2012

Acceptable noise levels for neonates in the neonatal intensive care unit

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ACCEPTABLE NOISE LEVELS FOR NEONATES IN THE NEONATAL INTENSIVE CARE UNIT

by

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A Capstone Project
submitted in partial fulfillment of the
requirements for the degree of:

Doctor of Audiology

Washington University School of Medicine
Program in Audiology and Communication Sciences

May 17, 2013

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Abstract: The study was a sound survey of naturally occurring noise in a metropolitan hospital NICU. The collected sound level samples were then compared to the noise standard recommended by the American Academy of Pediatrics. It was concluded that sound levels in the NICU exceed the standard and the standard does not have a proper foundation.

Acknowledgements

I would like to thank Dr. William Clark for his support and guidance throughout the completion of the capstone project. Thank you to Maggie Wolf and Johanna Schloemann from St. Louis Children's Hospital NICU for their valuable contributions as collaborators and second reader, Beth Fisher for responding efficiently to all of my requests in regards to scheduling numerous meetings and Rene Miller, for providing the necessary software programs needed for completion of the program. I would also like to thank the staff within St. Louis Children's Hospital NICU for all of their assistance. The capstone project would not have come to successful completion without the help of all these individuals.

I would also like to thank my family and friends for their constant love and support especially over the past three years.

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Abbreviations

AAP	American Academy of Pediatrics
BCPAP	Bubble Continuous Positive Airway Pressure
dBA	Decibel A-weighted
dB	Decibel
ECMO	Extracorporeal membrane oxygenation
HFNC	High-flow Nasal Cannula
HVAC	Heating, Ventilation, and Air Conditioning
Hz	Hertz
L90	A-weighted Sound Level 90% of the time
L50	A-weighted Sound Level 50% of the time
L10	A-weighted Sound Level 10% of the time
Ldn	Day-night Average Sound Level
Leq	Equivalent A-weighted Sound Level
Leq24	Equivalent A-weighted Sound Level over 24 hours
Lmax	Maximum A-weighted Sound Level
Lpeak	Peak A-weighted Sound Level
NICU	Neonatal Intensive Care Unit
O_2 Sat.	Oxygen saturation
SSA	Sound Spectral Analysis
SFR	Single Family Room
TcP02	Transcutaneous oxygen levels
US EPA	United States Environmental Protection Agency

Unnecessary noise, then, is the most cruel absence of care which can be inflicted either on sick or well.

-Florence Nightingale

Notes on Nursing, 1860

It is well known within the medical profession, specifically pediatric nursing, that care of fragile infants in the Neonatal Intensive Care Unit (NICU) can at times be challenging and draining, yet at the same time rewarding. Neonates admitted to the NICU are often premature, with potentially critical or life-threatening conditions, and are in need of constant medical monitoring. Neonatal nurses work as part of a team to provide appropriate interventions and exceptional care to those infants, and their families, who require assistance during their earliest stages of life.

NICUs across the country are classified from level I (basic) to level III-C (most advanced). Classification levels are stratified by the capability to provide advanced medical or surgical care for the neonate. For example, a Level III-C unit can provide comprehensive care for extremely low birth weight infants (1000 g birth weight or less and 28 or less weeks gestation), advanced respiratory care, advanced imaging (CT, MRI, echocardiography), and prompt on-site access to a full range of pediatric medical subspecialists, pediatric surgical specialists, and pediatric anesthesiologists. They also can provide ECMO and surgical report of serious congenital cardiac malformations that require cardiopulmonary bypass (American Academy of Pediatrics, 2004). Advanced care increases the chance of survival for these neonates, though there is concern regarding overstimulation with the number of providers, monitoring equipment and environmental stress.

Providing a suitable environment for development in the NICU is important because many infants admitted are born prematurely. Noise level in the NICU plays an important role in staff communication, family interactions, and infant development. The American Academy of Pediatrics recommends that sound levels be lower than 45 dBA in the NICU, based on a report from the US Environmental Protection Agency (EPA). According to the AAP, exposure to noise above 45 dBA may result in cochlear damage or disrupt the normal growth and development of premature infants (American Academy of Pediatrics, 1997). The AAP suggested pediatricians monitor sound in the NICU environments and within incubators. They did not provide adequate documentation to explain how 45 dBA was determined to be the appropriate sound level.

The 45 dBA recommendation from the AAP did not stem from an empirical study but from an environmental study developed by US EPA. The goal was to protect the public health and welfare with an adequate margin of safety (5dB). The EPA (1974) recommended all hospital environments maintain a sound level of 45 dBA to support 100% speech intelligibility among patients and staff. To protect individuals who spend time outside, an L_{dn} of 55 dBA was deemed adequate and an $L_{eq(24)}$ of 70 dBA was identified to prevent hearing loss. To prevent activity interference or annoyance in the indoor hospital environment, an L_{dn} of 45 dBA was recommended for patients (Environmental Protection Agency, 1974). With the adequate margin of safety added to the recommended level of 45 dBA there is an increase to 50 dBA. The EPA expressed concern that the specific sound level recommendations would be mistaken or interpreted as a federal noise standard in the future. More importantly, these recommendations were based on maintaining speech intelligibility and avoiding annoyance for patients and staff. The 45 dBA limits were not directly specified as an appropriate sound level for NICUs to abide by.

The human cochlea and peripheral sensory end organs complete their normal development by 24 weeks of gestation (American Academy of Pediatrics, 1997), making hearing the next to the last sensory system to mature. Auditory processing capabilities continue to develop with CNS organization and may be altered by auditory experiences that differ from the usual intrauterine influences (Blackburn, 1998). The auditory systems of premature neonates continue to develop during the time spent within the NICU, as births considered viable are around 23-25 weeks. Currently there is limited research regarding estimated intrauterine sound levels. Benzaquen, Gagnon, Hunse & Foreman (1990) suggest however that intrauterine noise consists predominantly of low-frequency noise with sound levels being 40 dB above 500 Hz. Ideally, to promote healthy auditory development, sound levels in the NICU should be consistent with intrauterine environment. This may not be considered practical, as NICUs are often characterized by loud unpredictable noise from extraneous sources such as alarms, ventilators, phones, and staff conversations (Wachman & Lahav, 2011).

Literature Review

Ambient sound levels in the NICU have been reported to range from 50 to 90 dBA, which far exceed the current recommended standards. Blackburn (1998) stated the goal for a NICU environment is to meet the physiological and neurobehavioral needs of each infant to aid in emerging organization, growth and development. Modifications may include physical environment (light and noise) and caregiving interventions. Sound occurring in the NICU can be categorized as background noise with occasional superimposed peak noises. Blackburn concluded that high background noise occurring in the NICU may interfere with an infant’s ability to discriminate speech, an important early step in language acquisition.

Williams, van Drongelen & Lasky (2007) recorded and compared noise in different levels of care; isolation, level II, and level III within NICUs in two separate hospitals. Sound level (L_{eq}) measurements were taken with a Larson Davis 703+ dosimeter and recorded for eight days. Comparison of different NICU classification levels indicated that sound levels exceeded 45 dBA, more than 70% of the time, for all levels of care.

Liu's (2010) main objective was to decrease measured sound levels in the NICU through implementation of human factors and minor design modifications. Their hypothesis was that modifications to human behavior and unit-design would result in a decrease in the measured occupied NICU sound pressure level. The study was a prospective time series, quasi-experimental design, with ongoing measurements before, during, and after intervention cycles. Sound level measurements were made with a Larsen Davis Spark 706 dosimeter over a 24-hour measurement period. Staff education included increased awareness of human sources of noise. The staff was encouraged to silence alarms immediately during care, set pagers to vibrate, and speak softly during conversations. There was also an increased awareness of noise-generating behaviors such as hand washing, opening disposable equipment, and opening and closing entry doors. Minor unit-design modifications included using plastic garbage cans and turning off the unit intercom. This study was unable to demonstrate a significant decrease in sound measurement levels from the baseline during or after implementation at any of the NICU sampling locations.

Kent, Tan, Clarke & Bardell (2002) examined the effect of staff activity on noise levels by comparing recordings from two rooms of the NICU. In addition, a comparison was made between ambient room noise levels and those in an occupied incubator. Sound level measurements were performed using a Larsen Davis sound level meter and noise was measured in the unit rooms A, B, C, and D. Recordings from two adjacent rooms indicated that room B had a significantly higher mean level (59 dB) than room C (56 dB). A significantly higher L_{eq} and L10 were noted inside an occupied incubator relative to ambient room noise level measurements.

Kellam & Bhatia (2008) stated the AAP guidelines make no recommendations about specific sound frequencies that occur in the NICU. This study was designed to obtain a description of high-frequency noise by using sound spectral analysis (SSA). It was an initial effort to understand the impact of sound frequency in the NICU. The SSA was conducted in two rooms of a level III nursery using a Larson Davis 824 sound level meter that was placed at a 45-degree angle within 15 cm of the infants' ear. SSA was performed at patient bedside during shift change and around oscillator ventilators over a four-week period. Findings suggested the most intense frequencies were clustered around one peak of 500 Hz forming a spike in the human speech frequency range. This indicates that staff speech contributed to atypical sound exposure. They concluded that there is a need to assess noise on a frequency basis and eliminate factors that add to high level of atypical sound.

