter #1 only had 3 days.

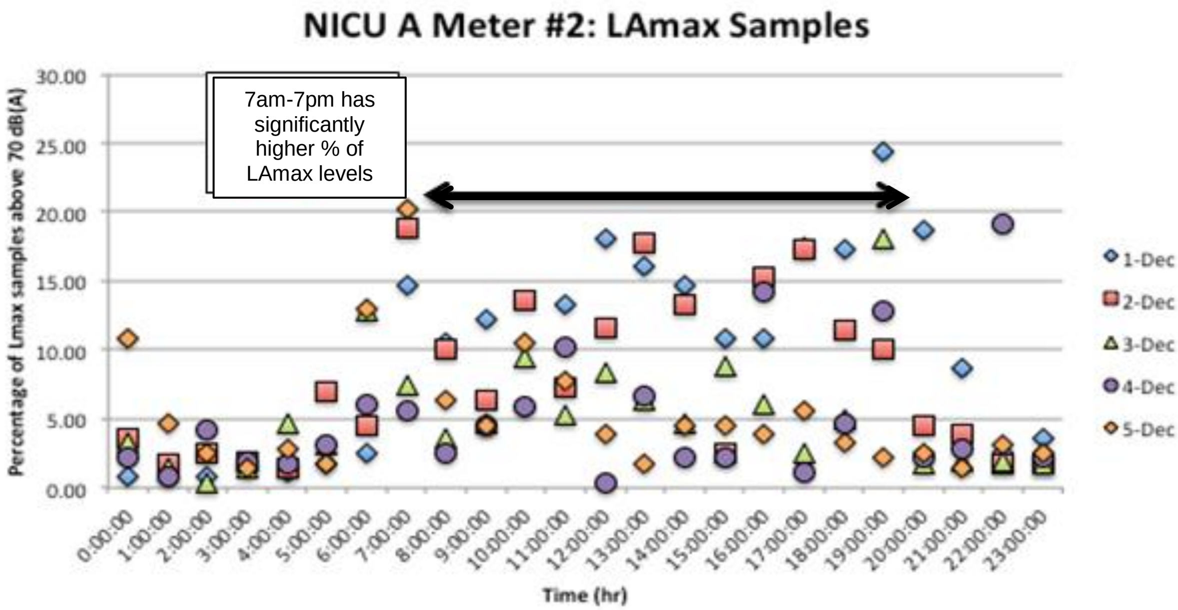


Figure 4-27. The LAmax samples from NICU A meter #2.

NICU A's Meter #2 (figure 4-27) shows that LAmax samples are greatest between 7:00 am and 7:00 pm. However, during the hours of 8:00 pm and 8:00 am there is usually one day that has excessive LAmax levels. This is assumed to occur because of a patient emergency that can happen at any hour.

NICU A sound level meter #3 is shown in figure 4-28. Meter #3 is in a patient area, and had significantly lower LAeq levels than meter's #1 and #2. Below you can see that it also has significantly less LAmax samples below 70 dB(A). LAmax levels increase between the hours of 7:00 am and 5:00 pm. The highest percentage of levels above 70 dB(A) is at 5:00 pm with 12.78%. It can be assumed that most alarms from the equipment used with the patients do not exceed 70 dB(A), because these levels are not exceeded all day long.

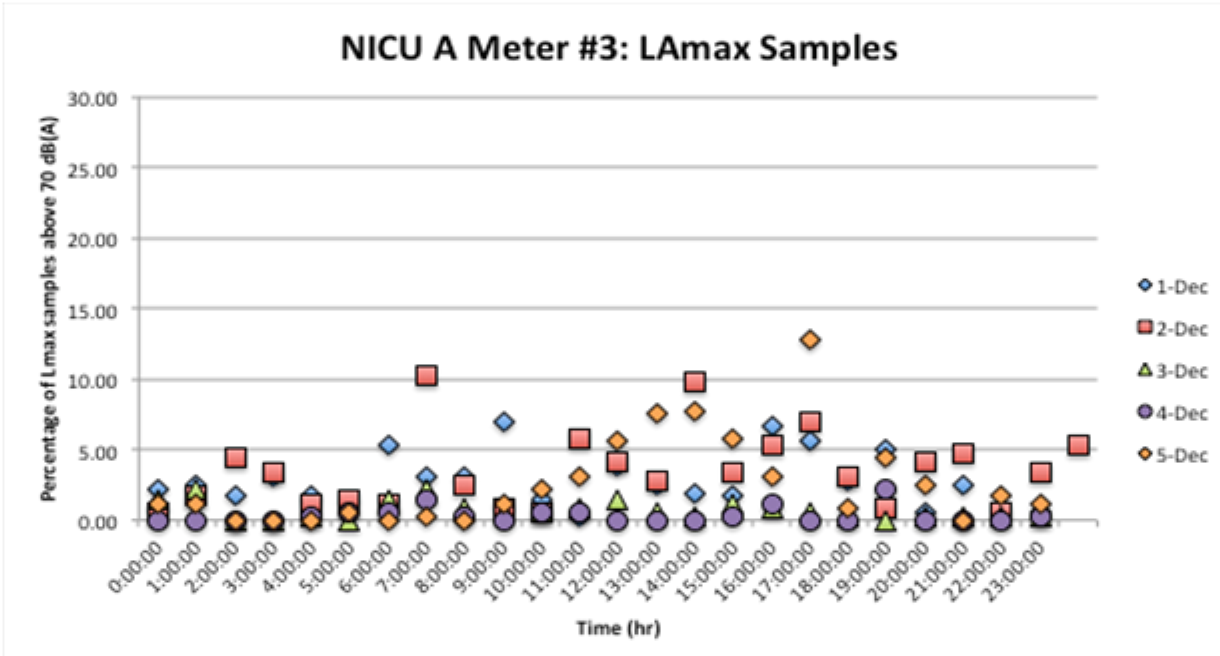


Figure 4-28. The LAmax samples from NICU A meter #3.

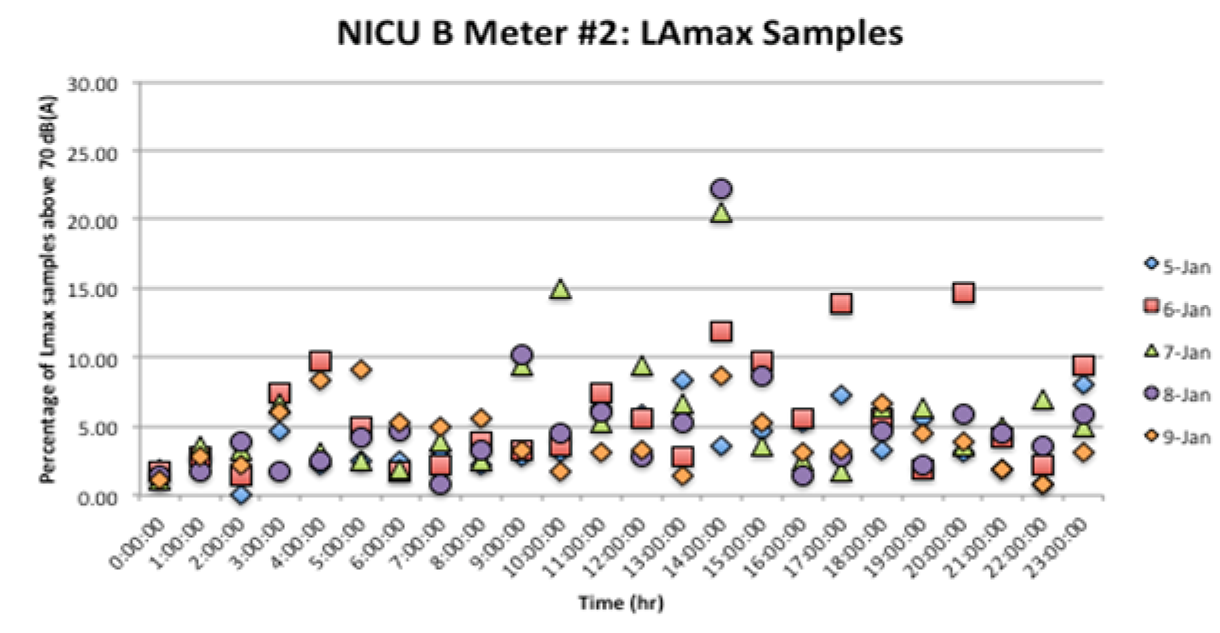


Figure 4-29. The LAmax samples from NICU B meter #2.

NICU B sound level meter #2 is shown in figure 4-29. In NICU A the hours between 8:00 pm and 7:00 am did not have many LAmax levels that exceeded 70 dB(A), however in NICU B these levels were exceeded routinely between 1 and 10 % of the samples. On January 6th, the percentage of samples at 8:00 pm that exceeded 70 dB(A) was 14.72%.

NICU B sound level meter #3 was placed in the Southeast patient area near a corner and there were more peak levels here as shown in figure 4-30. Further investigation will need to look at patient sounds and see if they reach levels above 70 dB(A) when events such as crying occur. At the hour of 7:00 am on January 6th, 7th, and 9th levels were exceeded 19.11-22.22 % of the time. This is significant because 7:00 am represents a shift change, so these levels are quite high during the shift change. The levels at 7:00 pm are also significantly louder on most days than at other times, and this also is a shift change. Further investigation of individual sounds in this patient area is needed to conclude what these LAmax levels are from.

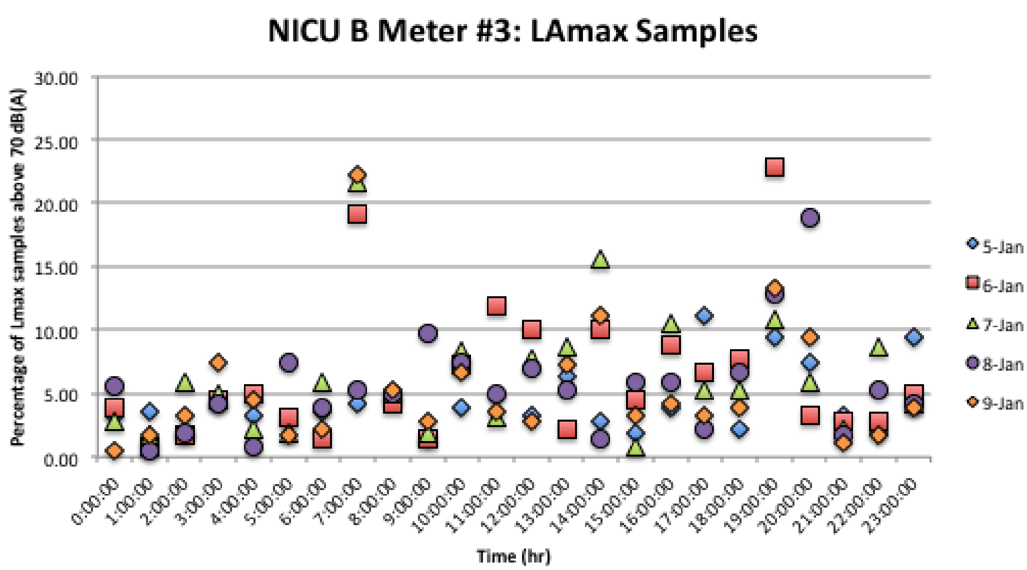


Figure 4-30. The LAmax Samples NICU B Meter #3.

Next, the LAmax samples are looked at by days in NICU A and NICU B. The figure below (fig. 4-31) shows the percentage of samples in NICU A per day that exceed 70 dB(A). The next chart shows the percentage of samples in NICU B per day that exceed 70 dB(A). A discussion follows both charts for a overall comparison of NICU A and B.

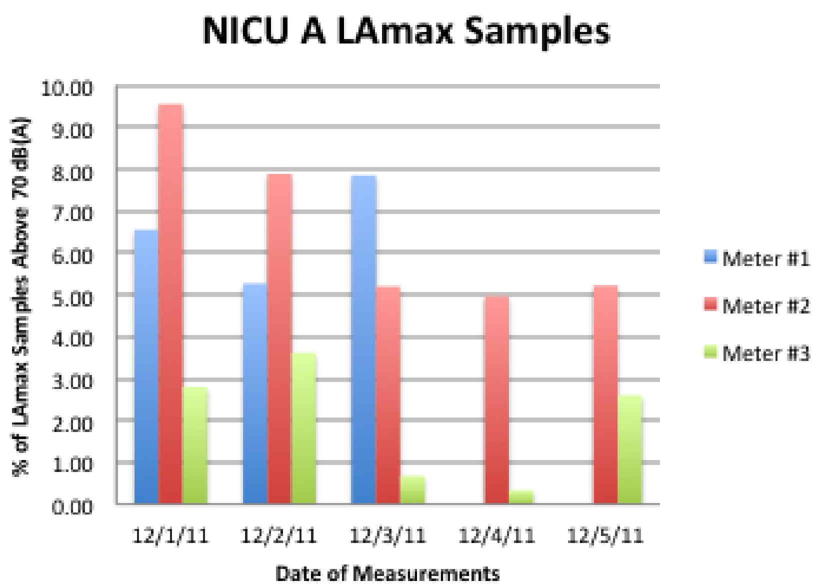


Figure 4-31. The LAmax samples from NICU A Meters #1,2, and 3.

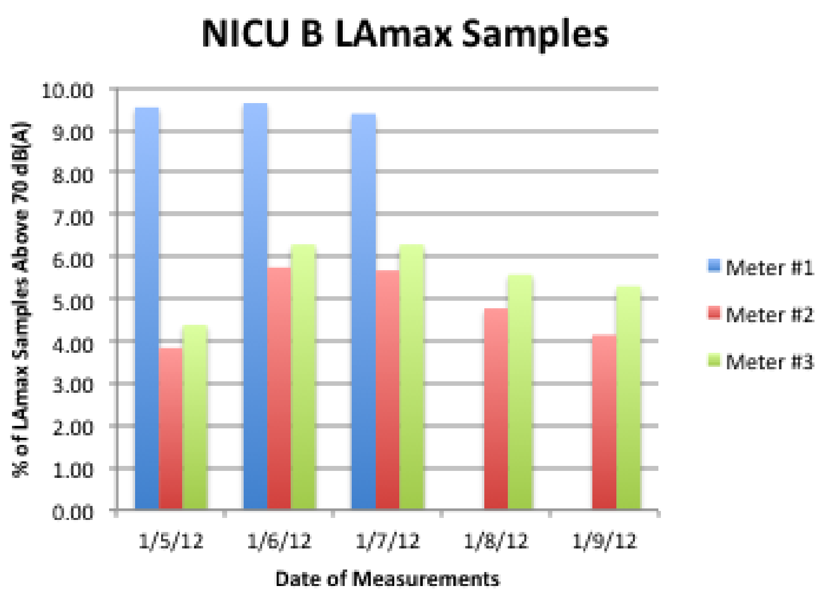


Figure 4-32. The LAmax samples from NICU B Meters #1,2, and 3.

