
# Soundscape analysis of a neonatal intensive care unit

Gary W. Siebein, FAIA, FASA[a]
School of Architecture
University of Florida
Gainesville FL 32611-5702

Reece Skelton[b]
Victoria McCloud
Siebein Associates, Inc.
625 NW 60th St. Suite C
Gainesville, Florida 32607

## ABSTRACT

A soundscape study was made of an existing Neonatal Intensive Care Unit (NICU) in a major urban hospital to document the nature and magnitude of sounds experienced by new born infants, caregivers, parents and other occupants in this environment. Focus group discussions were held with hospital administrators, NICU staff, design team members and families of patients to determine the types of sounds that are heard in normal operation of the NICU. Long term average sound level measurements of general sounds in the NICU were made for several work shifts. Short term acoustical measurements of specific acoustic events were also made to obtain octave band sound level data for each of the activities, medical equipment sounds and building infrastructure sounds that comprise the soundscape of the unit. Audio and video recordings of the specific acoustical events that comprise the soundscape of the NICU were also made. The acoustical measurement and soundscape analysis are used to evaluate proposed acoustical design criteria for NICU facilities compared to non-acoustic health risks reported in the literature.

## 1. INTRODUCTION

A NICU represents a true acoustic community that functions in an ecological manner as defined by Shaeffer[2] and Truax[3]. The entire community is intrinsically related through the variety of sounds that occur in the unit. Patients, medical staff, doctors, hospital support staff, parents and families all make various sounds that comprise the soundscape of the NICU and also must hear the sounds made by other occupants and all of the sophisticated equipment necessary for the NICU to function. As in any truly ecologically functioning community, all of the sounds found

[a] Email address: gsiebein@siebeinacstic.com
[b] Email address: rskelton@siebeinacoustic.com

in the NICU are necessary for it to function. None can be totally be eliminated. Most can be controlled and modified once one becomes aware of their impacts within the total soundscape.

Acoustical information plays an important role in the life of the inhabitants in 3 ways. First, there is a variety in the kinds and patterns of sounds. Second, there is a complexity in the sounds and the levels of information they convey. Third, a functional balance must be developed to control the variety and complexity of the sounds. There is a danger that some sounds, particularly those such as noise from building equipment; the chatter of staff during breaks; sounds from normal occupation of a workplace such as trash can lids, paper towel dispensers, and the like; and architectural "amplification" of sounds that allows them to propagate much farther from their source at elevated levels decrease the acoustic horizon of meaningful sounds and interfere with necessary communication disrupting the ecological balance that is necessary so essential sounds such as soothing communication between a mother and infant, conversations among staff about medical issues and a general sense of calm needed for a healthful, healing environment can be achieved. The perception of the inherent meaning of sounds in the NICU is critical to the medical mission of the unit. Sounds from infants and parents warning of medical crises, sounds associated with comforting patients and parents, monitoring vital physiological parameters and the warnings associated with medical emergencies must all hold a niche in the soundscape in the presence of each other and all of the other sounds in the unit. Masking of these sounds by building systems and intruding sounds from outside the unit or noise rhythms or levels related to health effects such as elevated blood pressure, sleep disturbance, excessive endocrine production among others must be reduced or controlled to the extent possible.

The acoustical environment of most Neonatal Intensive Care Units consists of high levels of noise due to equipment alarms, medical equipment processes, and the presence and noise associated with caregivers, patients and patient visitors. The impact of noise in the NICU environment affects staff members, patients and their families by elevating stress levels and hindering the ease of communication between staff members, patients and families.

To evaluate this complex acoustical environment, a soundscape study was conducted consisting of discussions regarding acoustical issues with hospital administrators, NICU staff and design team members; long-term sound level measurements of all of the specific acoustic events that comprise the ambient sound in the NICU; short term sound level measurements along with the video and audio recordings that catalog the specific acoustic events that constitute the soundscape of the NICU; an evaluation of acoustical design criteria; and investigations into planning strategies to address acoustical issues raised in the soundscape study and acoustical concerns raised by staff members.