Busch-Vishniac et. al (2005) focused on existing sound pressure levels in a major US hospital and used measured data to confirm the existence of a serious noise problem. Sound pressure level measurements were obtained at five different locations in Johns Hopkins Hospital, over a one year period. One minute L_{eq} were taken in many locations on the unit including patient rooms, hallways and nurses stations using a Larsen Davis system 824. Overall, the study found little variations in the measured sound levels from the five units studied. The average Leq varied between 50 to 60 dBA. These levels exceed the current recommended guidelines by 20 dBA on average levels and exceed the typical speech level of communication between two people of 45-50 dBA suggesting that staff may need to raise their voice routinely in order to be heard above the noise. This investigation concluded that the problem of hospital noise is clearly under-studied and not well understood.

Darcy, Hancock & Ware (2008) evaluated the average sound levels in three different NICUs and compared them to the suggested guidelines set by the EPA and AAP. They also looked at the differences between the average sound levels during day shift and night shift. Sound level measurements were made using a Sper Scientific Mini Sound Meter and sounds were measured for two different hours during the day and night shift. Twelve data readings were collected each hour (one measurement every five minutes) for each institution. The study found that the mean noise level for the three sites on the day shift was 57.2 dB and the mean noise level for the night shift was 57 dB. They concluded that noise levels across the three NICU studied were above the recommended national guidelines.

Krueger & Parker (2007) compared sound levels in an NICU before and after structural reconstruction. Sound level recordings were measured continuously for an eight-hour period between 0600 and 1400 before and after reconstruction. L_{eq} values were 60.4 dB prior to reconstruction and the average overall sound levels after reconstruction was L_{eq} 56.4 dB. This study concluded that even after reconstruction, sound levels still exceed the current recommendation and further interventions may be needed though a slight difference in sound levels was noted.

The objective of Robertson, Cooper-Peel & Vos (1999) was to plan a strategy for sound reduction in the NICU by measuring various sound parameters during manipulation of HVAC airflow and conversation. Recordings were taken on three days between 14:30 and 15:15 and dosimeters were suspended from the ceiling in two locations at opposite ends of the NICU. This data was then compared to recommendations for NICU noise limits, L_{eq}, L_{peak}, and L_{max}. They found during the measurement period, the ambient L_{eq} averaged 55.8 dBA and when eliminating the sound produced by conversation and airflow resulted in only a 4.5 dB reduction. They concluded that even after eliminating conversation and airflow the sound pressure level still exceeds the current recommendations for noise levels in the NICU.

Neonatal Intensive Care Units

NICUs are often designed as open units with cribs or incubators together in one open room. A single-family room (SFR) design is better as it allows for more privacy with one neonate (or one family if there are multiple births) in the room and is the current gold standard. Domanico, Davis, Coleman & Davis (2011) concluded that the SFR design also provided a quieter, more controllable environment for sick neonates and that medical progress was improved over the open unit. Liu (2011) compared specific equipment at a level III NICU and found the SFR to be a quieter (L_{90} and L_{50}) and less loud (L_{10}) environment compared to an open unit. Within the SFR environment the sound level was influenced by support systems for the neonate such as room air, high-flow nasal cannula (HFNC), bubble continuous positive airway pressure (BCPAP) or ventilators.

Current recommendations to adjust the NICU sound environment include monitoring sound levels, evaluating the sound environment of the individual infant, and moving sensitive infants away from high noise activity. The strategies suggested by the AAP for personnel to decrease noise in the NICU included not tapping or writing on the tops of incubators, and wearing soft shoes (American Academy of Pediatrics, 1997). Another study suggested using soundproof covers over incubators, removing water bubbling in oxygen and ventilator tubing, talking softly, and initiating quiet time. To reduce peak noises it was suggested that medical staff and families should avoid slamming portholes, set bottles or equipment onto pads, move rounds and reports away from sensitive infants, and reduce alarm volumes (Blackburn, 1998). In some circumstances, the suggestions are plausible such as holding in-services to inform staff not to tap or write on incubators and how to properly close incubator doors. Other practical changes include implementing the use of soundproof covers and moving rounds further away from the neonate. However, certain suggestions such as removing water bubbling from oxygen and ventilator tubing could prove to be detrimental to the neonate's health.

It is well known that sound levels in the NICU are a major source of environmental stress for premature infants (Peng et. al, 2009). The most common indicators of physiological stress and pain are similar and include changes in heart rate, respiratory rate, blood pressure, transcutaneous oxygen levels (tcP02), oxygen saturation (O2 Sat), intracranial pressure, vagal tone, skin blood flow, and palmar sweat (Peng et. al, 2009). The exact range of noise causing a change in the neonate's vital signs is not well documented in the literature. Determining sound levels that create negative physiologic effects will further help to determine a specific noise standard that is appropriate for NICU.

The purpose of this study is to evaluate noise exposures in an urban level IIIC NICU and determine the levels and sources of noise exposure. The assessments of the levels occurring in the NICU were compared to the 45 dBA noise standard recommended by the American Academy of Pediatrics. Finally, recommendations regarding behavior modifications and appropriate sound level for NICUs are provided.

Methods

This project included conducting sound surveys of naturally occurring noise in the NICU environments. There was no direct neonate involvement. This project was submitted for IRB review and was approved, Dec 21, 2011. On February 3rd, 2012 St. Louis Children's Hospital NICU Unit Based Joint Practice Team then approved the project and data collection was started. The project included two studies, one evaluated the NICU environment and the other evaluated the neonate environment within the incubator.

Study 1: Assessment of the NICU

Environment

St. Louis Children's Hospital, founded in 1879, is one of the premier children's hospitals in the United States. It serves children across the world and provides a full range of pediatric services. The NICU at St. Louis Children's hospital, established in 1984, is considered a level III-C unit. The NICU provides state of the art treatment and monitoring equipment and is staffed by 286 personnel. Many are trained physicians and nurses who specialize in treating sick newborns. The 75-bed unit can be adapted to hold more patients if required and consists of intensive care beds, transitional care beds and two family participation rooms where parents can stay with their baby before discharge. The total number of admitted patients to the NICU was 1330 in 2011 and had a mean length of stay of 30.79 days.

The NICU is designed with both an open-pod unit (West Unit) and single private rooms (East Unit). Multiple neonates are located in one large area in the traditional open West Unit and staff charting occurs at the bedside. Figure 1 displays the floor plan of the West Unit. It is divided into three large open sections labeled, room B, room C, and room D, and has space to care for about 37 neonates. Figure 2, illustrates a potential crib and incubator set up in room C. A pod allows for the placement of four or more cribs or incubators in the center of the room. Open units are more likely to have an elevated sound level environment due to the number of neonates, their families, equipment and NICU staff. The open unit has vinyl flooring and a dropped down ceiling throughout. Room C and D have two isolation rooms and room C and B have windows with venation blinds. Hand wash stations are located on each of the walls.

Figure 3 displays the East Unit, a 36 private room addition that opened in 2006. This unit is sub-divided into three sections labeled Spring, Water, and Summer, and the set-up is quite different from the West unit. The sub-divisions have 12 rooms each allowing for more privacy and the potential for reduced sound levels. There are six charting stations located in the hallways in each division. This allows staff communication to occur outside of the neonates' sound environment. The East Unit has tiled ceiling throughout with carpeted hallways and vinyl flooring in each individual room.

Instrumentation

The sound surveys of the NICU environment were recorded with a Larson Davis 706 and evaluated with Larson Davis Blaze Software (Larson Davis, Provo, Utah). Figure 4 displays an illustration of a dosimeter. For the purpose of this study the dosimeter was used to determine an A-weighted Leq value. It was set on A-weighting, slow time constant, and set to 30 dB gain, allowing for a range of 30 dB to 110 dB SPL. All results were reported as A-weighted Leq values, which are the average levels over a time period. The sample interval was 30 seconds for the 24 to 48 hour data collection period or every second for the 2-hour data collection period

Sample

In the West Unit, 10 sound surveys were completed. These recordings were collected between March 9th and 20th, 2012. In the East Unit, 27 sound surveys were completed in the hallways and inside the private rooms. These recordings were collected between March 9th and April 4th, 2012. Table 1, describes the sound surveys for the NICU environment including date and times for each recording.

Procedure

Prior to each placement the five dosimeters were calibrated and fresh batteries were placed to ensure continuous recordings during the 24 to 48 hour period. The dosimeters were checked for correct date and time, correct settings and that the auto-timer was turned on. Figure 5 illustrates dosimeter placement in rooms B and C in the West Unit NICU. Figure 6, illustrate dosimeter placement in different locations throughout the East Unit NICU. A sign regarding the sound survey was placed beside the dosimeter in order for it not to be touched or moved during the recording period.

Analysis

A mean difference was calculated and then compared to the current 45 dBA recommendations.

Study 2: Assessment of Incubator Environment

Environment

The St. Louis Children's Hospital NICU uses the Giraffe OmniBed Incubator in the both the East and West Unit. Sound level measurements were recorded inside of a Giraffe OmniBed Incubator in the East Unit Room 513. This particular incubator is used in the NICU to maintain appropriate environmental conditions for the neonate. The Giraffe OmniBed design is an incubator and radiant warmer in one that allows access to the neonate through six portholes.