Sound level meter #1 in NICU B recorded the most overall LAmax levels above 70 dB(A) in its 3-day sample. This is to be expected because it was located in a hallway that visitors frequented to talk and wash their hands before entering the patient area; it is not a quiet zone. In NICU A, a meter was not placed in the entrance hallway as there was in NICU B so a good comparison cannot be concluded. However, levels are expected to be similar at meter #1 in NICU A because of janitors' carts, people walking, and higher conversation levels. On the days 12/1/11 and 12/2/11 they are very similar to NICU B. In NICU B, meters #2 and #3 had a percentage of LAmax samples above 70 dB(A) that were consistently between 4.84 and 6.28 %. These meters were in a walk way and a patient corner in the patient area. In NICU A the percentage for meter #3, while located in a patient area, was significantly lower than NICU B's. It can be concluded that higher peak noises in NICU B frequent the patient areas more than in NICU A. However, levels at the NICU A's nurses' station for meter #2 surpass the levels measured in NICU B's walkway and patient areas. The percentages are between 4.97 and 9.55 %. This is assumed to be noise from conversation, people congregating, and carts rolling in these areas. This is a loud area in NICU A not only in LAmax levels that exceed 70 dB(A), but also the LAeq levels. Further, this is also noise that can be prevented because the patient areas do not directly influence it.

NICUs C and D

Figure 4-33 displays the 1-minute LAeq's measured in NICUs C & D at Tampa General Hospital. These long-term ambient measurements were recorded on Tuesday, December 23, 2008 at1:00 pm – Wednesday, December 24, 2008 at 3:00 pm. Both locations recorded in NICU C are very similar, as they were in patient areas away from nurses' stations. NICU D's measurements are much lower than NICU C.

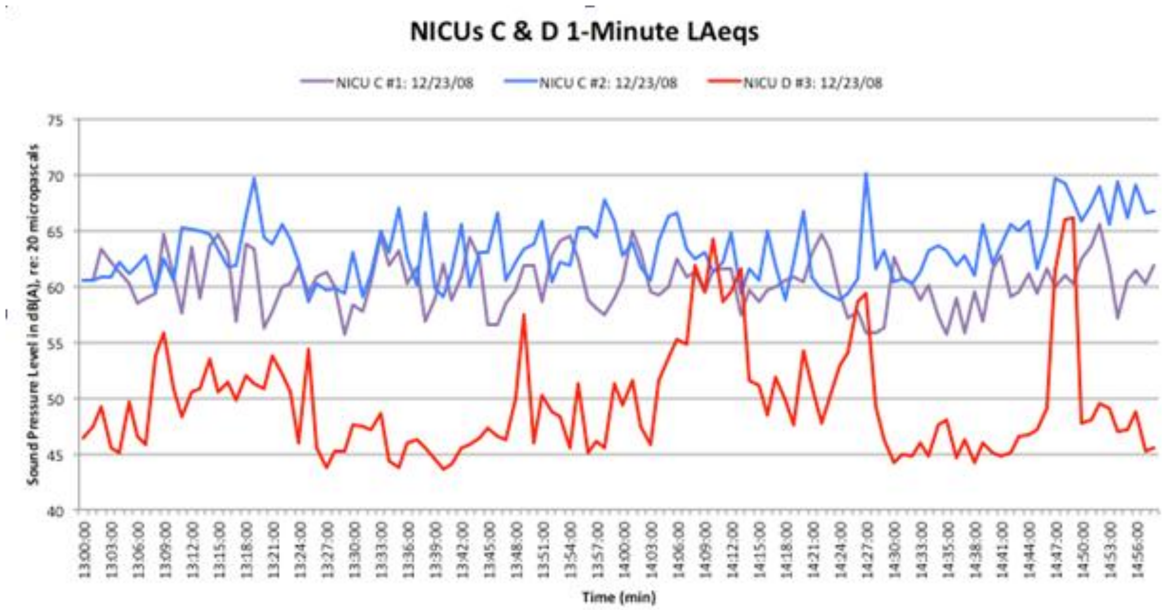


Figure 4-33. A comparison of NICU 1-minute LAeq's.

Table 4-1. 1-Hour LAeq's from NICUs

		Hour Leq dB(A)	
NICU	Date	1:00 PM	2:00 PM
A #3	12/5/11	57	56
B #3	1/9/11	55	58
C RION 1	12/23/08	61	61
C RION 2	12/23/08	64	65
D RION 3	12/23/08	50	56

The averaged 1-Hour LAeq's for these hours are shown in table 4-1. The measurements recorded in NICUs A and B from patients' bedsides and away from nurses' stations, are in the table for comparison. NICU C has two measurement locations, however their LAeq's are similar. In comparison to the measurements from

NICU A and B, they are up to 7 dB(A) louder the hour LAeq at 2:00 pm from meter #3 in NICU B. This is significant, as 10 dB is perceived by the human ear as twice as loud.

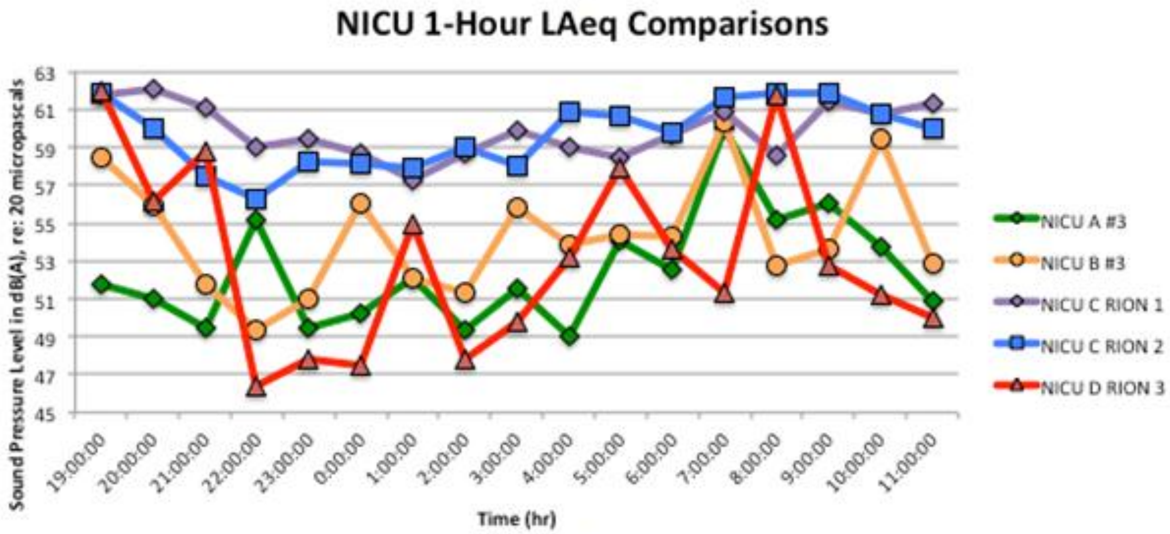


Figure 4-34. A comparison of NICU minute LAeqs.

In figure 4-34 the averaged 1-Hour LAeq's for NICUs A, B, C, and D are displayed in a comparison chart. The measurements for NICU C and D are shown from Wednesday, January 21, 2009 at 7:00 pm to Thursday, January 22, 2009 at 11:00 am. The measurements recorded in NICU A and B are from sound level meter #3 which was located in a patient area, away from the nurses' stations and footpaths for both rooms. NICU A was recorded on Wednesday, December 5, 2011 and NICU B was recorded on Monday, January 9, 2012 at the times shown. A weekday was chosen to provide a more accurate comparison. NICU C has measurements that are surprisingly consistent when averaged as 1-Hour LAeq's, this is different from the patient areas of NICUs A, B, and D that fluctuate levels throughout the day. It can be assumed that overall quieter ambients exist in NICUs A, B, and D such that when loud events occur over time, they significantly raise the LAeq average. However in NICU C, the loud events are not much louder than the overall sound levels in the room.

The events that occur within a healthcare setting are what make up the sound levels within the room, however by looking at long term measurements a conclusion can be made to the ambient environment of the room.   Both measurements recorded in NICU C are overall higher than any of the NICU patient areas measured in this study. At 2:00 am, normally a quiet time in the NICU, NICU D measured a 1-Hour LAeq that was 2 dB(A) below the level measured in the patient area of NICU A. NICU D and the patient area of NICU A ultimately show similar levels. This is valuable because NICU A sound level meter #3 has had the lowest sound levels in this study. The sound measurements recorded in these two areas will provide a baseline for the NICU development conclusions.

Short Term Octave Band Measurements in NICUs A and B

Short-term octave band measurements were made of ambient noise in NICU A and B at mapped locations shown in figure C-1 and C-2 respectively. Figures C-3 through C-8 show several sounds heard in the NICU, such as alarms, equipment, and patient noise. The LAeq is listed in the chart for each measurement, so it can be compared to the long-term measurements recorded in these areas.

Figure C-2 shows some ambient measurements taken around NICU B, the step down unit. As you can see, there is equipment that has an alarm around 500 Hz. Generally, the ambient in the area is low around NC-45.

In figure C-3, comparisons of ambient noise in NICU A versus ambient noise in NICU B are displayed. NICU A is generally perceived as quieter than NICU B. However the levels in NICU B are actually lower than NICU A at most frequencies during the times measured here. At 500 Hz the levels in NICU B meet or exceed those in NICU A. Increases in transient noise levels at these frequencies allow the occupants of NICU B to perceive this area as loud. It should be noted that the NICU is an ever-changing environment, and thus times of day, occupants, patients, etc. can influence sound measurements. Thus, hour LAeq's are beneficial to our study.

Figure C-4 presents two typical machine alarms compared to the quietest ambient in NICU 1. At 500 Hz, alarm 1 is 10 dB higher than the ambient, and alarm 2 is 13 dB higher than the ambient. At 2000 Hz, alarm 2 is 15 dB higher than the ambient.

Figure C-5 compares the ambient in the quietest part of the NICU with a piece of equipment needed by one of the patients in a different part of the NICU. This piece of equipment is very loud, and its noise carries to other patient areas in the NICU. At 63 Hz the equipment is 14 dB over the ambient. At 125 and 500 Hz the equipment is 16 dB over the ambient.

In figure C-6 the ambient noise level of the quietest section of NICU A is compared to speech levels measured in other parts of the NICU. You can see the greatest differences in sound pressure levels occur at 250 and 1000 Hz. At 500 Hz, a 10-decibel difference occurs.

Figure C-7 shows the ambient in NICU A compared to a common noise from the sink and paper towel dispenser adjacent to one of the patients areas. The different in the ambient and noise is 17 dB at 2000 and 4000 Hz. This is quite a loud noise compared to the normal levels in the NICU. These are the kinds of transient noises that contribute to loudness and patient disturbance.

Figure C-8 shows the NC-40 ambient compared to measurements taken of an infant crying and one of the alarms that you often hear in the NICU B. The alarm at 500 Hz is 13 dB higher allowing an acceptable signal-to-noise ratio that is audible. The infant's noise is up to 15 dB higher than the ambient at 2000 Hz. You can see that the patient's noise is significantly louder than the ambient in NICU B which allows for the occupants to perceive the increased loudness in the NICU B.

CHAPTER 5
DISCUSSION

Operating Room

From observations in the operating room environment it was determined that a considerable amount of the sounds present during surgery are human induced rather than equipment induced, and humans control most of the sound that is equipment induced. The environment consists of communication between multiple people, movement, clanking instruments, packages opening, beeping from the pulse oximeter, equipment (alarms, laser, drill, etc.), and sometimes background music. The equipment noise such as the laser and drill cannot be controlled, but the length of their use is dependent on the experience of the surgeon. In a teaching situation between a surgeon and surgical resident the use of a drill can be considerably longer than if an experienced surgeon was completing the task alone. As background music is used a stress reliever, this can be turned down if needed in a specific situation.

Communication in the operating room can be critical. Before the surgery begins, the surgeon communicates with those working in the room on who the patient is and what surgery is going to be taking place. A person records many things that the surgeon communicates to him such as time of operation, procedures, and difficulties experienced. A surgeon communicates with the surgical assistants on what instruments or equipment is needed, and the nurse anesthesiologist communicates with the surgeon on the patient’s state. Communication is also a stress reliever in the room; conversations occur about weekend plans or personal activities, just as many communicate in an office environment.

The operating room has a need to be sterile; therefore many of the surfaces are generally built of sound reflecting materials such as gypsum board or plaster ceilings and walls. The ceiling in the operating room observed was painted gypsum board and not acoustical ceiling tile. The floor is also a large, reflecting surface made of a vinyl material. Therefore noises in the operating room are heard more loudly than they would be heard in a room with more sound absorbent finishes because the reflections of the direct sound increase the overall noise level. With an ambient background of 50 dB(A) and three to four conversations occurring over equipment noise, the sound levels in the room can reach relatively high levels quickly.

The mid-frequency reverberation times in the operating room were 0.63 s and 0.71 s at 500 and 1000 Hz respectively. This is not unreasonable for speech clarity, however the measurements were conducted in a space with a 265 ft^2 area. In the larger room (415 ft^2 area) in which the surgery was observed and recorded, the RT is expected to increase according to Sabine's Equation. A reverberation time between 0.5 and 0.6 s would be ideal for communications purposed in the operating room environment. Because of sanitary reasons, the room's walls, floors, and ceilings need to be capable of being cleaned. Further research needs to be conducted for materials that can be easily sanitized for ceilings and walls that have sound absorbent properties.

It is important that operating rooms be designed with low NC levels. Most of the equipment used in the operating room is loud and will increase the ambient levels in the room. Allowing the background HVAC noise to be low will increase speech intelligibility.