## 2. ANALYSIS

This NICU soundscape study was conducted at a major urban hospital at an existing NICU facility that is divided into two small departments on the $4^{th}$ and $5^{th}$ floors of the hospital due to space constraints. A design process is currently underway for a new NICU expansion that will consolidate the existing NICUs into one large department.

The 4th Floor NICU has 35-40 patient beds divided among 3 aisles. Intensive monitoring systems and additional personnel are required to deal with the more critical patients located on this floor. The 5th Floor has approximately 9-12 beds consisting of less critical patients. Three groups of three to four infants each are located off a central corridor. There are two nursing stations and a private Sleeping Room on this floor.

## A. Focus Group Discussions

Meetings, interviews and telephone conversations were held with NICU staff members, hospital administrators, hospital facilities staff and design team members to develop a process for acoustical analysis of the existing facility and to initiate discussions for proposed acoustical design recommendations for the new facility. Further conversations were conducted with NICU staff members during several site visits.

## B. Long Term Ambient Sound Level Recordings

Long term average sound measurements were taken with Rion NL-32 integrating sound level meters to evaluate extended acoustical conditions in multiple areas of the NICU. The microphone was covered with a wind screen and positioned on a tripod approximately 4 ft. from the ground, the height of an infant in a crib. Long term average sound levels in the 4$^{th}$ floor NICU varied from 54 to 65 dBA and from 38 to 59 dBA in the 5$^{th}$ floor NICU.

## C. Short Term Ambient Sound Level Recordings

Short-term overall A-weighted and octave band ambient measurements were taken in the 4th and 5th Floor NICU for approximately one minute each with a Ceva SC-310 real time analyzer at multiple locations. The microphone was held approximately 4 feet from the ground.

## D. Sound Level, Video and Audio Recordings of Specific Acoustic Events

Acoustical measurements were taken to analyze specific acoustic events that occur in a NICU facility. Over 75 specific acoustical events were documented and cataloged. These acoustic events are grouped into five distinct categories which include intruding sounds from outside the NICU, building equipment sounds, occupational sounds, medical equipment sounds and conversational sounds. A sample of this NICU sound source catalog is shown in Figure 1.