Instrumentation

Figure 7 illustrates the precision sound level meter used to collect data. The sound survey within the incubator environment was recorded using a Larson Davis 831 precision sound level meter (Larson Davis, Provo, Utah). The precision sound level meter was used to collect 1/3 octave band measurements. It was set to collect the overall and A-weighted sound pressure level and all measures were reported using the slow time constant. Data is recorded digitally and then stored for frequency or temporal analysis.

Sample

In the East Unit, Room 513, 15 sound surveys were completed inside the incubator and the private room. These recordings were collected on April 3rd, 2012.

Procedure

The sound level meter recordings were made over 20 to 30 seconds and then saved for analysis. The measurements included background noise, incubator off, incubator on, improper porthole door closure, proper porthole door closure, incubator with the hood popped, average conversation, addition of humidity, and alarm. Recordings were also made with oxygen at 5, 6, and 8 L facing in and facing out of the incubator.

Analysis

The overall averages for all 15 conditions were then compared to the 45 dBA standard.

Results

Study 1: Assessment of the NICU

The purpose of the present study was to make sound level measurements in the NICU and to then compare them to the 45 dBA recommended by the American Academy of Pediatrics. A comparison examined the average A-weighted Leq sound levels in the East and West Unit. Average values for all of the measures made were calculated and then compared to determine statistical significance.

The overall average sound levels for all test conditions are listed in Table 2. A comparison of all 12-hour night average conditions versus all 12-hour day average conditions revealed no significant difference. All night average sound levels were within 1 to 3 dB of the day average sound levels. Detailed comparisons of the West Unit and the East Unit are included below.

Figure 8 illustrates the West Unit and East Unit sound level comparison. The sound level comparison between the West Unit (open) and the East Unit (single family rooms) indicates that there is not a significant difference between the two designs. The sound levels vary by 1 to 3 dB with the exception of the east units Summer room 508 which had a 4 to 7 dB difference. Potential reasons for the difference in sound level averages in the East Unit rooms will be discussed later. The solid line demonstrates the current recommended standard of 45 dBA. In this comparison between units the sound level averages ranged from 48 to 55 dBA, significantly above this recommendation.

Comparing sound levels from the SFR to sound levels occurring outside in the hallway indicated that the rooms do provide a lower sound level for the neonates. Figure 9 illustrates the East unit sound level comparison of the hallways to the single family rooms. In the East Unit there is a significant decrease in sound levels when comparing the hallway to the single family rooms. The Spring and Water areas had a 2-3dB difference from sound levels occurring in the hallway to sounds in the room. A significant decrease of 9dB was observed when comparing the Summer hallway to Summer room 508. Staff reports that the HVAC system is most audible in the East Unit, specifically in the Summer area. The sound level average of the HVAC system was 59 dBA which is significantly louder than the sound levels of the East Units Spring or Water hallway and room. The HVAC system was recorded in the Summer area but was 2 dB louder than the average sound level recordings of the Summer hallway. The line indicates the recommended standard of 45 dBA and the range of average sound levels in the hallway and rooms were 48 to 59dBA. These levels are significantly louder than the standard.

Figure 10 illustrates the 2-hour comparison of 1-second samples from the West Unit to the East Unit. The two-hour sound level comparison with a 1-second sample interval was recorded to determine if sound levels in the open unit (West) were elevated compared to the single rooms (East). The East Unit does have significantly lower sound level averages in the Spring and Summer rooms by 7 to 9 dB. The Water room was not significantly different from the sound levels occurring in the west unit. Explanations for the lower sound level averages in the Spring and Summer rooms will be discussed later. The line represents the 45 dBA recommendation and all rooms exceed this level by 3 to 12 dB.

Overall, when assessing the NICU environment in both the West Unit (open) and the East Unit (single family rooms and hallways) the sound level averages are higher than the current recommended standard of 45 dBA.

Study 2: Assessment of Incubator Environment

Table 3 illustrates the average sound level (dBA) in the incubator environment. Detailed comparisons of the West Unit and the East Unit are included below. Figure 11 illustrates the sound level averages for the background noise, the incubator off, the incubator on and common incubator manipulations. Sound levels were first recorded in the room to obtain background sound levels. These sound levels represent the sound environment of neonates in an open crib. Measurements taken from inside of the incubator before it was turned on are the same as the background noise levels, 43 dBA. The greatest significance for change in loudness of 15 dB is when the incubator is turned on in comparison to the background noise. The noise level of 58 dBA occurred within the incubator was further elevated by improper porthole door closure. With the use of proper door closure techniques there is no significant change of sound level compared to the incubator on condition. In times of emergencies or when an infant is being weaned off the incubator the top portion can lift up. When the hood is open or popped a 6 dB sound level decrease occurred from the incubator on condition. All sound levels occurring within the incubator were significantly louder than the 45 dBA recommendation.

Figure 12 demonstrates common occurrences in the room environment such as addition of humidity, alarms sounding, and average conversations are not significantly louder than the incubator turned on condition. All measurements obtained were significantly louder than the 45 dB recommendation.

Figure 13 demonstrates the increase in sound levels with the addition of oxygen placed within the incubator. A concern of the NICU staff was in regards to the amount of noise in relation to oxygen airflow in the incubator. The current practice used in the NICU is to face the oxygen out of the incubator. The most common levels of oxygen used for neonates are 5L, 6L, and 8L. All oxygen levels were tested using both conditions of oxygen facing in and oxygen facing out. A 1 to 2 dB decrease in sound levels occur when the oxygen is in the facing outwards condition compared to the oxygen facing inwards condition. A significant increase in sound levels occurs with the placement of oxygen inside of the incubator compared to the incubator on condition varying in an increase of 5 to 12 dB. All oxygen levels in each of the two conditions significantly exceed the 45 dB recommendation.

Sound levels were also evaluated using the 1/3 octave band as it includes the overall level and the frequency domain. Figure 14 compares background noise measurements made against noise inside the incubator with it turned off. The dark bars are the background noise and it was characterized by energy concentrated in the low-frequency region. The level of the background noise was 43 dBA. In contrast the measurements made inside the incubator with it turned off are about the same in the low frequencies and slightly higher in the high frequencies. The overall levels were the same, 43 dBA. Figure 15 compares background noise against noise inside the incubator with it turned on. The dark bars are the background noise and the light bars are the incubator turned on. When the incubator is turned on it contributes a significant amount of in the high-frequencies. The overall level when the incubator is turned on was 58 dB which is an increase of 15 dB from the background noise. Similarly, Figure 16 compares the incubator off to the incubator on condition. The dark bars are the incubator turned off and the light bars are the incubator turned on. There is no significant change in energy concentration in the low frequencies but increases in mid to high-frequencies are noted once the incubator is turned on. The overall increase from incubator off to incubator on condition is 15 dB.

Figure 17 compares the incubator on condition and improper porthole door closure. The dark bars are the improper porthole door closure and it was characterized by energy concentrated in the high-frequency region. The level of improper porthole door closure noise was 71 dB, a 13 dB overall level increase from the incubator turned on condition. Figure 18 compares the incubator on to the proper porthole door closure. There was no change noted in energy concentration and the overall level between the incubator on and proper door closure were the same, 58 dBA.

In times of emergency when access to the infant is needed or when the infant is being weaned off the incubator in order to move to the open crib, the hood of the incubator must be opened. Figure 19 compares the incubator on to the hood open condition. The light bars are once the hood is opened and energy concentrations across the frequencies decrease. The overall level also decreases from 58 dBA in the incubator on condition to 52 dBA in the hood opened condition, a 6 dBA difference.

The other issue of noise in the incubator is in relation to airflow. The oxygen levels can be set dependent on the need of the neonate and the most common levels for neonates are 5 L, 6 L, and 8 L. Figure 20 illustrates the sound level for 8 L of oxygen within the incubator when it is turned on in the two conditions. The dark bars are the oxygen facing inwards and the light bars are the oxygen facing outward conditions. A slight decrease in energy concentration can be noted across the frequency domain. The overall sound level increased from the incubator on condition by 12 dB when the oxygen was facing inwards compared to only a 10 dB increase when the oxygen was facing outward.

Other conditions such as average conversations occurring outside of the incubator, the addition of humidity, and alarms are not significantly louder from the incubator turned on condition. This may suggest that the incubator provides some protection to externally occurring sounds. The average sound level occurring within the incubator exceeds the current 45 dBA standard in all conditions tested.

Discussion

Study 1: NICU Environment

The average sound levels measured in the NICU at St. Louis Children's Hospital were above the maximum level of 45 dBA recommended by the American Academy of Pediatrics. Levels above 45 dBA were observed in the hallway, and treatment rooms in both the East and West Units, during all work shifts, in occupied rooms, in rooms which infants were in incubators and others where infants who had been weaned from the incubator could be safely housed in an open crib design. The lowest sound level measured during the study was 48 dBA which was observed in the single room in the East Unit (Summer room 508). Several factors may have contributed to the lower sound level in this room including; the room was located at the end of hallway limiting foot traffic and attendant noise. The neonate's condition may have improved, reducing noise associated from staff providing care.