NICU Sound Levels

The 1-Hour LAeq's were calculated from the 10 second LAeq measurements for NICU A and B. This gave an overview of the sound levels one could expect in the

NICU's. Two meters were placed in the louder areas of the patient room; In NICU A this was near the nurses' stations, and in NICU B near the walkway and entrance. One meter was also placed in a quieter area of the rooms near a patient area and away from frequent foot-traffic. Through conversations with staff, it was acknowledged that sound levels in NICU B were perceived as louder than NICU A. Occupants of NICU A also acknowledged that the nurses' stations were the loudest areas in NICU A. It was also discussed, and verified through measurements, that the shift changes of nurses at 7:00 am and 7:00 pm were very loud, and sometimes the loudest events due to the increased occupants in the room and conversations that take place about patients to the incoming nurses.

Comparing the 1-Hour LAeq's between days displayed differences in sound levels, presumably due to changes in patients, visitors, other occupants, and emergency events that happen within the NICU. However, when looking at the average 1-Hour LAeq's over a period of time, these levels showed more consistency and were necessary to show trends in the acoustic calendar of the NICU.

NICU A is a Level III unit and has patients that are in need of more critical care than those of NICU B, therefore there is not a lot of noise directly from the patient in NICU A. Most of the noise from the patient area is from equipment, alarms, visitors, nurses, doctors, janitors, and their activities. Activities include talking, cleaning, or tending to the patient. If a high frequency ventilator is in use, the sound levels around that area are significantly increased. Appendix M shows the LAeq of the ventilator at 59 dB(A), compared to the patient area away from the ventilator at 49 dB(A). This means that it was twice as loud next to the patient using the ventilator as compared to other parts of the NICU. By locating the equipment away from the patient, or even in a shielded closet or container with doors, the noise levels in the vicinity of the equipment can be significantly decreased. Further, having more private patient rooms would separate patients not using the equipment from the increased noise levels.

It should be noted that none of the areas measured in NICU B had levels as low as those measured in NICU A with sound level meter #3. This meter was located in a part of the patient area that was in a corner away from the main foot traffic and nurses' stations and often had 1-Hour LAeq's as much as 6-7 dB(A) quieter than measurements from meters #1 and 2. This is noteworthy because patient noise and machines are similar from one bedside to the next, however this location in the NICU in relation to foot traffic and nurses' stations contributed to the overall quieter noise level. Doctors, nurses, visitors, and other occupants walk to the different locations in the patient area by using the pathways between incubators in the NICU. Patients that are closer to these pathways experience a greater amount of noise than those located off the main path. Nurses congregate at the nurses' stations to talk to each other, use the computers and printers, and talk on the phone. There are two nurses' stations in NICU A and none in NICU B. In NICU A this is a major source of noise as nurses tend to congregate and talk in these areas. Both of these stations are positioned directly next to patients and noise tends to flood into the patient area. The outside walls in NICU A have sound absorbing materials applied to them and the patient's beds are arranged in pods in the middle allowing noise to not overflow from patient areas. Acoustical ceiling tile is also installed in the ceiling. These sound absorbent room finishes contribute to the attenuated noise levels in NICU A.

In NICU B LAeq's between the different meters had a difference of 4 dB(A) or less. There are no nurses' stations in NICU B; Nurses generally stay in the patient area at all times. Because patients in NICU B are at a less critical state than patients in NICU A, many of these patients are held by nurses and rocked in rocking chairs. Therefore nurses have more hands on care and are typically sitting in the patient area chatting with each other and visitors. There are also mostly hard surfaces in NICU B with wood floors and no noise attenuating fabric on the walls. There is also no acoustical separation between rows of patients. Acoustical ceiling tile is installed in the ceiling. It can be concluded from the measurements and room effects that noise travels greater distances in NICU B, and contributes to the noise levels being similar in all locations. Not having a nurses' station means conversations are not generated from one specific loud area, however conversations are also taking place all over the patient area. A solution would be to still provide nurses' areas, however have them located away from the patient area, possibly before an entrance hallway. This would designate a place for healthcare professionals to talk, but not disturb the patient area.

Daytime and Nighttime Shifts

Working hours are separated into two 12-hour shifts for the NICU nurses. The daytime shift is from 7:00 am to 7:00 pm and then the night shift works from 7:00 pm to 7:00 am. NICU A and B both experienced quieter sound levels at nighttime hours than during daytime hours. Most of the sound level meter locations measured their lowest LAeq's per hour between 8:00 pm and 7:00 am. Through conversations with staff, the loudest perceived hours were during shift changes at 7:00 am and 7:00 pm. This was verified with 1-Hour LAeq measurements. Most sound level meters experienced their maximum LAeq at these times. Between the hours of 7:00 am and 7:00 pm 1-Hour

LAeq's varied within 5 dB(A) for each individual sound level meter. NICU A experienced as much as a 7 dB(A) difference in daytime versus nighttime shifts and NICU B experienced as much as a 8 dB(A) difference.

LAmax Levels

The healthcare literature is concerned with the affects of loud, transient noises on patients. Loud noises contribute to raised stress levels and sleep disturbance. In order to fully control these sounds one needs to know what the sources of these sounds are and how often they occur. From observations in the NICU's the sources with the highest sound levels noted were intercom systems, security alarms, paper towel dispensers, high frequency ventilators, elevated personal conversations, telephones, and carts. In NICU B there was also noise from patients, such as crying. Some of these are avoidable, others are not, however most of these noises can be controlled.

The long-term surveys measured sounds in increments of 10 s. In each 10 s sample the loudest dB(A) level was recorded as the LAmax, regardless of duration. The guidelines for the American Academy of Pediatrics (AAP) recommend that the LAmax should not exceed 70 dB(A). Therefore, the percentage of LAmax levels greater than 70 dB(A) for each hour and each day were calculated. Because the guidelines are for 1 s and the recordings were 10 s intervals, these are not exact percentages of how much of the sound level for the hour or day was greater than 70 dB(A). Rather, it is the percentage of the samples that exceeded 70 dB(A) that hour or day. This was done to also see how loud sounds affect the overall LAeq's previously discussed.

The percentage of LAmax samples greater than 70 dB(A) varied greatly among the days measured. In NICU A there was a significantly higher percentage at the nurses' station than the patient area. In the patient area it was frequently less than 10%

and normally less than 20% at the nurses station. In NICU A the LAmax percentages were greatest between the hours of 7:00 am and 5:00 pm, corresponding to our loudest LAeq hours.

In NICU B there wasn't a significant difference between the percentages of LAmax samples that exceeded 70 dB(A) amongst the different hours. Sound level meter #3 in the patient area did see an increase among LAmax levels between the hours of 7:00 am and 8:00 pm. This means that in the patient area in NICU B there were more times that the sound level of 70 dB(A) was exceeded than in NICU A. Further analysis of patient noise sources in NICU B is needed for additional conclusions regarding what is causing the LAmax levels.

The overall daily calculation of the percentage of LAmax samples above 70 dB(A) showed that in NICU A, the nurses' stations had significantly more LAmax levels above 70 dB(A) than the patient area measured. In NICU B the LAmax percentages of the patient corner versus the central walkway in the patient area were similar with between 0.5 and 1 percent difference. However the visitors' entrance had significantly higher LAmax levels at a difference of 5%. The noise sources that most affected this were the pneumatic tube dispenser, the sink, foot traffic, and the first row of patients in the NICU. This denotes why separation between these devices and the patient area is so important to control noise levels. The lack of sound absorbent materials further contributes to the flooding of noise into the patient area. The percentage of LAmax measurements greater than 70 dB(A) did follow the trends of increased levels of LAeq measurements. Therefore it can be concluded that loud, maximum noise levels in the

NICU contribute to the higher LAeq levels, meaning high intensity and transient noises are a significant contributor to the NICU soundscape.

NICUs C and D

Comparing NICUs A and B to previous data acquired for NICUs C and D provides substantial evidence for leveraging data obtained in this study to other intensive care units. Many similarities were found in these environments meaning that similarities could potentially be found in other healthcare units around the world.

Observations in NICU C concluded that there were high levels of mechanical noise in the patient area. Therefore sound levels of alarms were turned up and conversations occurred at an elevated level for comprehension. The LAeq measurements show this increased noise level when compared to the patient areas of NICU A and B. The measurements were conducted in the patient area, away from a nurse station or entrance. LAeq's for NICU C when compared to similar day LAeq's in NICUs A and B for 1:00 and 2:00 pm, were 6 – 10 dB(A) greater.

NICU D did not have similar mechanical noise as described for NICU C. In addition, there were significantly fewer beds than any of the other NICU's studied and the beds were grouped into clusters of 3 or 4 beds in a room off a main hallway. This significantly decreased noise levels in rooms, as foot traffic and conversation did not flood the patient areas. NICU D had LAeq's up to 5 dB(A) lower than NICUs A and B. Measurements in NICU D were also lower than the sound level meter #3 measurements in NICU A, which thus far were the lowest in this study.

It should be noted that when loud events occur in NICU C, they do not affect the overall LAeq's as occurred in other NICUs studied. Occupants perceive them differently because they are not considerably louder than the background ambient sound level of the room. In NICU D, when a loud event occurs, it is significantly louder than the ambient background sound level in the room and therefore is perceived by the occupants as very loud. Ultimately, sound levels should be kept at a lower ambient in the noise sensitive patient areas to encourage lowered voices and a lower setting of alarms on mechanical equipment. An ambient environment with lower sound levels will be beneficial to the patient.

Short-Term Measurements

Sound levels in a room are dependent on the distance, direction, and room effects between the sources and receivers.[1] By comparing individual short-term measurements of equipment and occupants of the room to overall sound levels acquired through long-term measurements, an understanding can be gained of what sound sources are contributing to the room's soundscape. The ambient measurements were recorded between 6-7 am on Tuesday, October 25, 2011. According to the 1-Hour LAeq measurements conducted, NICU A on average had higher sound levels than NICU B for this hour. Therefore, the ambient measurements acquired follow the previous results. The NC rating for NICU A followed the NC-45 curve (see fig. C-1). It is noted that in addition to HVAC noise this NICU has occupants, patients, and patient equipment noise. NICU B's ambient measurements mostly followed the NC-45 curve (see fig. C-2). A spike in the 500 Hz octave band was prevalent from equipment noise in the patient area. The frequency spectrum for this equipment recorded levels of 67 dB at the 63 Hz octave band and 68 dB at the 125 Hz octave band. The overall LAeq for this equipment was 59 dB(A) which is 10 dB(A) higher than the ambient measured at a different location away from the equipment in NICU A. This means that it was twice as loud in this patient's vicinity when utilizing this equipment.

Speech was measured at a distance of approximately 4 feet from the source at a patient's bedside and at a nurses' station. A difference of 10 decibels from the ambient was measured in the 500 Hz octave band. Speech is a common source everywhere in the NICU; nurses congregate at the nurses' stations to talk personally and about patients. Speech is generally not suppressed during this communication and sound levels can be reasonably loud. The measurement shown in figure C-6 does not quantify this observation, however LAeq measurements at the nurses' stations show how levels are affected at the nurses' station compared to a quiet patient area in NICU A. It would be beneficial to move the nurses' station outside of the patient area to suppress sound levels around patients. Computers are located near patient's bedsides to input data for the patient. During shift changes, two nurses sit at these and go over the events of the day so that the next nurse can take over for their shift. During this event sound levels are raised, but it is necessary. Speech is usually soft-spoken as to not arouse the patient.

Alarms are one of the most common noise sources in the NICU. They alert the healthcare personnel to react and tend to patient as needed. In NICU A two different common alarms were recorded (see Appendix L). One was at 500 Hz, and the other was a dual tone at 500 and 2000 Hz. An alarm in NICU B was measured at 45 dB(A) with a maximum sound level of 57 dB at 500 Hz. The range of frequencies between 500 and 2000 Hz represent the normal frequencies of speech. Therefore communication may be inhibited by these alarms.

The loudest source found and recorded in NICU A was the high frequency oscillator ventilation as shown in Appendix M, which is used for critical patients.

Patients utilizing this equipment are in the same patient area as other patients, and all are affected by the extra noise.

NICU B had additional noise from patients; this is generally not a concern in NICU A because of the patient's critical condition. However in NICU B, one baby crying can mean all the babies will be crying eventually if they are aroused. An infant crying was measured at 57 dB(A) with a maximum of 55 dB at the 250 Hz octave band, 3 feet from the bedside (see fig. 4-42). At 1000 Hz, 53 dB was recorded. This is a difference of 12 dB from the ambient.

In healthcare facilities it is essential to maintain cleanliness. A sink and paper towel dispenser is a common entity in the NICU patient area. However it also can be loud. Running water and a paper town dispenser that tears off a towel to be thrown away can be loud and disturbing. In the comparison of frequency spectrums (see figure C-7), at the 2000 Hz octave band there was a difference of 17 decibels. The LAeq was 62 dB(A) integrated over the process of washing and drying one's hands. Suggestions in guidelines include having hot water immediately available at the tap to decrease the time water is running.

CHAPTER 6
CONCLUSIONS

Healthcare spaces are ever-changing environments where the mechanical noise, equipment, patients, alarms, occupant and schedule directly influence sound levels. In the open patient area of an intensive care unit, noise levels can drastically change within 15 ft. or within a few minutes time lapse. The distance, direction, and room environment that surround a sound source effect what the receiver will hear.[1] Therefore in the design of a patient area one must consider where the sources of noise are and the distance and direction of the patients in relation to them to decrease noise levels. The finishes of the room must also be carefully selected in order to absorb the reflections of the sound off of the room's surfaces and attenuate it before it reaches the patient area. Alarm noise levels for patients and healthcare professionals can be adjusted. If mechanical and HVAC noise is at minimum levels, the alarms can be lowered and still be audible. Lower alarm levels contribute to lower annoyance levels to occupants.[23] Alarm noise in the 500-1000 Hz octave bands allows conversation to be kept at lower levels as well. Lower mechanical noise, and thus lower residual noise levels will contribute to overall quieter sound levels in the healthcare environment.

Most of the overall sound pressure level measurements from this study were comparable to those found in the literature. In the operating room at the Florida Surgical center, sound pressure levels in surgery were between 62 – 77 dB(A). During surgeries at Johns Hopkins Hospital, sound pressure levels averaged between 55 and 70 dB(A) with significant peak levels exceeding 95 dB(A).[16] Peak levels were taken into account during the soundscape study, however healthcare professionals did not discuss concern for potential hearing loss. Disruption of clear speech communication was observed.