| Sound / Equipment type | Description / Purpose | Manufacturer and Model | Image | Acoustic Observations / Concerns | Sound Data $L_{Aeq}$ / $L_{Amax}$ |
|---|---|---|---|---|---|
| Phototherapy Lights - "bili lights" | Bili lights use blue light to convert bilirubin that can be excreted. These lights are positioned directly above the patient requiring the infant to wear soft eye shields. | Drager Photo Therapy 4000 |  | Clicking noise created from the switching of the thermal lamp unit causes concern due to the close proximity of the unit to the patient. However, the action of switching the lamp on and off is infrequent. A sound measurement was taken while a nurse switched on and off the lamp three times. | 72 dBA with peaks to 95 - 96 dBA as unit is switched on<br>53 - 62 dBA during operation<br>Measurements taken 1 ft. away |
| Overhead Electric Photo Light Warmer | Radiant warmers use infrared light to warm a baby directly after birth, regulate a baby's temperature during long term care in hospital, keep the patient warm during or after surgery or keep a patient warm when they are minimally covered. | Ohmeda Giraffe Infant Warmer System |  | Alarms sound in the event that equipment malfunctions, maximum and minimum temperatures need to be set, the machine becomes unplugged or the patient becomes too hot or too cold. The alarms do not sound as often or as intensely as monitors but the proximity to the patient is of concern; approximately 2 feet from the head of the patient. | 78 - 80 dBA with peaks to 83 - 85 dBA when equipment malfunctions, short "beep" on 1 second interval<br>71 - 74 dBA with peaks to 75 - 82 dBA when unplugged or temperature not set, short "beep" on 2 second interval<br>75 - 76 dBA with peaks to 79 - 81 dBA when patient temperature is out of range, 1 second beep with 1 second pause<br>Measurements taken 2 ft. away |
| Suction Pump | Suction pumps provide regulated continuous suction for tracheal and pharyngeal airway management and continuous nasogastric drainage. Pumps may also provide intermittent suction for nasogastric drainage | Ohmeda Medical Suction Pump |  | The Suction Pump has two apparent acoustic characteristics. First, there is nominal motor noise from the pump itself. There is also a constant hissing and gurgling noise made by fluids moving through the tubes. Neither of these noises was distinguishable from more than 2 feet away from the device or tubes due to the relatively high background noise level in the 4$^{th}$ Floor NICU. However, in a quieter environment such as the 5$^{th}$ Floor NICU, these machines have more of a relative impact on the Soundscape. | 63 - 65 dBA with peaks to 73 - 76 dBA of "hissing and "gurgling" of fluids<br>50 - 59 dBA normal motor operation<br>Measurement taken 1 ft. away |
| Ventilator | A ventilator is a machine that breathes for a patient when too weak or sick. The machine provides originated air directly to the lungs through an endotracheal tube. The device is located directly adjacent to the patient on a wheeled base. | Trigger |  | This device alarms when overheated or in the event of equipment malfunction such as a kink in a hose. Minimal pump noise is also audible within 1 ft. of the machine. | 72 - 79 dBA alarm "beep"<br>66 - 75 dBA ambient sound level<br>Measurement taken 1 ft. away |
| | | Maquet |  | This device also alarms when overheated or in the event of equipment malfunction such as a kink in a hose. Minimal pump noise is also audible within 1 ft. of the machine. | 72 - 79 dBA alarm "beep"<br>66 - 75 dBA ambient sound level<br>Measurement taken 1 ft. away |

**Figure 1:** Sample sound level, video and audio recording catalog of specific acoustic events in the NICU.

## D.1 Intruding sounds from outside the NICU

Exterior intruding sounds include sounds such as Helicopters taking off and landing, transportation noises such as traffic, aircraft and trains; and emergency vehicles. Maintenance and construction noise generated in different departments of adjacent corridors within the hospital are also included in this category. In particular, helicopter noise in the proposed NICU will be of special concern due to the close proximity of the new facility to the helipad. Acoustical measurements were taken while a helicopter initiated its takeoff sequence, lifted off, flew away, returned and landed. These measurements were taken at three different locations; on grade directly adjacent to the helipad, on the roof of the 4$^{th}$ Floor where the proposed NICU will be located, and in the 4$^{th}$ Floor ICU directly below the proposed NICU expansion. As an approximation of exterior intruding sound possible in the proposed NICU expansion, sound levels measured in the 4$^{th}$ Floor ICU were 50-61 dBA as the helicopter lifted off the helipad and hovered while exterior sound levels on the roof of the existing ICU where the new NICU will be located varied from 75 to 101 dBA.

## D.2 Building equipment noise

Building equipment noise includes HVAC system noise, exhaust fans, electric lights and ballasts and other noises associated with the normal operation of building equipment. Noise from HVAC systems are a major contributing factor to the background noise levels in the existing NICU where noise levels are approximately 55 to 60 dBA or NC 45 to 55 and 62 to 74 dBA or NC 55 to 65 in the vicinity of a large return air grille in the center of the NICU. 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. The consequences are that medical staff must speak louder to communicate with one another, alarms must be set at a higher volume and general communication is deteriorated between and among caregivers and parents. These noise levels may also result in annoyance and physiologic responses typical of noise exposure for adults and infants.