Comparison revealed the noise levels in the hallways of the East Unit were slightly elevated from the levels inside the rooms therefore; the infants may experience louder noises in the hallway when they are transported for procedures.

Data analysis revealed that the sound levels occurring in the East and West Units of the NICU over a 24 to 48 hour period were stable. Data collected with a one-second sample interval over a two-hour period was used to determine if a significance difference existed between the East and West Units during busy hours in the NICU (0800-1000). Sound levels in the open West Unit and Water room in the East Unit were comparable. The Spring and Summer rooms in the East Unit were 7 to 9 dB quieter than in both the open West Unit and the Water room in the East Unit. The neonates sleep cycle, decreases in activity, equipment in the room, or hallway traffic flow may have contributed to the lower noise levels observed in the Spring and Summer rooms.

Since no significant differences were observed between the East and West Units most of the noise may be attributed to the HVAC system that runs throughout the hospital and therefore is not directly related to the staff activity.

Sound levels determined in this study ranged from 48 to 55 dBA, which exceed the 45 dBA ± 5 dB noise level provided by the AAP. Most of the noise is thought to be from the heating and ventilation system. Realistically, making modification to the heating and ventilation system to reduce the noise occurring in the NICU by 5 to 10 dB would be a lengthy and cost consuming endeavor. Another fact to consider is that the constant sound levels from the HVAC system might provide the appropriate amount of masking to avoid instantaneous sounds alarming the neonate.

Study 2: Incubator Environment

Measurements taken in one of the NICUs Giraffe OmniBed Incubator provided detailed sound levels occurring within the incubator. These measurements indicate that sound levels within the incubator environment far exceed the current recommendation of 45 dBA. Certain manipulations to the incubator, such as closing the doors improperly cause significant increase to sound levels within the incubator. When the incubator was turned on without any additional equipment the noise level was 58 dBA. Bellini et al. (2003) demonstrated background noise ranged from 46-50 dBA, closing portholes ranged from 70-74 dBA and baby cry ranged from 81-87 inside the incubator. The current study has found comparable sound levels occurring within the incubator for background noise and closing the portholes. No significant changes were observed when humidity was added, alarms sounded, or a conversation was started in the room so the incubator may have some noise protection for sound occurring in the external environment. When the hood of the incubator was opened, the sound levels decreased to 52 dBA as sound occurring within the incubator dissipated into the background noise.

Most, if not all neonates require the use oxygen in the NICU at some point. The measurement conditions included facing the oxygen inside and outside of the incubator at 5 L, 6 L, and 8 L. All conditions had lower sound levels for the oxygen facing out therefore; it is recommended that NICU staff place the oxygen in this position. Overall this investigation revealed that once the incubator is turned on and manipulations are performed to provide appropriate care, sound levels increase to well above the standard.

The Role of the Incubator

Incubators protect the neonate from spikes in background noise but do not protect from the other noise sources (Altuncu, Akman, Kulekci, Akdas, Bilgen & Ozek, 2009). When the incubator was turned on, the levels increased to 58 dBA which is notably different from the background noise occurring in the room. Incubators are used in the NICU because they provide a safe and controlled environment for the neonate. The use of warmed, humidified environment decreases insensible water loss, heat loss and subsequent caloric expenditure. Neonates less 28 weeks gestation have poor skin integrity and therefore at greater risk for increased water loss, creating thermal and electrolyte instability (AAP, 2007). The shift for neonates from an intrauterine to extra uterine environment creates a significant thermal change that challenges the infants' thermoregulatory abilities; neonates are therefore vulnerable to both under heating and overheating (Thomas, 1994). The current guidelines for weaning a neonate off an incubator include procedure for decreasing the amount of thermal support, insulating an infant, and assessing infant temperature. Success of weaning a neonate is most likely measured by the infants' weight gain and temperature stability post weaning (Medoff-Cooper, 1994). This investigation revealed the sound levels within the incubator remains stable at 58 dBA thus eliminating HVAC noise or other sources outside will not help the infants inside of the incubator.

Suggested sound levels for the NICU

It is recommended that the American Academy of Pediatrics consider reviewing the current standard for acceptable noise levels occurring in the NICU. The 45 dB standard was based on a recommendation for hospitals in general, not specifically NICUs. It also related to maintaining 100% speech intelligibility for staff and was not intended to indicate a safe sound level for neonates. Staff in the NICU, are seldom more than a few feet away from one another while providing care and very rarely raise their voices above low conversational level. Nurses and physicians most often discuss medical treatment for neonates in a separate private area. From these examples it can be concluded that NICU environments have a close talker to listener distance relative to communication.

The current noise level standard set for the NICU environment is 45 dBA. The goal is to create a standard that makes the NICU sound environment as comfortable and tranquil as possible. Complete elimination of noise in the NICU would not promote tranquility because all audible sound would cause disruptions. There needs to be enough masking noise in the environment so that the neonates are not disturbed or startled by certain instantaneous sounds in the environment. The gold standard would be to determine intrauterine sound levels, as this is the natural sound environment the fetus develops in. The invasiveness and potential to cause harm to both the mother and fetus is not recommended. Obtaining neonate physiologic responses to naturally occurring sound in the NICU would be the most appropriate suggestion.

At this time a recommended appropriate sound level that promotes healthy auditory development while still maintaining a level of speech intelligibility cannot be determined.

Recommendations

When neonates are in an incubator we recommend that staff use the proper behavior modifications such as porthole door closure technique and place oxygen facing out to decrease sound level exposure to them.

Limitations and Future Research

This study was a sound survey of the NICU to determine the sound levels occurring and then to compare them to the current standard. Future research regarding noise and corresponding neonatal physiologic affects must be completed for a more accurate and appropriate standard. This will help determine what sound levels occurring in the NICU create a negative change to the neonate's vital signs, indicating signs of physiological stress. This study took measurements at a Level III-C NICU; a multi-centered study to take further measurements should be conducted at a Level I to Level III-B NICU for comparison. There is also a need for the promotion of quiet incubators, as the measured 58 dBA sound level far exceeds the current recommended limit and the effects of this noise level on neonates is still unknown.

Conclusion

Sound levels in the NICU and incubator environment were found to be much higher than the recommended standard of 45 dBA. The recommendation does not appear to have a good justification for why 45 dB is the appropriate sound level in the NICU. Sound levels ranged in the NICU environment from 48 to 55 dBA which may be attributed to the HVAC system. Sound levels within the incubator ranged from 58 to 71 dBA. Using behavior modifications such as properly closing doors of the incubator and turning oxygen to face out will help to lower sound level exposure to the neonate. Further research needs to be completed to determine appropriate sound level that promotes neonate tranquility.

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Figure 1 West Unit Floor Plan