The background noise of the operating room at the Florida Surgical Center measured 50 dB(A). This is comparable to those measured in Wallace et al.'s[17] study. Wallace et al. measured background levels ranging from 46 to 57 dB(A), with an average level of 52 dB(A).[17]

WHO[7] guidelines for intensive care units state that daytime and nighttime levels should not exceed 30 dB(A) LAeq and LAmax levels on Fast setting should not exceed 40 dB(A). LAeq levels observed in all NICUs in this study surpasses these levels. LAmax levels also exceeded 40 dB(A). The American Academy of Pediatrics[22] recommends less strict levels at LAeq of 45 dB(A), however these levels were surpassed as well. Busch-Vishniac et al.[3] found that most studies showed sound levels were 20 -40 dB(A) than the recommended. The 1-Hour LAeqs for the NICU's at Shands Hospital ranged between 45 – 66 dB(A) for NICU's A and B. These levels are up to 21 dB(A) higher than the recommended which follows Busch-Vishniac et. al's results.

Choniere's[26] review of "The effects of hospital noise," states that sound levels greater than 50 dB(A) have shown sleep disturbance in hospital patients and can also induce negative effects on the immune system or patient recovery. The levels experienced in the NICU average above 50 dB(A) and up to 66 dB(A). Williams et al.[20] found that levels ranging from 55 to 60 dB(A) caused an increase in heart rate in low birth rate newborns (454 to 694 grams).

In both the operating room and intensive care suite, it is important to lower the background noise levels caused by the mechanical equipment. This influences the occupants of the rooms to lower the levels of sound they are creating and adding to the space. Creating white noise to mask levels could influence occupants to increase their levels of conversation to communicate. As shown in the NICU study at the Tampa hospital, higher background noise also initiated the need to increase alarm levels to hear them properly.

Communication is important in healthcare environments.[16] However, not all conversations are advantageous to healthcare, and if problems arise in noise levels these should be controlled. Sanctioning dedicated nurses' stations with seating areas encourages congregation. This is productive in this kind of environment as it contains a place for speech to occur that is not necessarily at the patient's beside, and by removing these locations away from the patient area it will keep noise levels lower. Measurements from NICU A meter #3 and NICU D support this theory. They were overall the quietest environments measured and they were also farthest away from any group speech sources such as the nurses' station. The sound level meter #3 in NICU A was in a less-travelled patient area and the NICU D sound level meter was located in a room for 3-4 patients that was branched off a main hallway. To create this environment in all intensive care units, pods of 2-6 patients can be located off a main hallway that leads to all the patient rooms. Therefore, all main foot traffic is distanced from the infants, unnecessary communication is kept out of the patient areas, and loud patient equipment can be kept outside the direct patient area in the hallway. Alarms can even be outside the immediate patient area or utilize lights above the entrance to notify nurses when needed. One problem identified in NICU A's sound attenuating pods was when an alarm was sounding it was difficult for the nurses to quickly identify which patient's bedside it was coming from. A light mechanism would solve this problem immediately. A vibrating paging system on the nurses', such as a beeper, could also provide a solution without causing a disturbing noise.

Analysis of LAmax levels that exceed 70 dB(A) in the NICU concluded that it is a routine occurrence. In a worst case scenario, NICU B meter #2 saw 22% of its LAmax measurements above 70 dB(A) at 2:00 pm on January 8, 2012. NICU A meter #2 recorded 9.5% of its LAmax measurements above 70 dB(A) on December 1, 2011. Further physical observations need to be conducted to conclude what these max levels are from. Possibilities include patient noise, loud conversations, security alarms (NICU B), and the intercom system.

NICU A in its redesign located some sound sources away from the patient area, such as the pneumatic tube system, nutrition area, medicine area, and reception. Without comparing similar environments at the same level of care it is difficult to quantify the direct correlation this had on overall sound levels. However, in NICU B the pneumatic tube system is a frequent complaint of noise from patients' visitors and the NICU nurses. Sinks for washing hands of the healthcare professionals are also major sources of noise. Because occupants must wash their hands upon entering the units and healthcare professionals wash their hands many times within the unit, this is a major contributor to the background noise in these spaces. The process of washing and drying one's hands in NICU A was measured at an average of 62 dB(A) within proximity of the device. This is well above the average SPL in the area. These devices are easy to relocate in a NICU away from patients and should be done so in the schematic design phase. In an intensive care unit where it is unfeasible to have private rooms, distancing the nurses' stations or congregation areas for occupants away from the patient area can decrease sound levels significantly.

Room finishes greatly affect the way noise travels in the NICU and operating rooms. Acoustical ceiling tile and fabric wrapped panels can be beneficial to intensive care units as they will absorb reflected sound energy and keep noise contained within a limited area. This was evident in NICU A as noise occurring at meter #2 at a nurses' station did not affect levels at meter #3 in a patient area. In the previously recommended design with patient pods extending from a main hallway, the use of sound absorbing finishes would contain noise within the hallways and constrain it from flooding into patient areas. These are easy and effective ways to control noise. In the operating room environment many historically used fabrics and finishes for use in reducing reflections off reflective surfaces cannot be used due to sanitary reasons. Further research in sanitary materials is needed for analysis.

Previously discussed in the literature was education for healthcare employees. If a nurse knows that sound can negatively affect the patient's healing process, then he or she will have a responsibility to contain the noise they are making. As instinctive as it may be, education is needed to instill this in employees. Observations conclude that some employees are more apt to suppress noise than others.

Further Research. It is essential that maintainable code requirements for healthcare spaces be required and enforced. The past research in healthcare has repeatedly shown that hospital noise does not comply with existing standards. It has been documented that noise can deteriorate the environment for patients and professionals in various ways, and it needs to be addressed. This study has concluded that the sound levels recorded in these environments can vary significantly depending on locations of the source and receiver. Measurements of sound levels in hospital environments need to have a standard associated with them, otherwise it would be advantageous to the tester to locate the quietest and least traveled location to position the sound level meters.

The standards that are available for healthcare spaces often have conflicting acoustical metrics. LAeq, LAmax, and LApeak levels are used most often. This study showed LAmin levels were also effective in showing residual noise. More research on Ldn and percentile levels is necessary to find an accurate description of noise in these areas as related to the outcomes desired.

For the operating room, sound levels of specific equipment used can be found in equipment data and the literature. This will provide a more accurate description of the levels surgeons experience in different surgeries. Also, a variety of surgeries can be observed and measured to find a baseline for these environments.

In NICU environments there are many different levels of care provided for neonates. More research into the health effects of noise on patients can be beneficial to providing an adequate space. If the infants have the ability to cry and create noise more often, it would be favorable to locate them in single-bed rooms as to not disturb other patients.

Research into the use of lights or beeper type alarms to notify healthcare professionals of patient alarms would be instrumental in the use of such devices. It is difficult to change the way people have worked for a long time. However, evidence of successful systems is hard to deny. It would be beneficial to know the response rates of nurses and doctors that utilize these systems compared to the time it takes to answer a sounding alarm; such evidence would be invaluable in promoting the use of these devices in healthcare.

This study provided a quantitative analysis of the sound levels found in five healthcare environments. To further analyze these spaces, questionnaires of all the occupants of these rooms could be collected and evaluated. Questions related to the stress and annoyance caused by the sound sources, background noise, and transient noise levels can provide a better understanding of the effects of living and working in these spaces. A qualitative to quantitative analysis will also further benefit the conclusions to this study.

APPENDIX A

1-HOUR LAEQ'S FOR SOUND LEVEL METERS IN NICU'S A & B

Table A-1. 1-Hour LAeq's for Sound Level Meter #1 in NICU A

	11/30/11	12/1/11	12/2/11	12/3/11	12/4/11	Avg (dB)
14:00:06	56	54	55	56	60	**56**
15:00:06	54	58	55	59	54	**56**
16:00:06	56	57	56	56	56	**56**
17:00:06	55	59	55	55	57	**56**
18:00:06	56	56	54	60	59	**57**
19:00:06	55	58	55	57		**56**
20:00:06	54	56	54	53		**54**
21:00:06	55	58	51	56		**55**
22:00:06	57	54	52	57		**55**
23:00:06	54	52	53	53		**53**
0:00:06	55	51	53	54		**53**
1:00:06	51	51	50	53		**51**
2:00:06	53	52	50	51		**51**
3:00:06	52	53	51	53		**52**
4:00:06	52	53	51	57		**53**
5:00:06	53	54	51	54		**53**
6:00:06	56	52	55	55		**54**
7:00:06	57	57	55	60		**57**
8:00:06	56	53	56	58		**56**
9:00:06	54	60	55	59		**57**
10:00:06	54	55	59	58		**56**
11:00:06	55	54	57	57		**56**
12:00:06	56	53	54	59		**55**
13:00:06	53	54	54	56		**54**

Table A-2. 1-Hour LAeq's for Sound Level Meter #2 in NICU A

	11/30/11	12/1/11	12/2/11	12/3/11	12/4/11	12/5/11	Avg (dB)
14:00:08	55	58	57	54	53	55	**55**
15:00:08	54	58	55	57	52	54	**55**
16:00:08	54	57	58	56	57	55	**56**
17:00:08	57	59	58	54	52	55	**56**
18:00:08	56	58	57	54	55	55	**56**
19:00:08	57	60	57	59	59	56	**58**
20:00:08	52	59	54	51	53	53	**54**
21:00:08	51	55	54	53	53	53	**53**
22:00:08	53	53	51	51	58	53	**53**
23:00:08	54	53	54	52	51	53	**53**
0:00:08	52	53	53	52	59	51	**53**
1:00:08	51	51	50	53	54	53	**52**
2:00:08	50	51	51	54	51	51	**51**
3:00:08	50	52	51	53	50	51	**51**
4:00:08	50	52	53	54	54	50	**52**
5:00:08	51	56	53	55	51	52	**53**
6:00:08	52	54	57	56	57	55	**55**
7:00:08	59	60	58	56	60	57	**58**
8:00:08	57	56	55	55	55	54	**55**
9:00:08	57	57	55	54	53	56	**55**
10:00:08	55	58	56	56	56	54	**56**
11:00:08	59	56	55	58	56	56	**57**
12:00:08	59	58	55	53	54	54	**55**
13:00:08	58	58	55	56	52		**56**

Table A-3. 1-Hour LAeq's for Sound Level Meter #3 in NICU A

	11/30/11	12/1/11	12/2/11	12/3/11	12/4/11	12/5/11	Avg (dB)
14:00:04	56	51	50	49	47	56	**52**
15:00:04	49	52	54	50	49	55	**51**
16:00:04	49	54	55	49	48	53	**52**
17:00:04	51	53	52	50	47	58	**52**
18:00:04	54	53	49	46	47	51	**50**
19:00:04	56	52	53	49	50	52	**52**
20:00:04	52	50	52	46	47	51	**50**
21:00:04	49	51	46	47	49	49	**48**
22:00:04	49	50	53	48	46	55	**50**
23:00:04	48	48	49	47	48	49	**48**
0:00:04	50	47	48	46	48	50	**48**
1:00:04	49	49	50	44	46	52	**49**
2:00:04	52	50	46	45	47	49	**48**
3:00:04	51	47	45	45	45	52	**47**
4:00:04	51	47	46	46	48	49	**48**
5:00:04	49	48	45	47	47	54	**48**
6:00:04	54	55	48	49	49	53	**51**
7:00:04	53	50	50	50	49	60	**52**
8:00:04	53	49	49	49	48	55	**50**
9:00:04	53	48	48	49	50	56	**51**
10:00:04	50	54	48	50	49	54	**51**
11:00:04	49	53	49	48	52	51	**50**
12:00:04	55	50	51	48	55	53	**52**
13:00:04	52	57	48	46	57	53	**52**

Table A-4. 1-Hour LAeq's for Sound Level Meter #1 in NICU B

	1/4/12	1/5/12	1/6/12	1/7/12	Avg dB(A)
14:00:08	57	56	58	58	**57**
15:00:08	58	57	57	56	**57**
16:00:08	55	56	59	54	**56**
17:00:08	55	57	57	55	**56**
18:00:08	54	56	54	53	**54**
19:00:08	56	56	54	56	**55**
20:00:08	56	55	57	56	**56**
21:00:08	57	55	56	55	**56**
22:00:08	56	55	53	53	**54**
23:00:08	55	56	55	55	**55**
0:00:08	55	54	52	52	**53**
1:00:08	55	54	53	51	**53**
2:00:08	54	53	52	52	**53**
3:00:08	54	55	53	51	**53**
4:00:08	55	55	52	51	**53**
5:00:08	55	55	50	51	**53**
6:00:08	55	52	52	54	**53**
7:00:08	56	57	55	53	**55**
8:00:08	56	57	51	54	**54**
9:00:08	55	56	55	55	**55**
10:00:08	57	57	57	51	**55**
11:00:08	58	58	55		**57**
12:00:08	57	57	58		**57**
13:00:08	59	57	55		**57**

Table A-5. 1-Hour LAeq's for Sound Level Meter #2 in NICU B

	1/4/12	1/5/12	1/6/12	1/7/12	1/8/12	1/9/12	Avg dB(A)
14:00:06	55	54	58	66	60	57	**58**
15:00:06	57	55	58	61	55	56	**57**
16:00:06	52	55	57	53	51	56	**54**
17:00:06	53	56	60	55	53	56	**55**
18:00:06	53	56	56	57	56	57	**56**
19:00:06	56	56	54	56	55	56	**56**
20:00:06	56	55	63	55	63	56	**58**
21:00:06	57	53	54	55	54	54	**55**
22:00:06	59	53	53	55	61	50	**55**
23:00:06	53	56	58	55	59	50	**55**
0:00:06	53	56	55	55	50	52	**53**
1:00:06	54	53	54	50	54	52	**53**
2:00:06	53	54	53	60	53	58	**55**
3:00:06	55	57	53	52	60	64	**57**
4:00:06	55	58	52	51	62	52	**55**
5:00:06	54	56	52	53	63	53	**55**
6:00:06	52	53	51	54	52	51	**52**
7:00:06	56	57	57	54	55	57	**56**
8:00:06	55	58	53	55	56	57	**56**
9:00:06	56	55	58	57	55	64	**57**
10:00:06	55	55	59	55	54	53	**55**
11:00:06	55	57	56	56	54	55	**55**
12:00:06	55	55	58	57	55	64	**57**
13:00:06	59	56	55	57	55	55	**56**