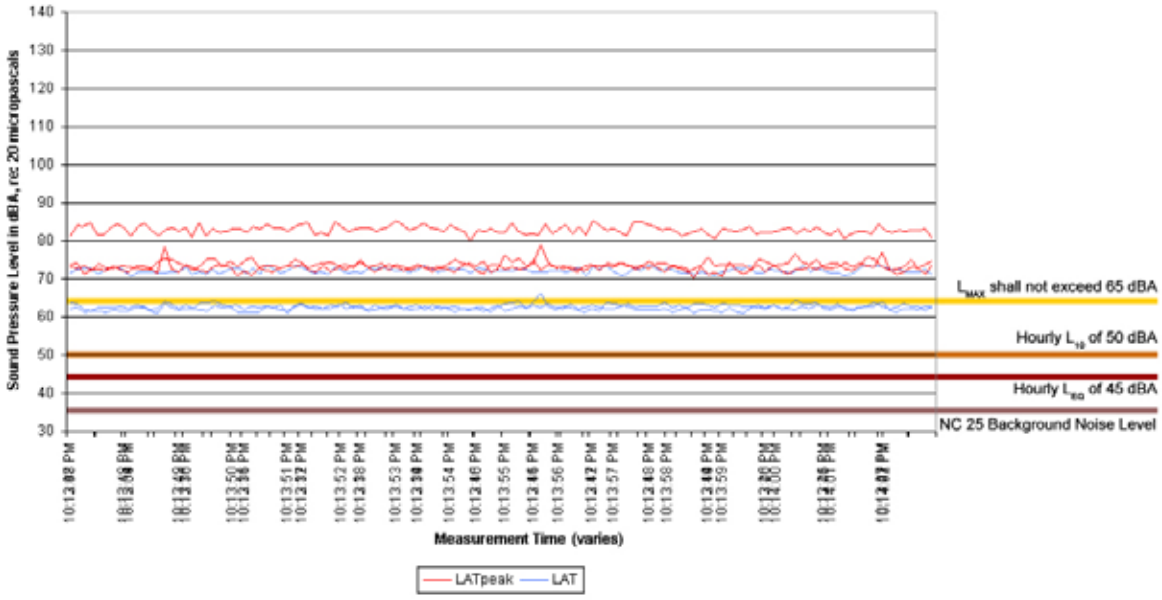


**Figure 2:** Graph showing building equipment noise levels compared to NICU acoustical design criteria.

## D.3 Occupational sounds

Occupational sounds near patient areas include opening and closing of various drawers and bins, use of paper towel dispensers, soap / sanitizer dispensers, sinks, trash bind, soiled linen bins, footsteps, doors opening and closing, etc. Occupation sounds associated with the administrative areas of the NICU include computer sounds, printers and telephones. Additionally, pneumatic tubes are located in the administrative area near the Isolation Rooms that are used frequently to submit and receive patient lab work and results. Occupational sounds were measured at approximately 60 to 79 dBA. Louder events included Pneumatic Tube, Trash Disposal and Code Phone which were measured at 65 to 94 dBA.

Occupational sound levels were consistent from the 4th Floor to 5th Floor NICU's. However, the lower ambient sound levels in the 5th Floor NICU caused a perceived increase in noise levels due to occupational sounds.