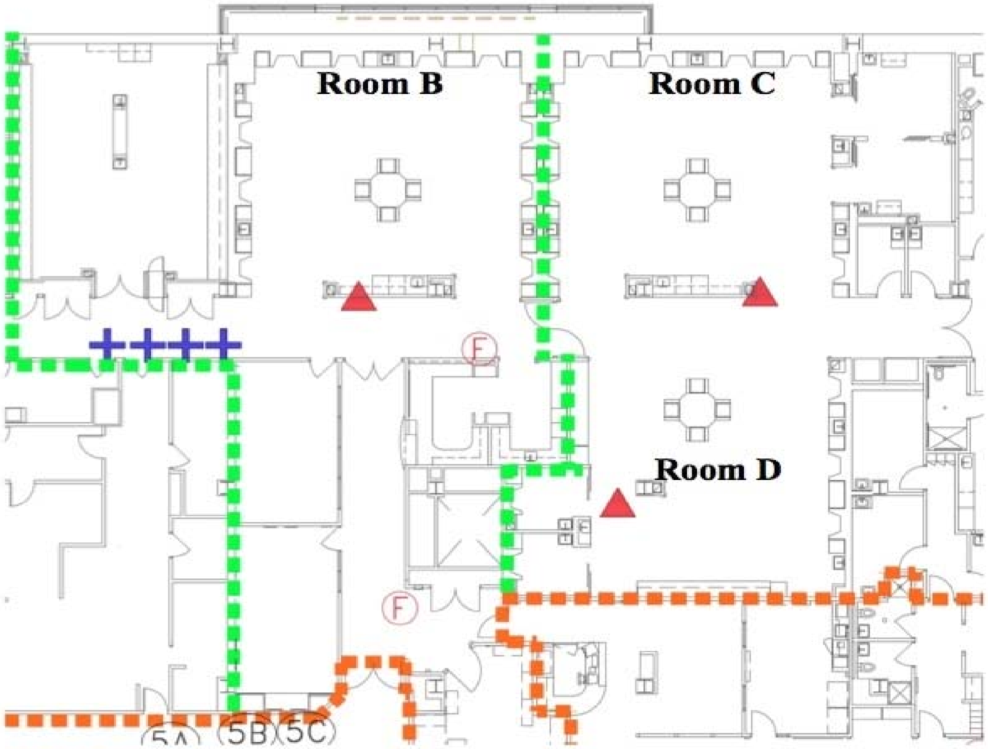

Figure 2 West Unit Room C

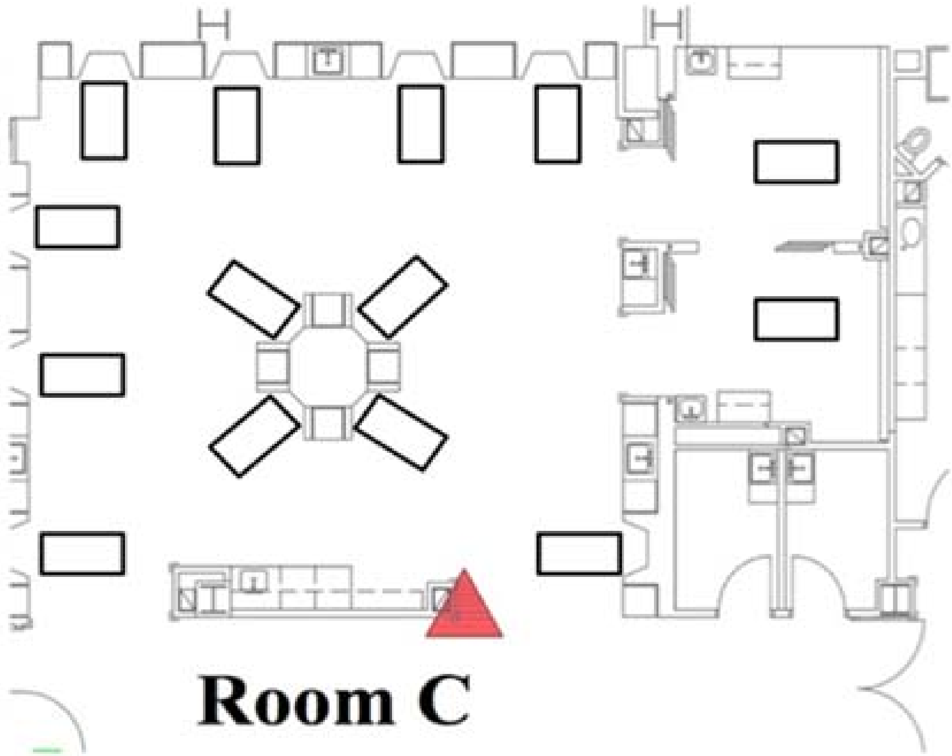

Figure 3 East Unit Floor Plan

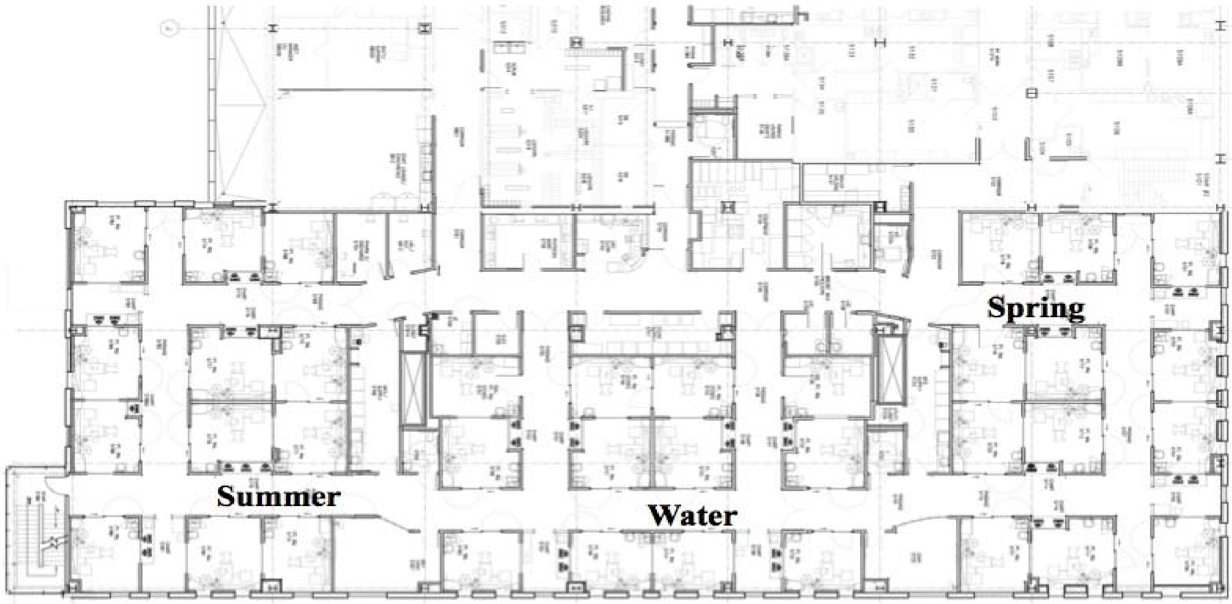

Figure 4 Larson Davis 706 Dosimeter

Table 1 Sound Survey Dates

NICU Environment Sound Survey					
Start Date	**Area Recording**	**Start Recording**	**End Recording**	**End Date**	**Total Days**
March 9	Room B Room C Spring Hallway Water Hallway Summer Hallway	18:30	18:30	March 12	2
March 16	Room B Room C Spring Hallway Water Hallway Summer Hallway	18:30	18:30	March 17	1
March 18	Room B Room C Spring Hallway Water Hallway Summer Hallway	18:30	18:30	March 20	2
March 23	Summer Hallway (HVAC)	06:30	06:30	March 25	2
March 29	Spring Room 525 Water Room 518 Summer Room 508 Summer Hallway (HVAC)	18:30	18:30	March 31	2
April 4	Room B Room Spring Room 525 Water Room 518 Summer Room 508	08:00	10:00	April 4	2-hours
April 4	Spring Room 525 Water Room 518 Summer Room 508	18:30	18:30	April 6	2