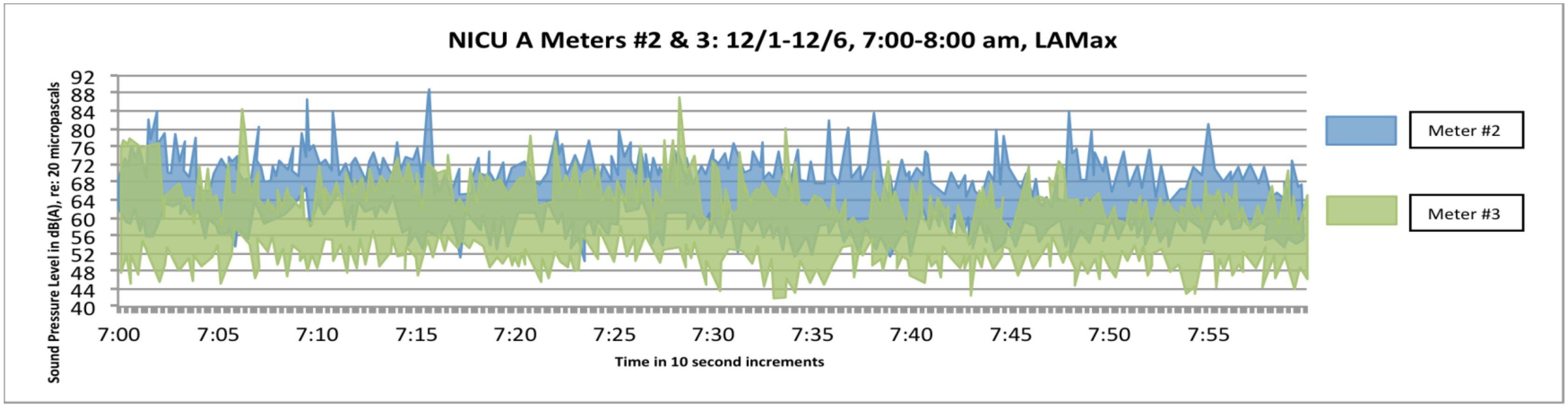
Table A-6. 1-Hour LAeq's for Sound Level Meter #3 in NICU B.

	1/4/12	1/5/12	1/6/12	1/7/12	1/8/12	1/9/12	Avg dB(A)
14:00:00	58	53	56	57	52	58	**55**
15:00:00	53	51	56	51	55	53	**53**
16:00:00	49	54	56	56	54	53	**55**
17:00:00	54	57	55	55	50	53	**54**
18:00:00	54	53	57	51	54	53	**54**
19:00:00	58	57	59	59	57	58	**58**
20:00:00	57	55	54	54	60	56	**56**
21:00:00	56	53	53	53	52	52	**52**
22:00:00	54	53	51	57	52	49	**52**
23:00:00	52	58	54	55	53	51	**54**
0:00:00	54	54	50	54	48	56	**53**
1:00:00	51	52	51	50	52	52	**51**
2:00:00	51	53	53	50	54	51	**52**
3:00:00	54	55	53	54	56	56	**55**
4:00:00	55	57	50	50	54	54	**53**
5:00:00	52	52	49	55	51	54	**52**
6:00:00	53	52	53	53	51	54	**53**
7:00:00	56	60	59	54	61	60	**59**
8:00:00	55	54	54	55	55	53	**54**
9:00:00	51	52	51	56	52	54	**53**
10:00:00	51	55	56	55	56	59	**56**
11:00:00	53	58	54	55	53	53	**55**
12:00:00	53	57	56	54	53	55	**55**
13:00:00	57	52	56	54	55	53	**54**

Table A-7. Average Hourly LAeq's for Locations #1, #2, and #3 in NICU A and B

	Average Hourly Leq (dB)					
	NICU A			NICU B		
Hour	#1	#2	#3	#1	#2	#3
7:00:00	57	58	52	55	56	59
8:00:00	56	55	50	54	56	54
9:00:00	57	55	51	55	57	53
10:00:00	56	56	51	55	55	56
11:00:00	56	57	50	57	55	55
12:00:00	55	55	52	57	57	55
13:00:00	54	56	52	57	56	54
14:00:00	56	55	52	57	58	55
15:00:00	56	55	51	57	57	53
16:00:00	56	56	52	56	54	55
17:00:00	56	56	52	56	55	54
18:00:00	57	56	50	54	56	54
19:00:00	56	58	52	55	56	58
20:00:00	54	54	50	56	58	56
21:00:00	55	53	48	56	55	52
22:00:00	55	53	50	54	55	52
23:00:00	53	53	48	55	55	54
0:00:00	53	53	48	53	53	53
1:00:00	51	52	49	53	53	51
2:00:00	51	51	48	53	55	52
3:00:00	52	51	47	53	57	55
4:00:00	53	52	48	53	55	53
5:00:00	53	53	48	53	55	52
6:00:00	54	55	51	53	52	53

APPENDIX B
COMPARISON OF LAMAX AND LAMIN LEVELS IN NICU'S A AND B



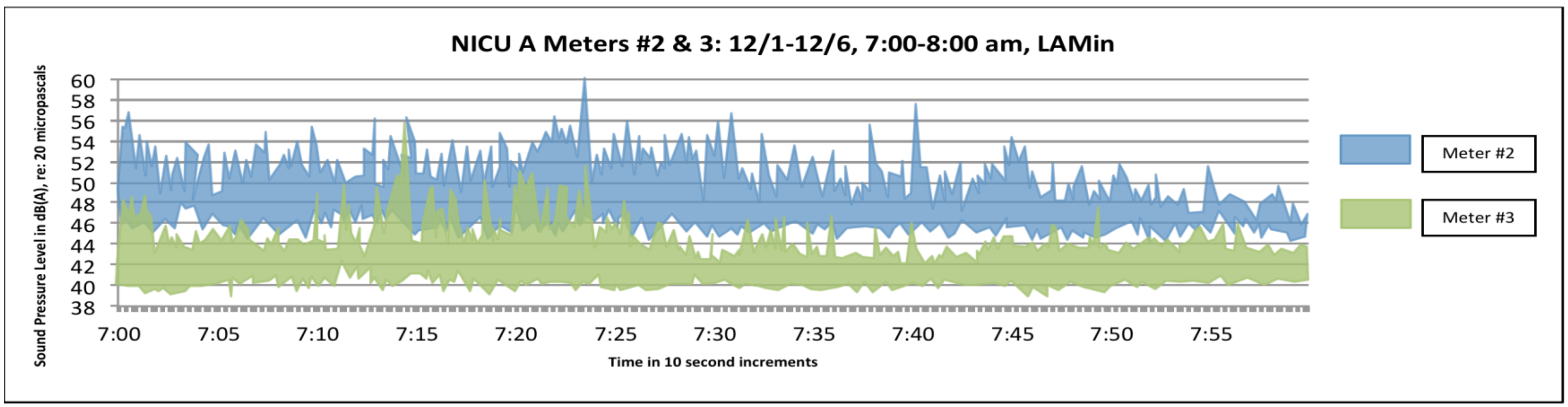
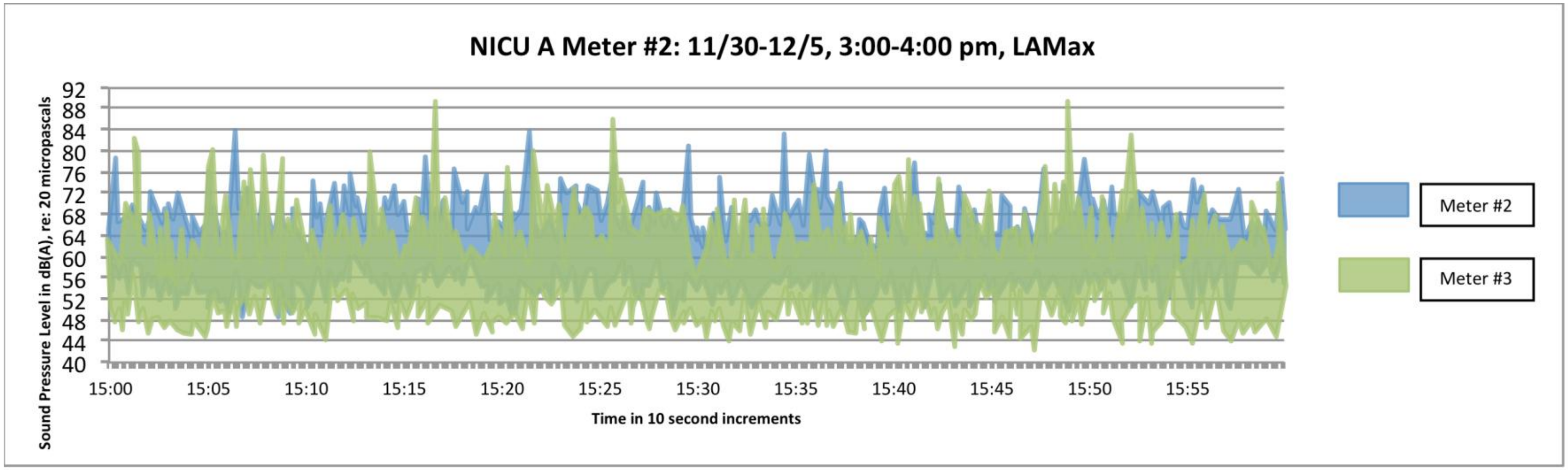


Figure B-1. Comparison of LAmax and LAmin levels in NICU A at sound level meters #2 and #3, 7:00-8:00 pm.



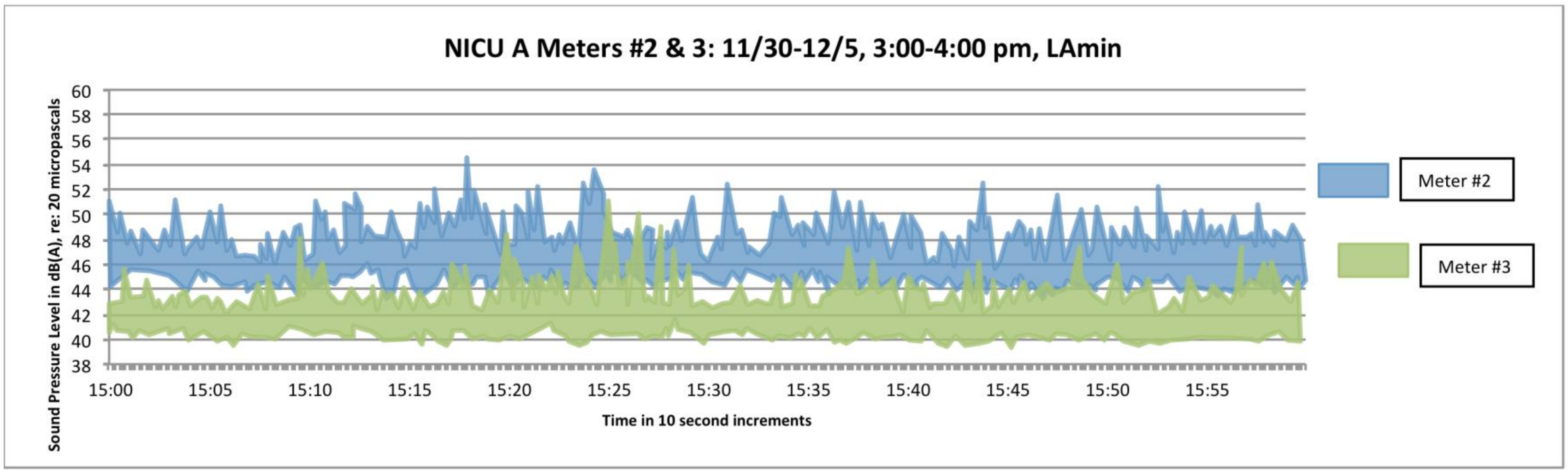
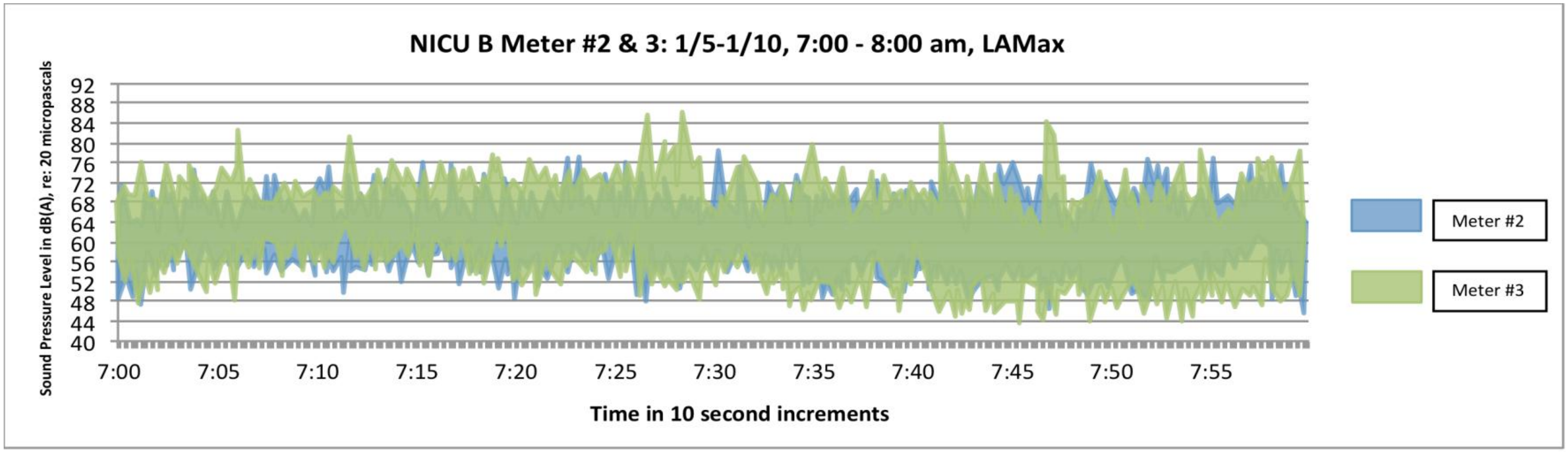


Figure B-2. Comparison of LAmax and LAmin levels in NICU A at sound meters #2 and #3, 3:00-4:00 pm.