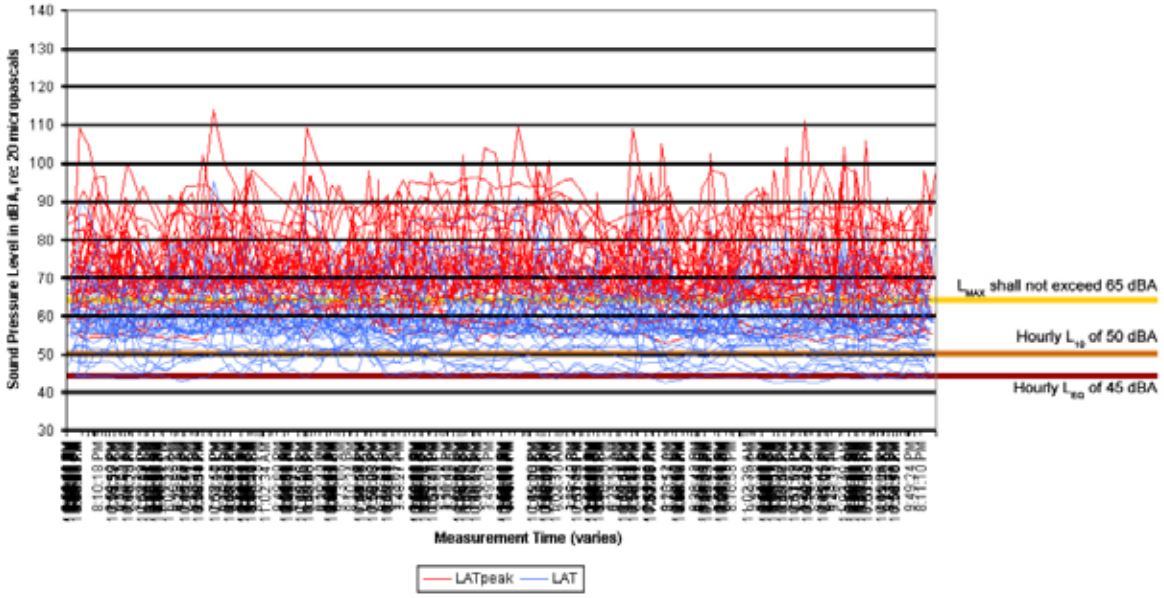


**Figure 3:** Graph showing occupational sound levels compared to NICU acoustical design criteria.

## D.4 Medical equipment sounds

A large variety of medical equipment is used to care for the infants in the NICU; each with its own set of acoustical features typically consisting of normal operational sounds and alarms. Normal operational sounds consist of the "humming" of small motors, the "buzzing" of lights and the "pulsing" of pumps. These sounds were measured at approximately 53 to 79 dBA. The "beeps", "chirps" and other alarm noises from medial equipment were measured at approximately 79 to 86 dBA. The open plan layout of the existing 4th Floor NICU creates an environment where alarms are constantly competing with each other. This, in turn, requires that alarms be set to higher volumes which eventually reduces the effectiveness of the alarm altogether along with impeding communication between caregivers.

Medical equipment sound levels were consistent from the 4th Floor to 5th Floor NICU's due to the use of similar equipment. However, the reduced amount of medical equipment used in the 5th Floor NICU coupled with the compartmentalizing of patients into separate areas resulted in less of an impact from medical equipment sound on the overall soundscape. Additionally, lower ambient sound levels in the 5th Floor NICU caused a perceived increase

in individual acoustic events such as alarms and regular operational sounds compared to the ambient than in the 4th Floor NICU.