Figure 5 West Unit Dosimeter Placement

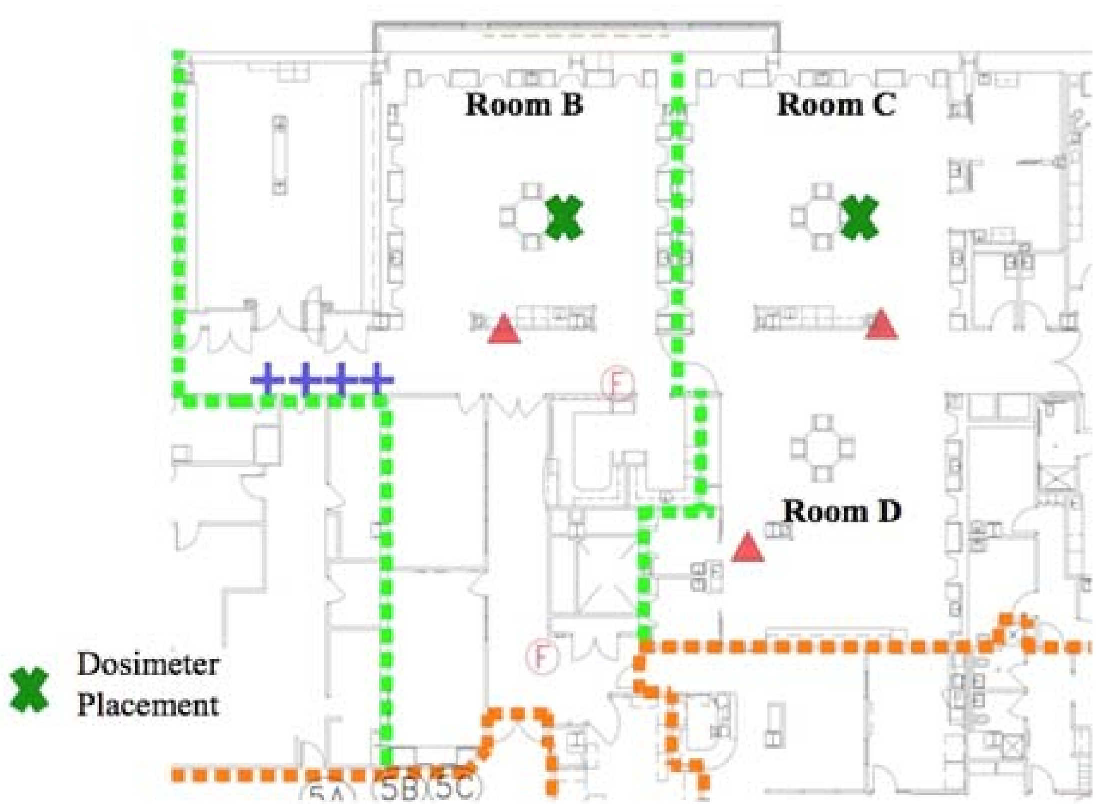

Figure 6 East Unit Dosimeter Placement

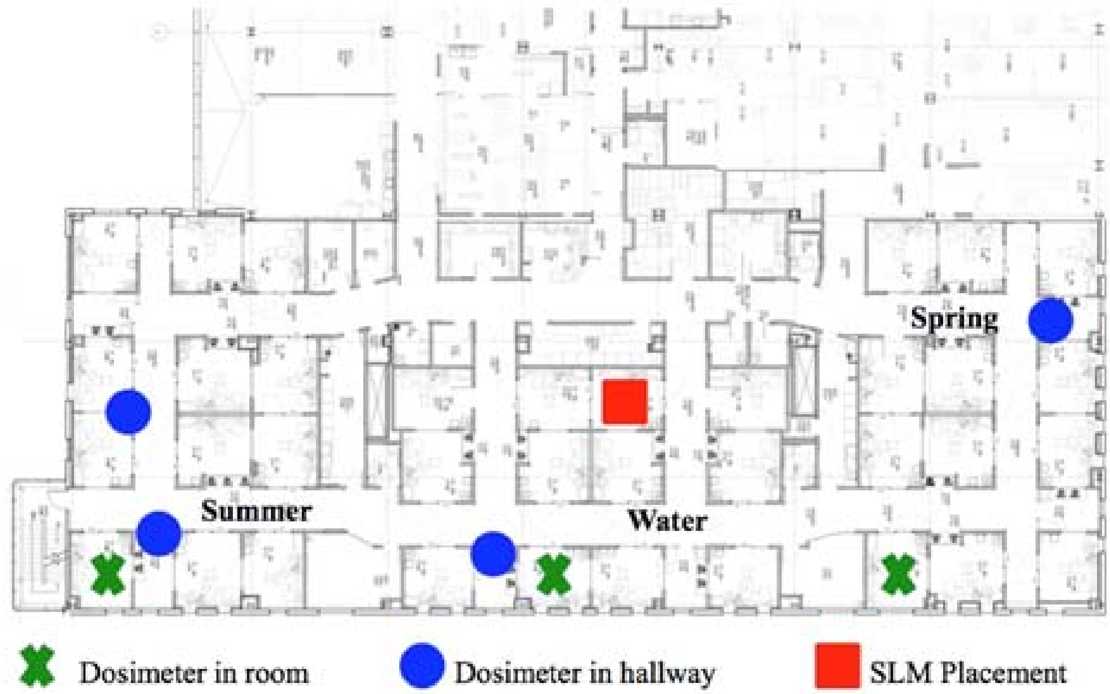

Figure 7 Larson Davis 831 Precision Sound Level Meter

Table 2 NICU Environment Overall Sound Level Averages

NICU Environment Overall Sound Level Averages			
	Overall Level		
NICU Area	**24-hour Average Leq dBA**	**12-hour Night Average Leq dBA**	**12-hour Day Average Leq dBA**
West Unit			
Room B	55	55	56
Room C	54	53	55
East Unit			
Spring Room 525	53	51	54
Spring Hallway	56	56	56
Water Room 518	52	51	54
Water Hallway	54	53	54
Summer Room 508	48	47	49
Summer Hallway	57	56	58
HVAC	59	59	60

Figure 8 West vs. East Unit Sound Level Comparison

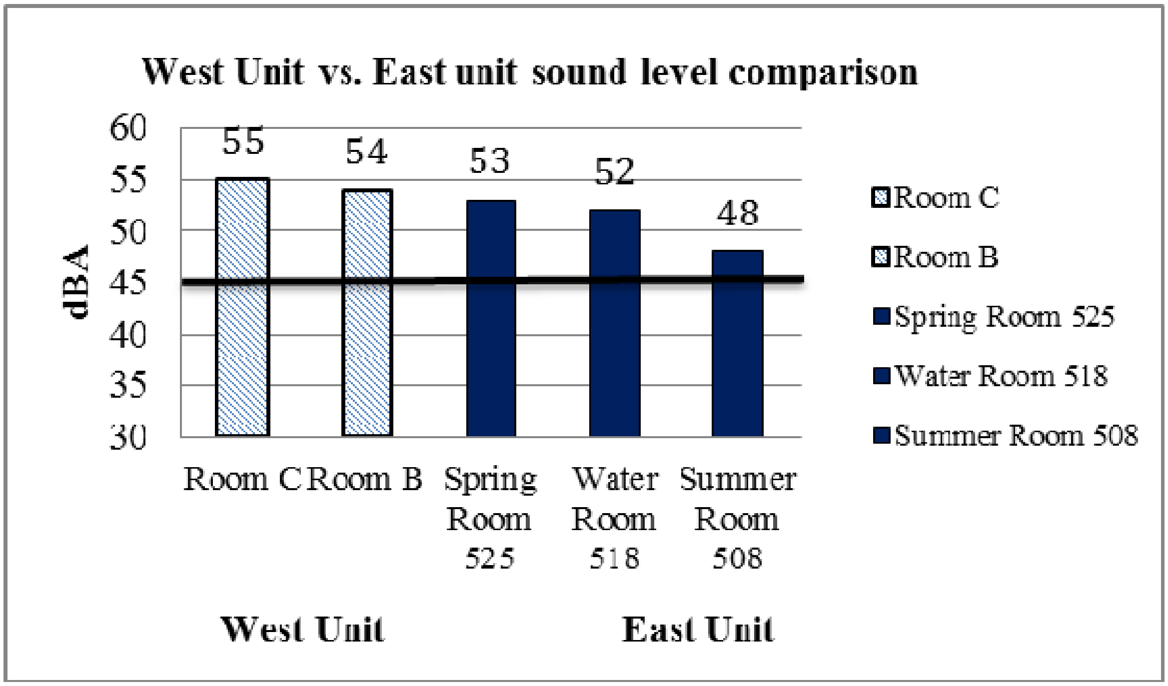

Figure 9 East Unit Hallway vs. Room Sound Level Comparison

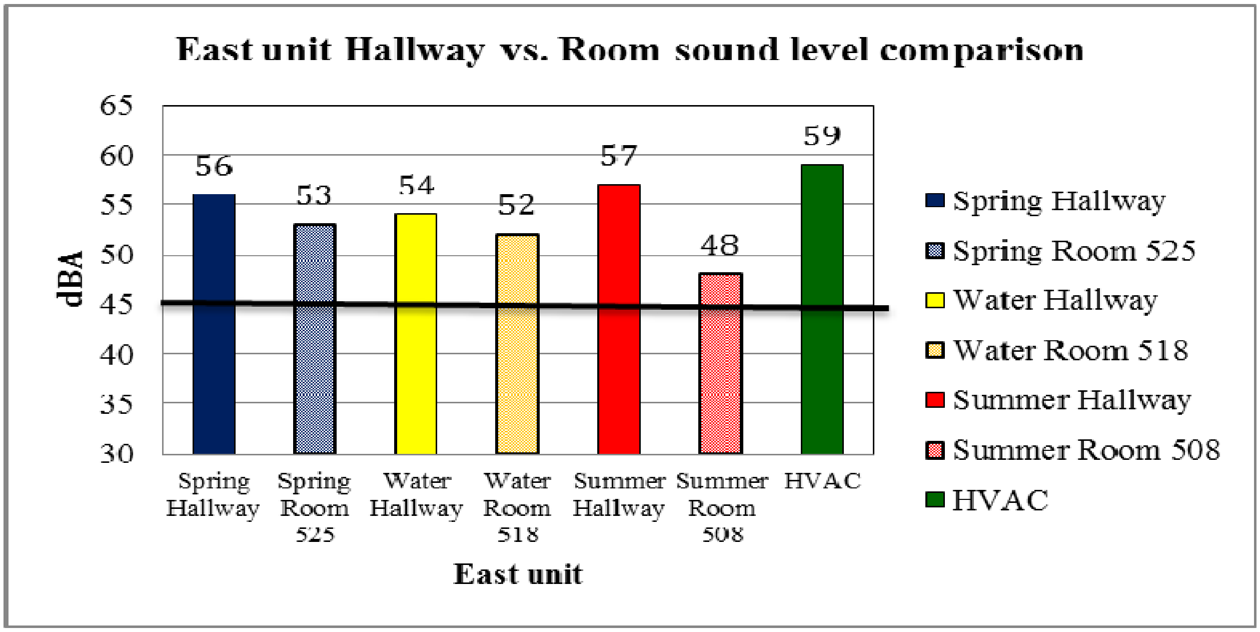

Figure 10 2-hour Sound Level Comparison

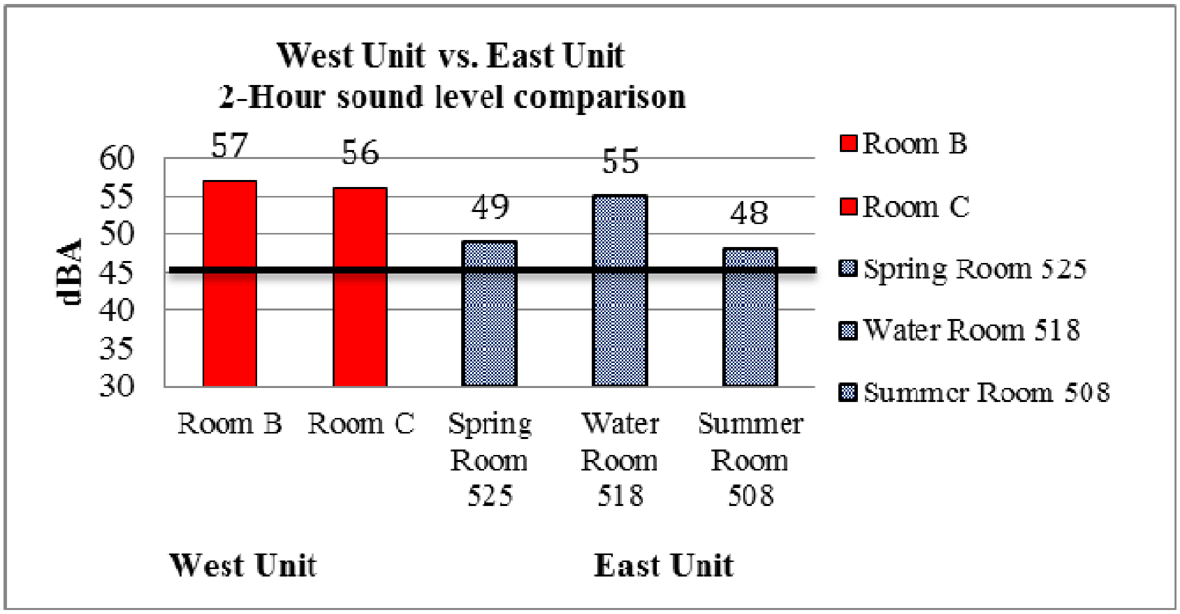

Table 3 Average Sound Level in Incubator

Condition	dBA	Condition	dBA
Background Noise	43	Addition of Humidity	58
Incubator Off	43	5L O2 Facing In	66
Incubator On	58	5L O2 Facing Out	63
Improper Door Close	71	6L O2 Facing In	67
Proper Door Close	58	6L O2 Facing Out	66
Incubator Hood Open	52	8L O2 Facing In	70
Average Conversation	59	8L O2 Facing Out	68
Alarms	59		