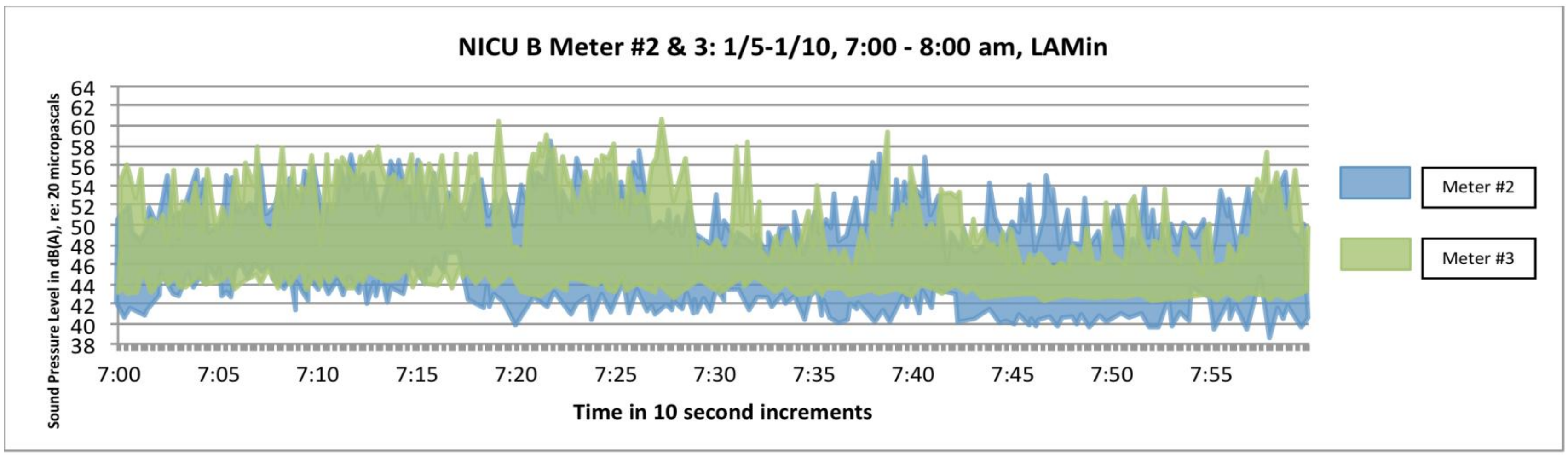
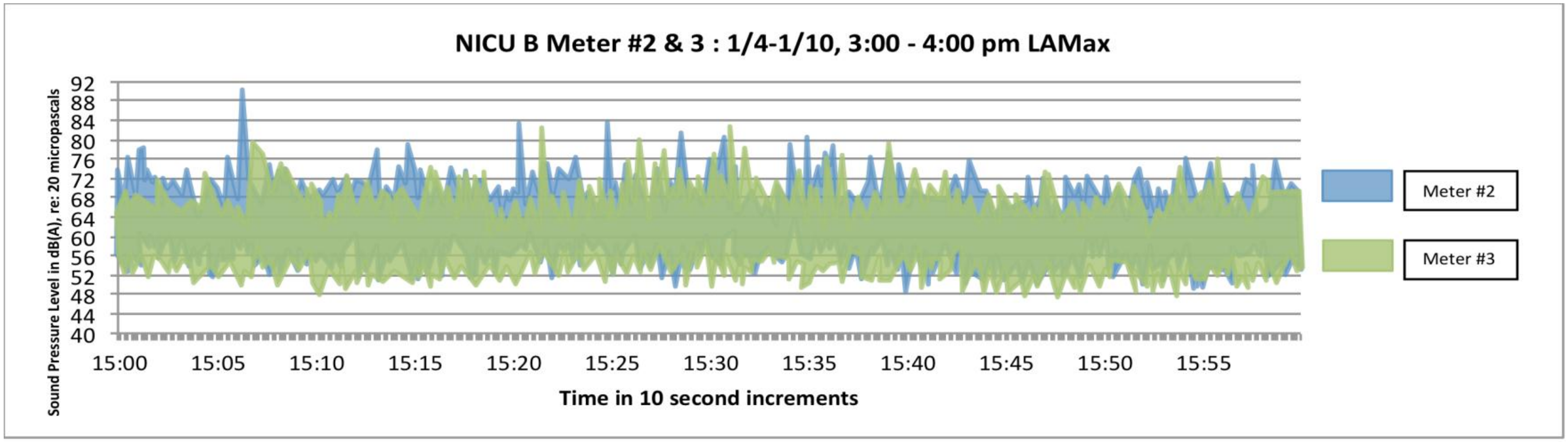


Figure B-3. Comparison of LAmax and LAmin levels in NICU B at sound level meters #2 and #3, 7:00-8:00 am.



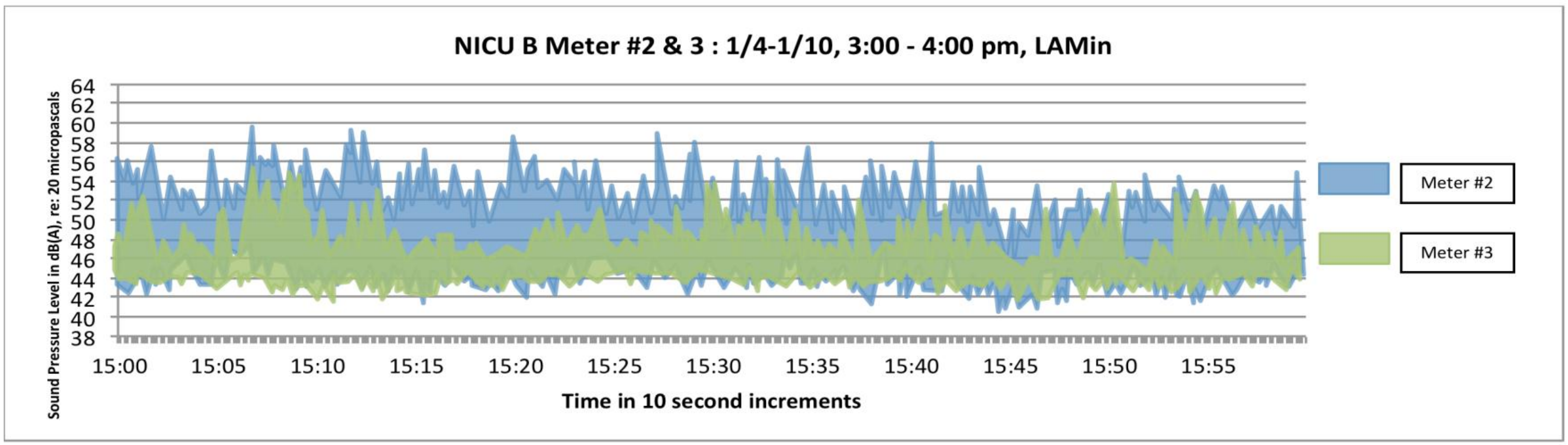


Figure B-4. Comparison of LAmax and LAmin levels in NICU B at sound level meters #2 and #3, 3:00–4:00 pm.

APPENDIX C
OCTAVE BAND MEASUREMENTS IN NICU'S A AND B

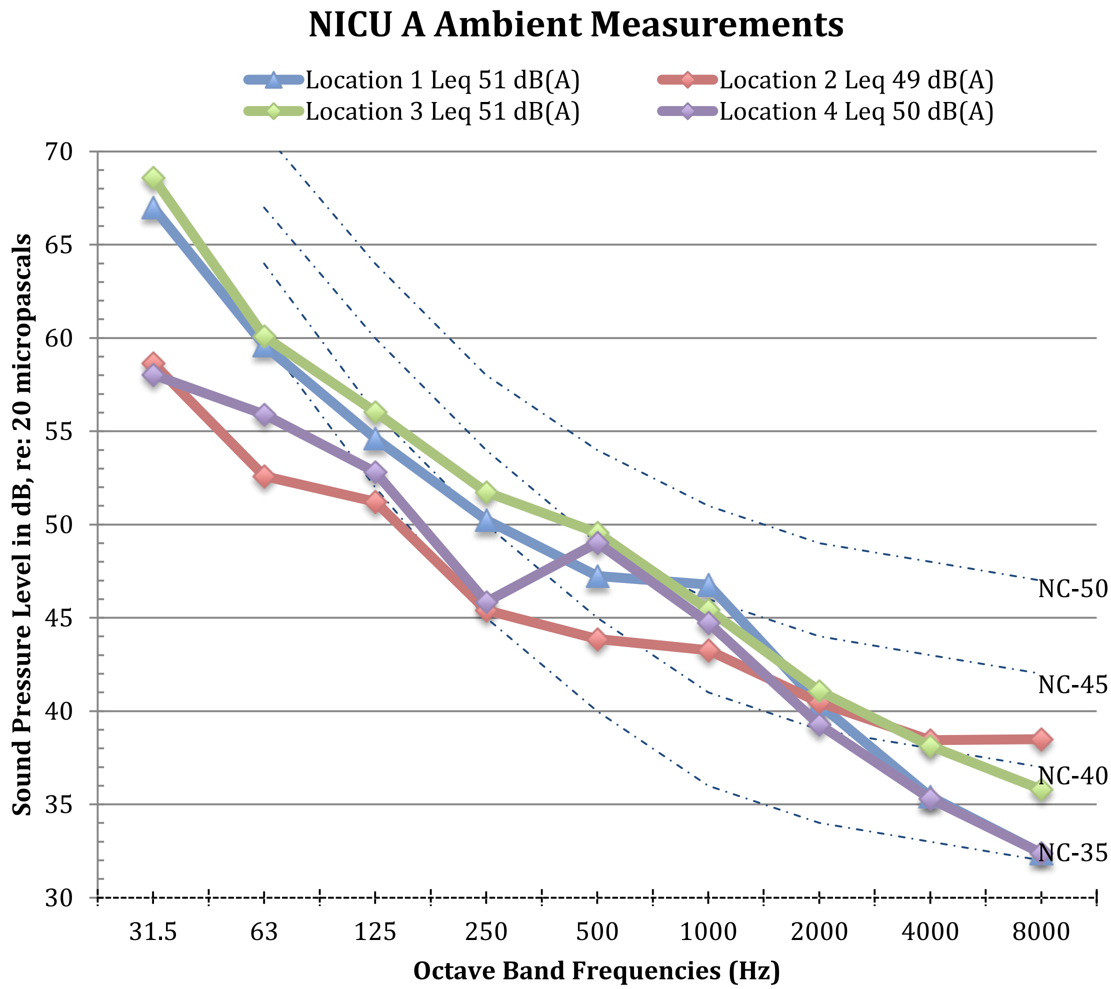


Figure C-1. Ambient levels measured in NICU A.

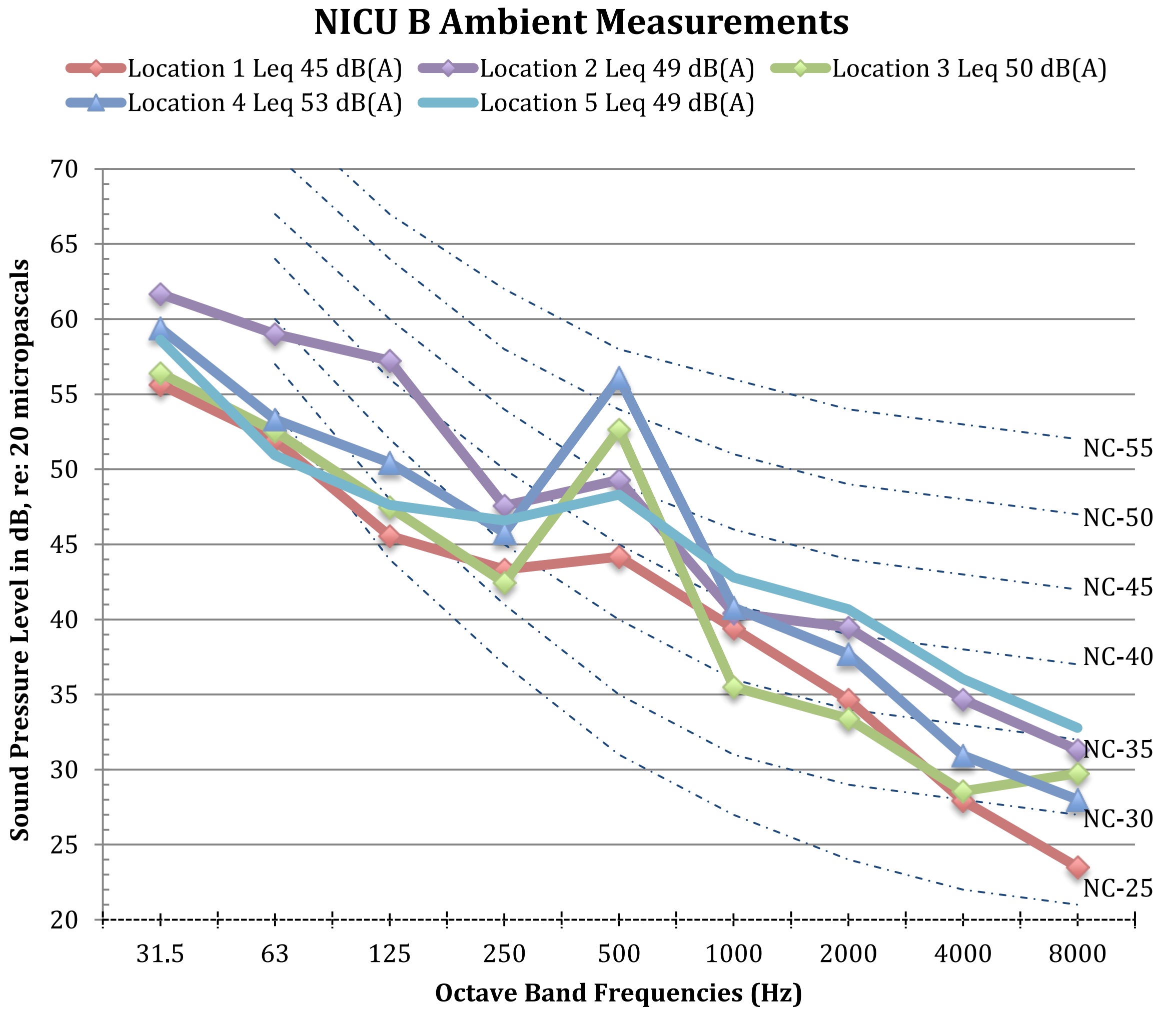


Figure C-2. Ambient levels measured in NICU B.