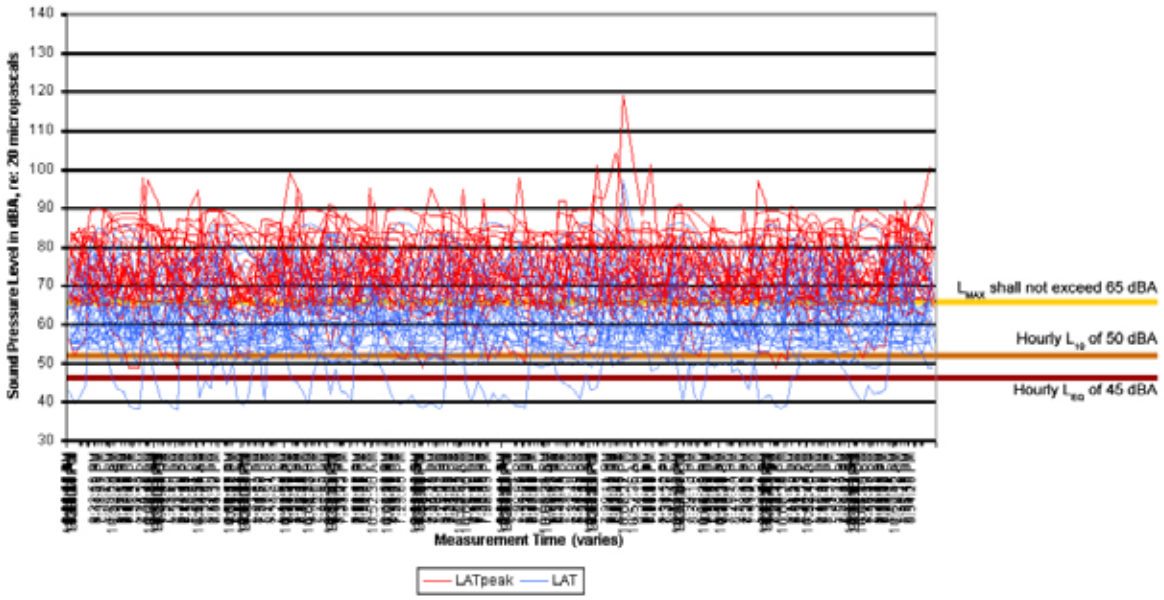


**Figure 4:** Graph showing medical equipment sound levels compared to NICU acoustical design criteria.

## D.5 Conversational sounds

Nurses, doctors, parents and other visitors are constantly speaking to one another in the NICU. The communication between and among these groups of people is a significant source of noise. Conversations are constantly competing with medical and building equipment noise which causes the volume of voices to be raised. Additionally, specific events, such as morning rounds when a doctor and resident visit and discuss multiple infant cases at their crib side, result in even higher noise levels attributed to conversational sounds. These sounds were measured at approximately 54 - 68 dBA at 3 to 5 ft. increasing to 60 to 68 dBA in the 4$^{th}$ Floor NICU when rounds occurred and multiple people were talking. Five distinct types of conversations were observed.

1. Parents and family members talking to infants

2. Parents and family members talking to each other, talking on cell phones, etc. while they wait for infants

3. Nurses talking to each other and to parents (sometimes medically oriented discussions, sometimes gossip)

4. Doctors and students making rounds

5. Nurses, doctors and staff talking during emergency events

Noise from conversational sounds on the 5th Floor NICU is considerably less than the 4th Floor NICU at approximately 54 to 64 dBA. This reduction in noise levels can be attributed to less vocal competition with medical and building equipment sounds. However, not all

caregivers followed suit and used the same level voice in the 5th Floor NICU as in the 4th Floor NICU.