Figure 11 Incubator Assessment- Internal

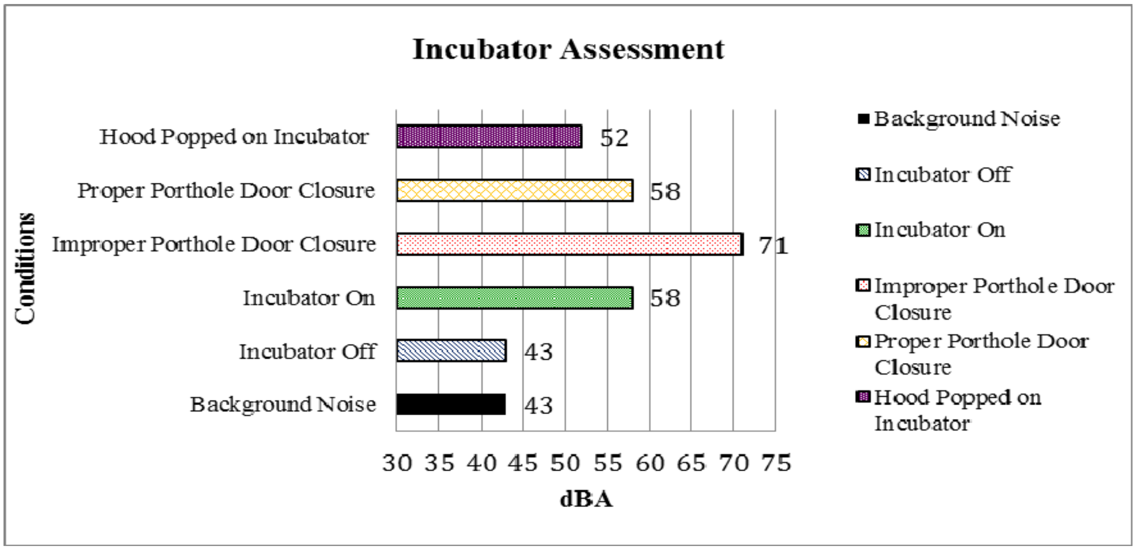

Figure 12 Incubator Assessment- External

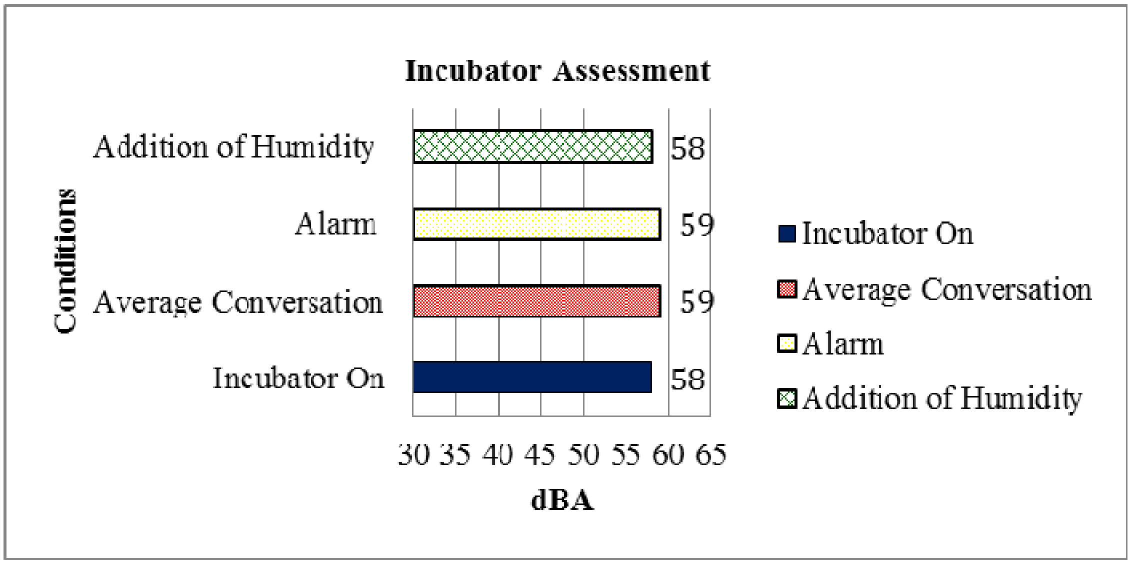

Figure 13 Oxygen Sound Levels

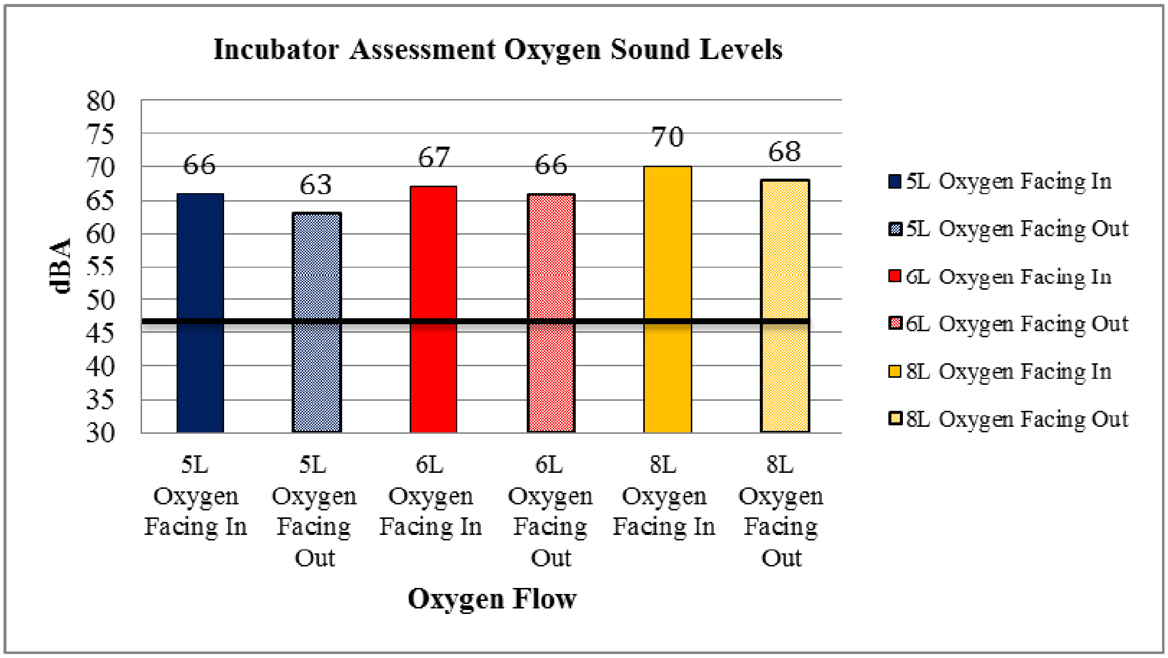

Figure 14 1/3 Octave Band Levels Background Noise vs. Incubator Off