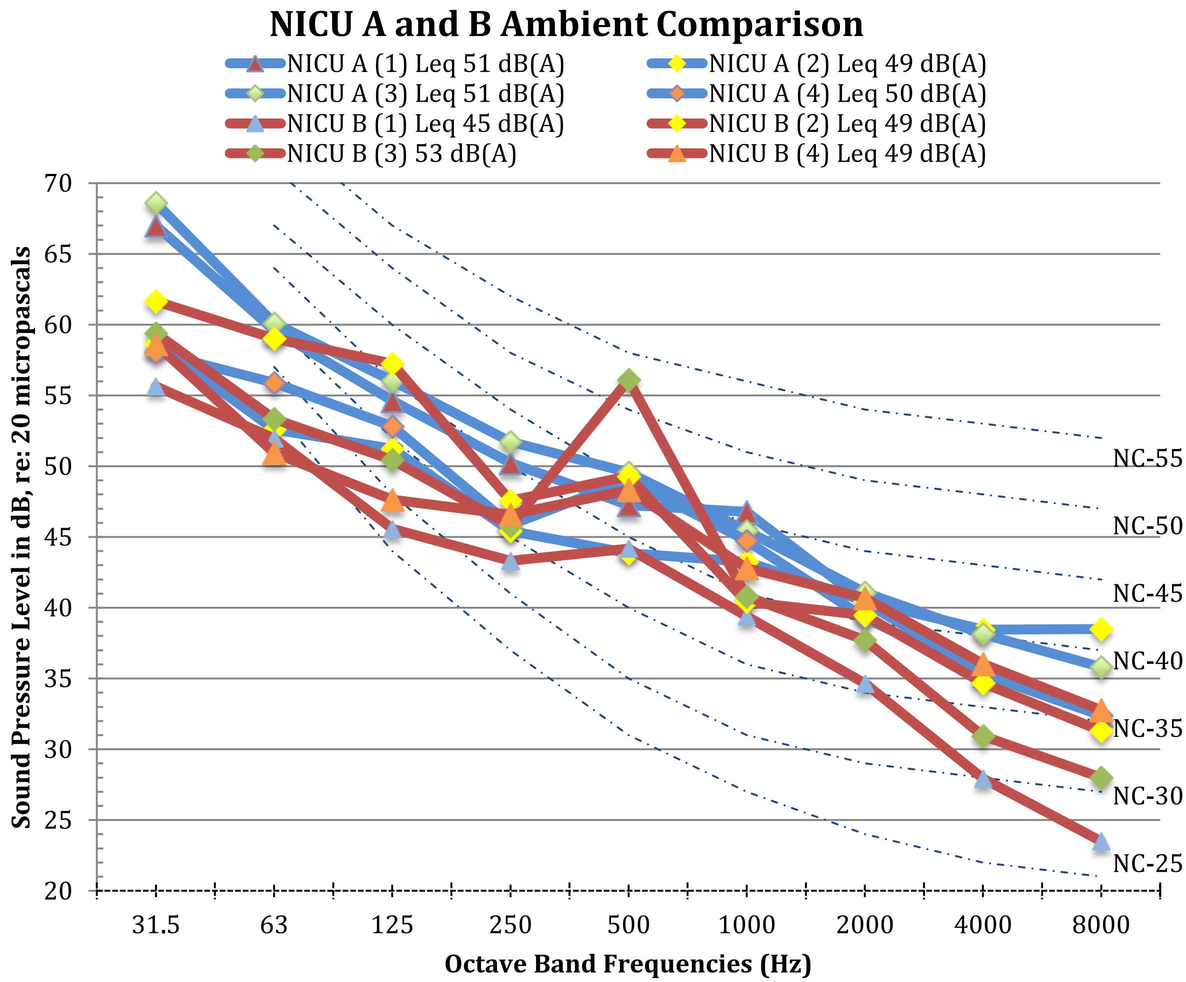


Figure C-3. Comparison of ambient levels measured in NICU A and B.

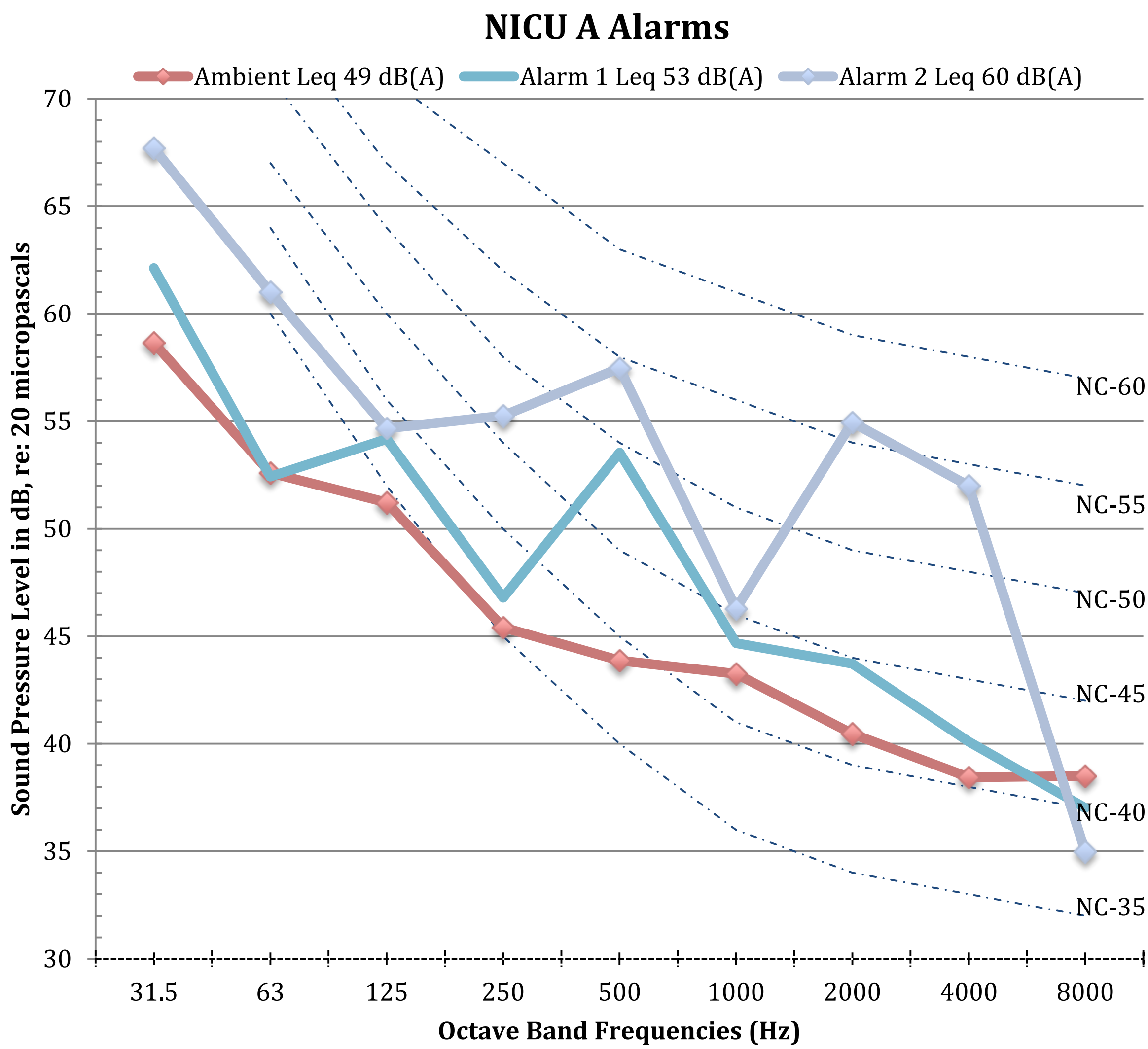


Figure C-4. NICU A alarm sounds.

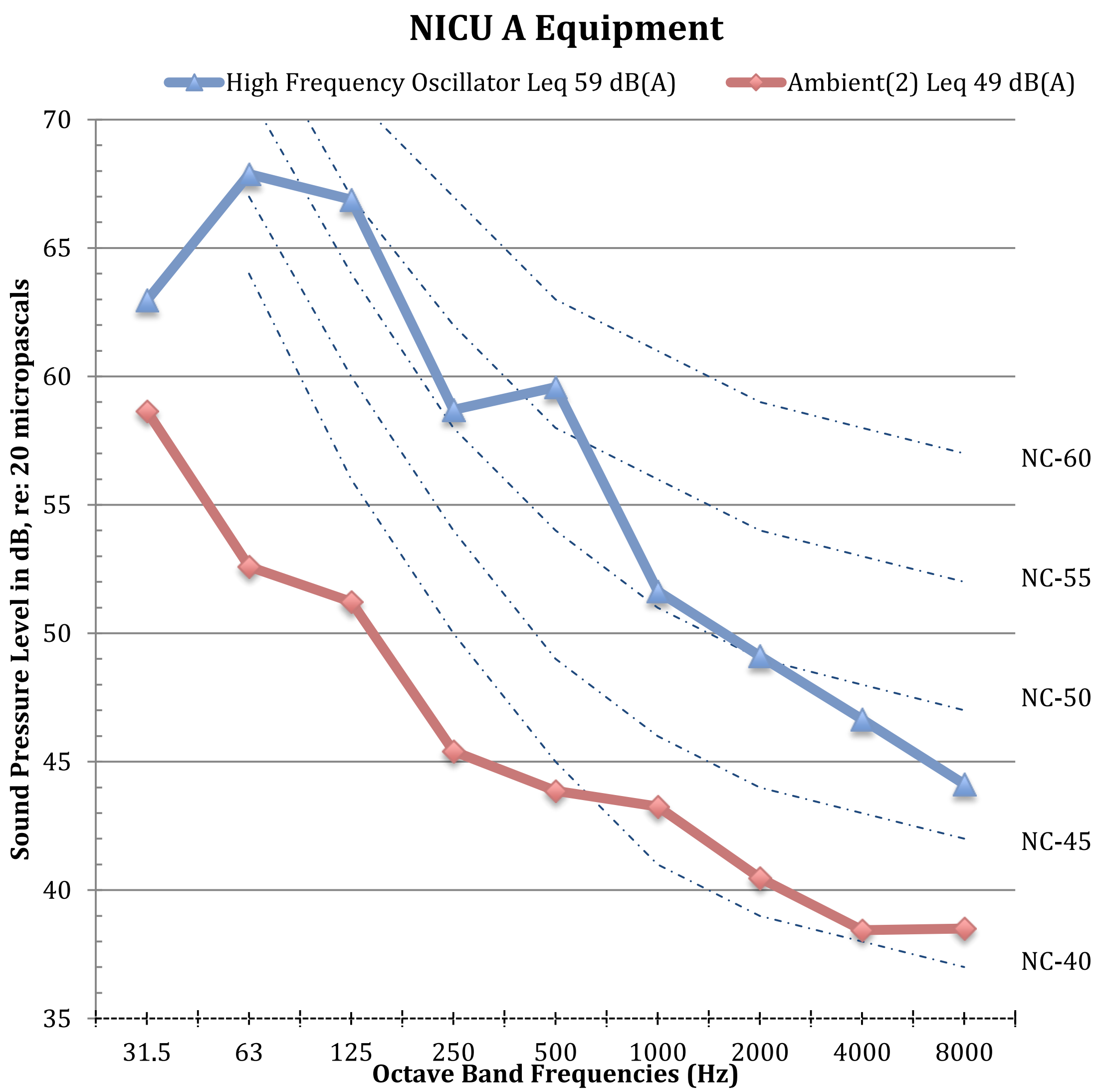


Figure C-5. Equipment sounds in NICU A.

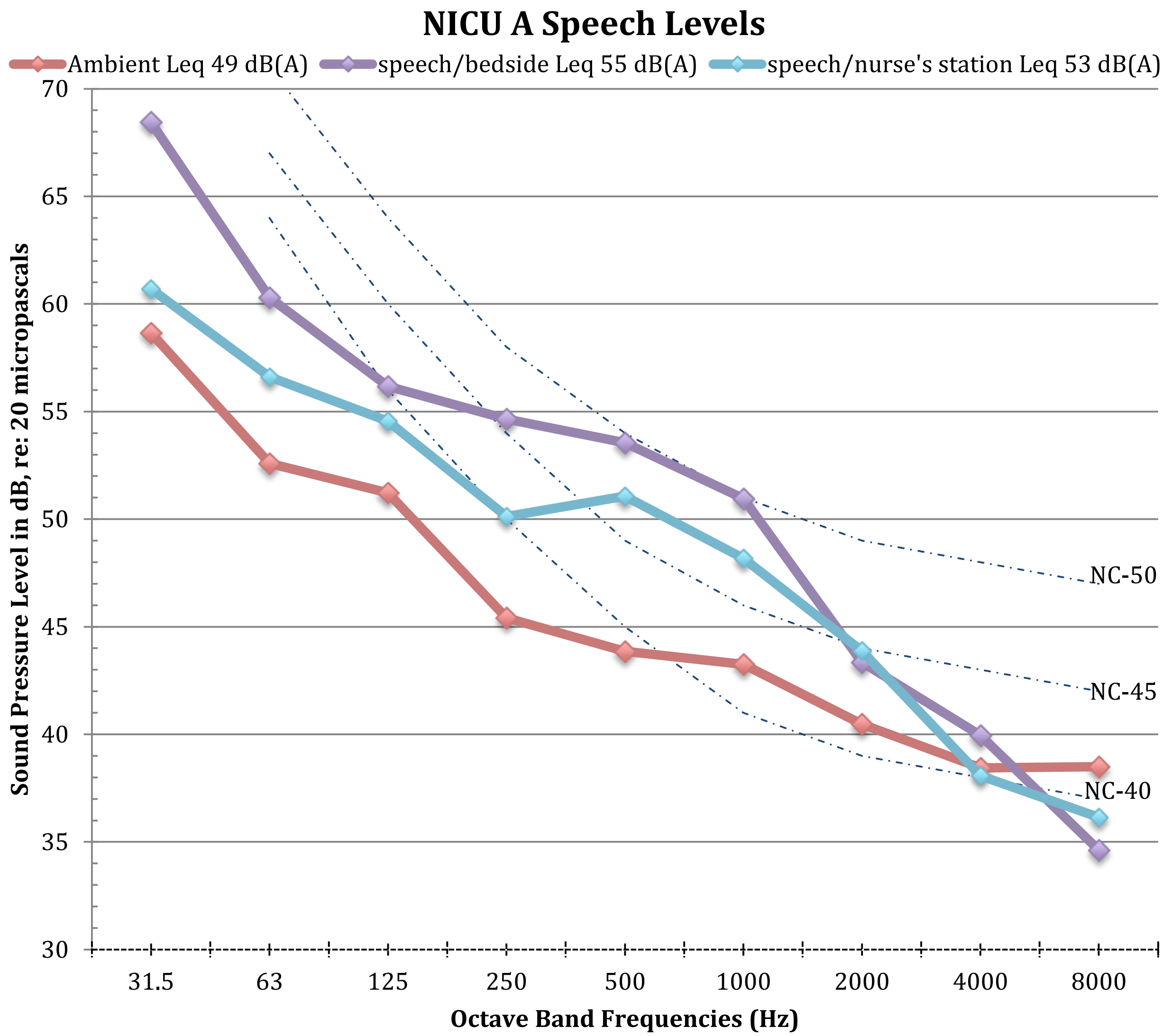


Figure C-6. Speech levels in NICU A.