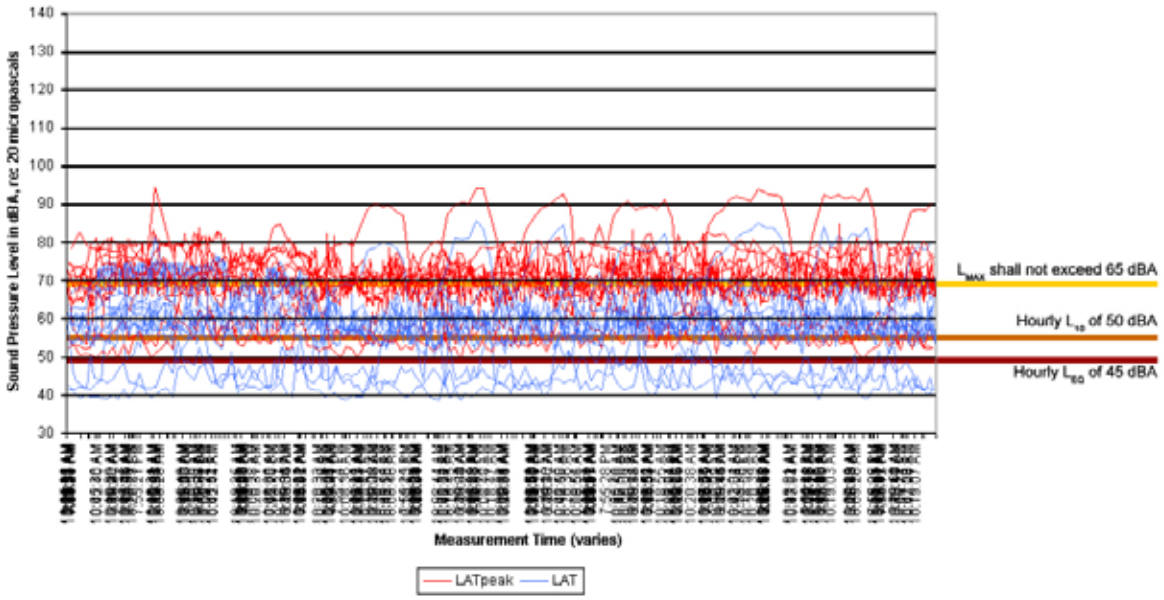


**Figure 5:** Graph showing conversational sound levels compared to NICU acoustical design criteria.

## E. Acoustical Design Criteria

Acoustical criteria for NICU's were first proposed by Philbin and Evans[1]. They consist of an $L_{MAX}$ of 65 dBA, an $L_{10}$ of 50 dBA and an $L_{EQ}$ of 45 dBA with building equipment operating at NC 25 or less. While the literature shows sleep disturbance and physiological responses to noise at levels just above the LMAX selected, it does not contain evidence that NC 25 is necessary for building equipment. The rationale presented by Evans is that to reach the LEQ of 45 dBA, equipment noise must be more than 10 dB less so it does not add to the equipment sound levels, thereby raising the ambient noise level. However, it is important to realize that the rhythm or time history and spectrum of typical building equipment noise is quite different from those associated with medical equipment, alarms, conversations and occupational sounds that comprise much of the soundscape of the NICU. A study on the health effects of low level noise with an HVAC system type spectrum on the health of infants in a NICU would be worthwhile to determine if the NC 25 criterion is actually necessary. Graphs of sound levels versus time for each of the major categories of sound sources in the N ICU are presented in each section compared to the acoustical criteria. None of the sound sources found in the NICU fall within the suggested criteria levels. In fact, the ambient noise level in the NICU when no near by specific acoustic events could be identified was approximately 55-62 dBA.

## F. Sound Mitigation Strategies

A taxonomy of noise mitigation strategies was developed for each specific acoustic event in each category with 4 general areas of responsibility for action.

1. Building design and infrastructure
2. Hospital fixtures, furnishings and equipment
3. Administrative Controls
4. Education and training

The taxonomy was used as a vehicle to develop a comprehensive soundscape improvement pan to transform the new NICU into a healthful, healing environment. Each of the sets of NICU sounds discussed above has a particular source and sound level associated with it, travels a specific path from the source to a potential receiver and each has a unique set of possible noise reduction techniques that can be associated with it to reduce sound spread through the NICU.

### F.1 Control of intruding sounds from outside the NICU

Controlling intruding sounds from outside of the NICU requires the implementation of several strategies. An analysis must be undertaken to examine the sound level and spectrum for each transportation source and designing the exterior building skin to reduce these sounds to the design criteria levels will occur as part of the design and construction process. Maintenance and construction activities should be scheduled and coordinated by hospital facilities staff and the various contractors so they occur to the extent possible away from areas where they can directly impact the NICU. Investigations into the development of alternative construction and maintenance methods to reduce the noise produced by the sources of sound would have to be investigated by the contractor and hospital facilities staff with the assistance of an acoustical consultant. Hospital facilities staff and the contractor should consider limiting the times that construction and maintenance operations can occur.