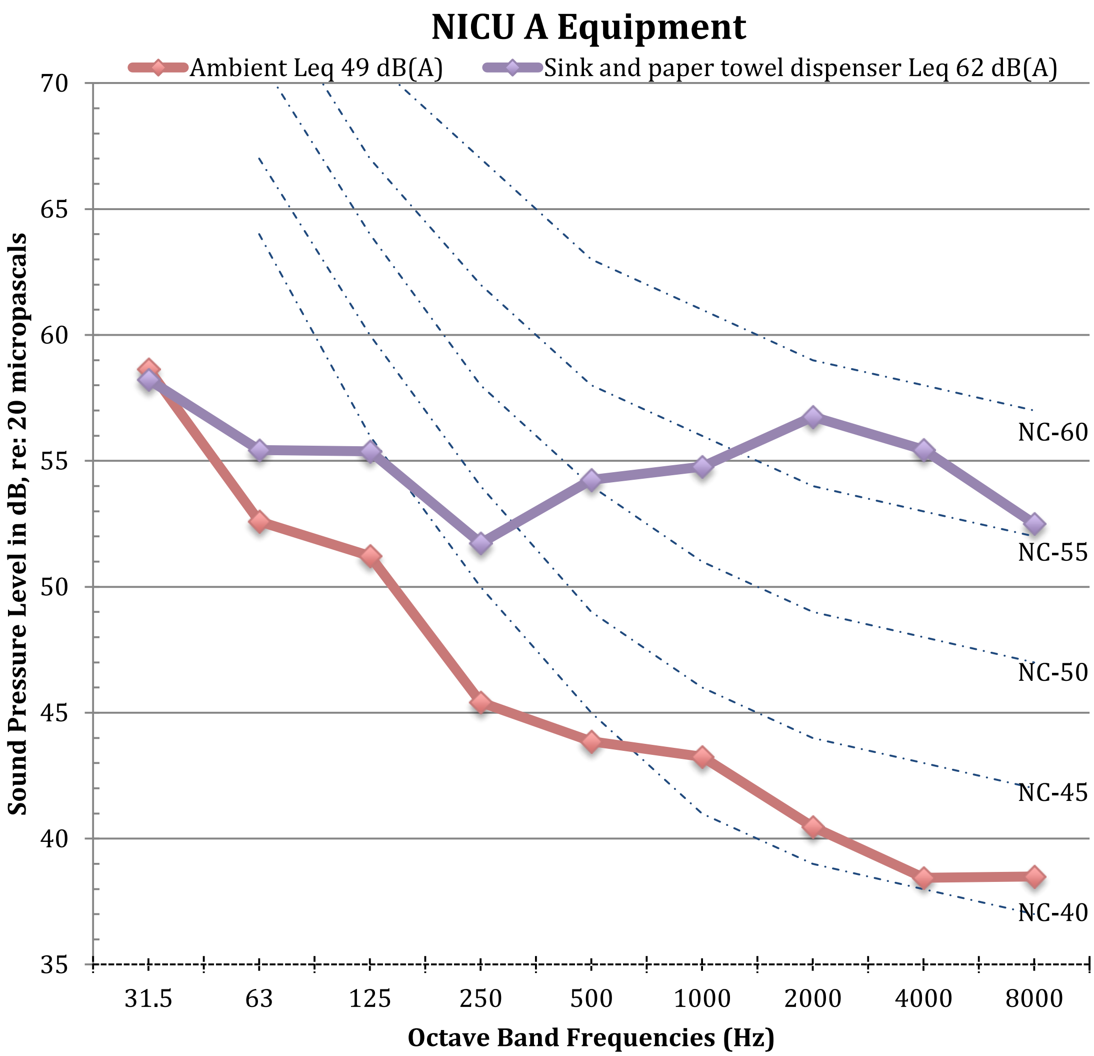


Figure C-7. Equipment noise levels in NICU A.

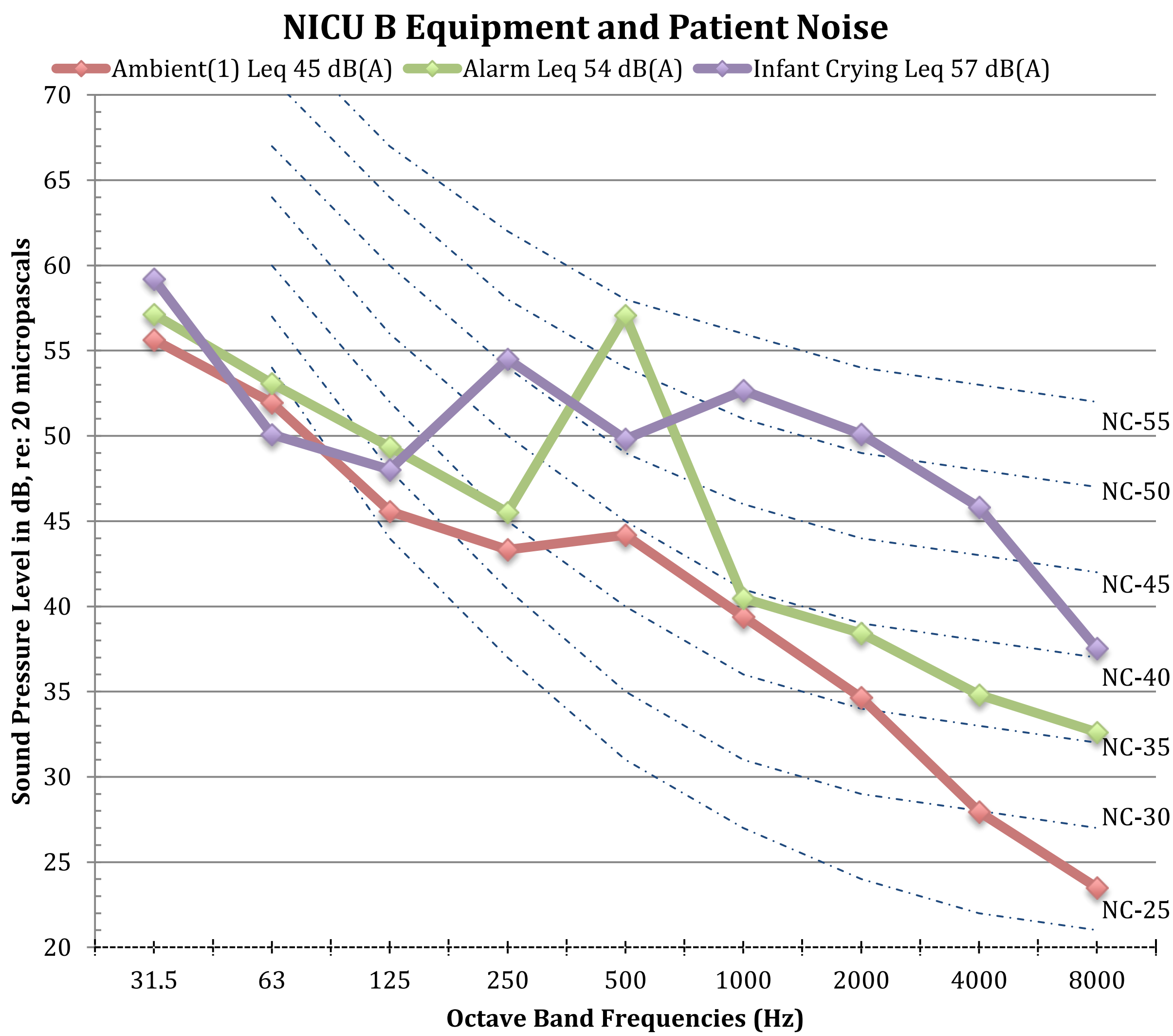


Figure C-8. Equipment and patient noise in NICU B.

LIST OF REFERENCES

[1]Siebein et al., *Acoustical criteria study, Tampa General Hospital NICU*. (Gainesville, FL, 2009).

[2]F. Nightingale, *Notes on Nursing.* (Dover, New York, 1969)

[3]I. J. Busch-Vishniac, J. E. West, C. Barnhill, T. Hunter, D. Orellana, and R. Chivukula. "Noise Levels in Johns Hopkins Hospital." J. Acoust. Soc. Am. **118**, 3629-3645 (2005).

[4]B. H. Morris, M. K. Philibin, and C. Bose, "Physiological effects of sound on the newborn," J. Perinatol **20**, S54-S59 (2000).

[5]K. A. Thomas, and P. A. Martin. "The acoustic environment of hospital nurseries: NICU sound environment and the potential problems for caregivers." J. Perinatol **20,** S93-S98 (2000).

[6]L. Goines, and L. Hagler, "Noise pollution: a modern plague," Southern Medical Journal **100**, 287-294 (2007).

[7]B. Berglund, T. Lindvall, and D. H. Schwela, and K. T. Goh (ed.), "Guidelines for community noise," Technical Report, World Health Organization (1999).

[8]C. M. Harris, *Handbook of Acoustical Measurements and Noise Control*. (Woodbury, NY, 1998).

[9]D. B. Choiniere, "The effects of hospital noise," Nursing Administration Quarterly **34**, 327-333 (2010).

[10]E. M. Wachman, and A. Lahav, "The effects of noise on preterm infants in the NICU," Archives of Disease in Childhood Fetal Neonatal Ed., (2010) as cited in http://brighamandwomens.org/Research/depts/newbornmedicine/researchers/lahav/documents/Wachman&Lahav_2010_Effects%20of%20noise%20on%20premature%20infants.pdf, (last viewed 3/17/2012).

[11]A. L. Williams, M. Sanderson, D. Lai, B. Selwyn, and R. E. Lasky, "Intensive care noise and mean arterial blood pressure in extremely low-birth-weight neonates," Am. J. Perinatol **26**, 323-329 (2009).

[12]American Academy of Pediatrics, Committee on Environmental Health, "Noise: A hazard for the fetus and newborn," Pediatrics **100**, 724-727 (1997).

[13]E. Stennert, F. J. Schulte, M. Vollrath, E. Brunner, and C. Frauenrath, "The etiology of neurosensory hearing defects in preterm infants," Arch Otorhinolaryngol **221**, 171-182 (1978).

[14]A. Joseph, and R. Ulrich, "Sound control for improved outcomes in healthcare Settings," The Center for Health Design, (2007).

[15]C. Tsiou, G. Efthyiatos, and T. Katostaras, "Noise levels in Greek operating rooms," J. Acoust. Soc. Am. **123**, (2008).

[16]J. M. Kracht, I. J. Busch-Vishniac, and J. E. West, "Noise in the operating rooms of Johns Hopkins Hospital," J. Acoust. Soc. Am. **121**, 2673-2680 (2007).

[17]M. S. Wallace, M. N. Ashman, and M. J. Matjasko, "Hearing acuity of anesthesiologists and alarm detection," Anesthesiology **81**, 13-28 (1994).

[18]R. D. White, "Recommended standards for the newborn ICU," J. Perinatol **27**, S4-S19 (2007).

[19]S. N. Graven, "Sound and the developing infant in the NICU: conclusions and recommendations for care," J. Perinatol **20**, S88-S93 (2000).

[20]A. Williams, Wim van Drongelen, and R. E. Lasky, "Noise in contemporary neonatal intensive care," J. Acoust. Soc. Am. **121**, 2681-2690 (2007).

[21]S. Okcu, E. E. Ryherd, C. Zimring, and O. Samuels, "Soundscape evaluations in two critical healthcare settings with different designs," J. Acoust. Soc. Am **130,** 1348-1358 (2011).

[22]"Levels of Neonatal Care," American Academy of Pediatrics. Pediatrics **114**, 1341-1347 (2004).

[23]E. E. Ryherd, K. P. Waye, and L. Ljungkvist, "Characterizing noise and perceived work environment in a nurological Intensive care unit," J. Acoust. Soc. Am **123,** 747-756 (2007).

[24]*Neonatal Intensive Care Unit (NICU II & III),* Shands HealthCare University of Florida, as cited in http://www.shands.org/jobs/nursing/uf/unitscopes/motherbaby/NICU.asp, (last viewed 1/11/2012).

[25]M. Long, *Architectural Acoustics*. (Burlington, MA, 2006).

[26]D. B. Choiniere, "The effects of hospital noise," Nurs. Admin. Q. **34**, 327-333 (2010).

BIOGRAPHICAL SKETCH

Jennifer Nelson attended Georgia Tech to earn a Bachelor of Science in electrical engineering in 2008. At an early age she had a passion for music, and she tried to find her niche in electrical engineering with this in mind. She learned about the field of architectural acoustics as an undergraduate, and realized that she could obtain her graduate degree in this field, combining her love of engineering and music with new areas in architecture and design. Jennifer started her graduate studies at the University of Florida in January of 2011 and never looked back. She completed an internship in New York City with Cerami & Associates in the summer of 2011 and started full time employment at the firm after graduation.