### F.2 Building equipment noise control

Building equipment noise can be controlled as part of the normal design and construction process by designing the mechanical, plumbing and electrical systems to meet the design criteria for NICU's. This will involve special acoustical design of HVAC systems including selecting relatively quiet air handling units and fans, designing effective vibration isolation systems for equipment, using silencers and other noise mitigation devices within air ducts, limiting air velocities within ducts to reduce turbulent air flow noise, selecting air inlet and outlet devices to meet criteria and locating mechanical equipment at distances from the NICU that will allow the criteria to be met

### F.3 Occupational sound control

Occupational sounds can be controlled by hospital staff and administration by taking a creative look at each noise source and location within the NICU and developing strategies to reduce the noise created by the source, protecting the infants (with private rooms) through design and having hospital administrators limit the time for which these sources can occur. An important element of this strategy is educating staff and visitors about the sensitivity of infants to excessive noise and encouraging "quiet" within the unit.

### F.4 Medical equipment sound control

Continuously operating medical equipment that produces louder levels of noise can possibly be remotely located from the patient or mounted in an enclosure, perhaps with glass doors, within the patient room as joint decisions between the design team and hospital staff. The warning sounds from medical equipment may be routed to PDA's used by staff. Further, PDA's may be set to "vibrate" to reduce overall noise levels due to systems purchased by the hospital. Larger size visual displays can be used at staff locations or in patient rooms to display warnings visually or blink when a warning goes off if elected by hospital staff.

### F.5 Conversational sound control

Conversational sounds can be controlled by several means. The use of a single patient room NICU as in the proposed facility will effectively limit the propagation of sound from all talking sources to infants other than the one where the talking occurs.

In a large open plan NICU, the use of a sound absorbent ceiling with high NRC acoustical ceiling tile and strategically placed space dividers with sound absorbent facings can be used to reduce the propagation of sounds from any of the talking sources to other beds in the unit. A sound absorbent ceiling in the individual patient room and possibly some sound absorbent finishes on upper walls can reduce the sounds of talking sounds within the individual patient room.

Nurses, doctors, parents, family members and other staff members should be educated about the relative sensitivity of newborns to excessive noise and about the difference between soothing conversation from a parent and "noise" from other activities such gossip among visitors or staff, etc., so the talkers can limit their conversations. Unfortunately, many of the sounds made in rapid communication among doctors, nurses, etc., during medical emergencies and the clear communication required in potentially life threatening situations likely must occur as they currently do so effective treatment from the medical team can be administered quickly and effectively when needed.

## 2. CONCLUSIONS

Over 75 specific acoustic events that occur in the NICU were identified and cataloged in 5 general groups of sounds that comprise the totality of the soundscape. The categories are 1. Sounds from people talking; 2. Medical Equipment; 3. Sounds from normal occupation and use of space; 4. Building equipment; and 5. Sounds from outside the NICU. Comprehensive documentation of the types of sounds, locations in space, rhythms, levels, spectra as well as video recordings of the operations associated with each sound are included in the catalog. A taxonomy of noise mitigation strategies was developed for each specific acoustic event in each category with 4 general areas of responsibility for action identified so a comprehensive soundscape enhancement plan could be developed for the new NICU. The 4 areas of responsibility for the sounds are 1. Building design and infrastructure; 2. Hospital fixtures, furnishings and equipment; 3. Administrative Controls enacted by the hospital; and 4. Education and training of staff, visitors and others conducted by t hospital to sensitize all participants in the soundscape to the vital role of sound, communication, clam and repose in the complex environment of the NICU.

## REFERENCES

[1] M K Philbin and J B Evans, "Standards for the acoustic environment of the newborn ICU," *Journal of Perinatology* **26**, S27–S30 (2006).

[2] R. Murray Schafer, *The Soundscape, Our Sonic Environment and the Tuning of the World*, Destiny Books, Rochester, NY (1977).

[3] Barry Truax, *Acoustic Communication*, Greenwood Publishing Group, CT (2001).