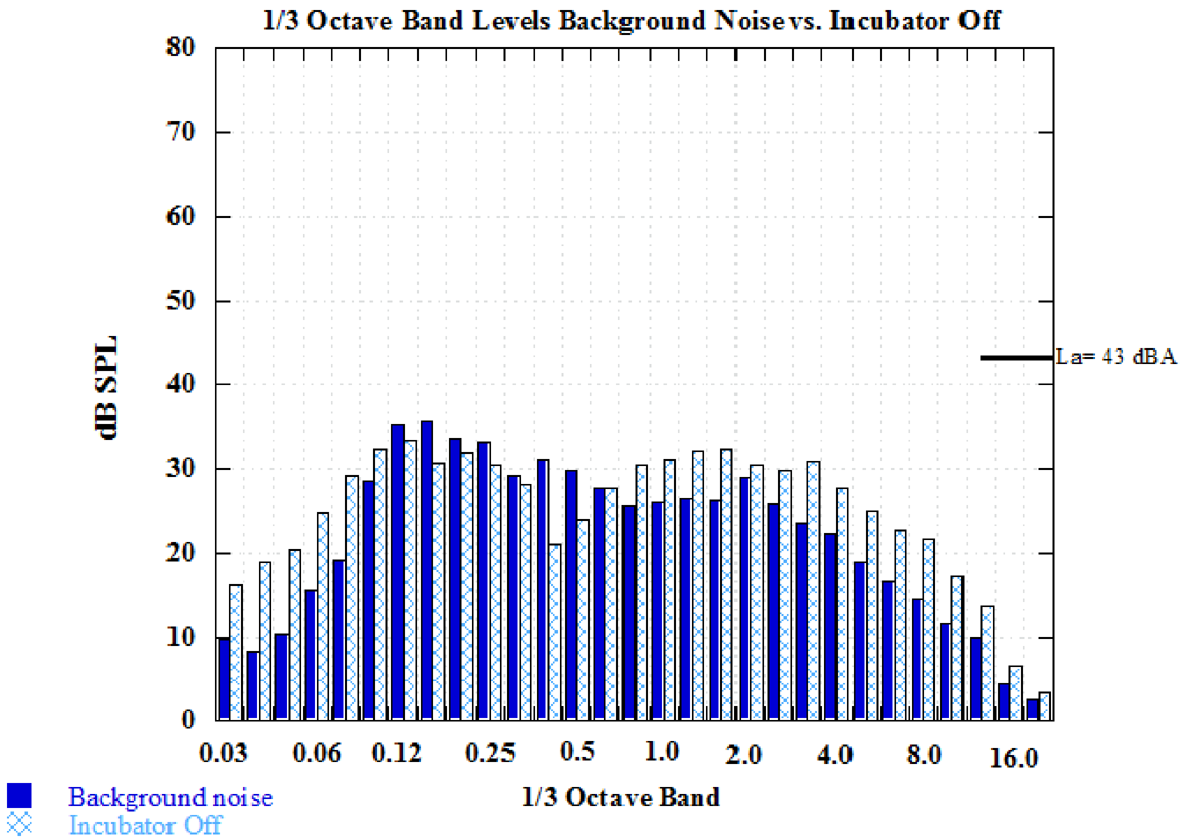

Figure 15 1/3 Octave Band Levels Background Noise vs. Incubator On

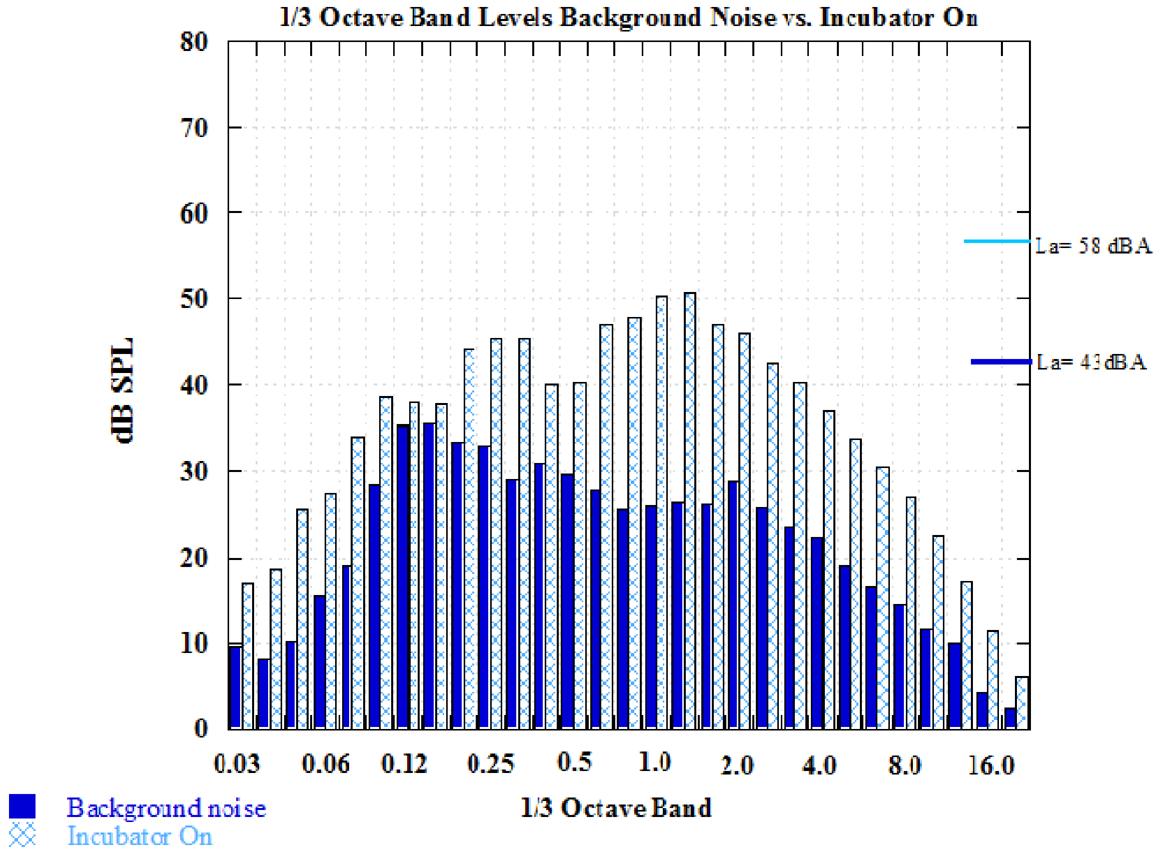

Figure 16 1/3 Octave Band Levels Incubator Off vs. Incubator On

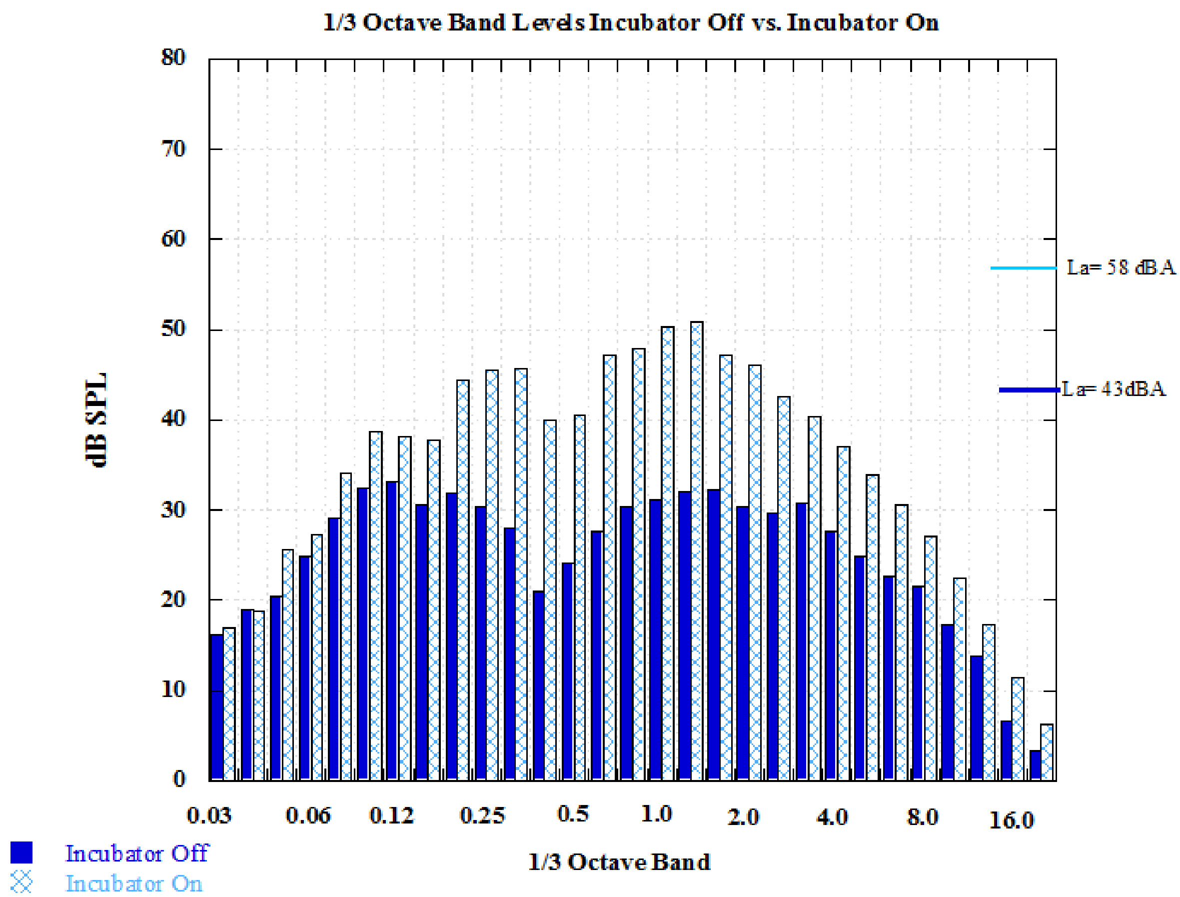

Figure 17 1/3 Octave Band Levels Incubator On vs. Improper Door Closure

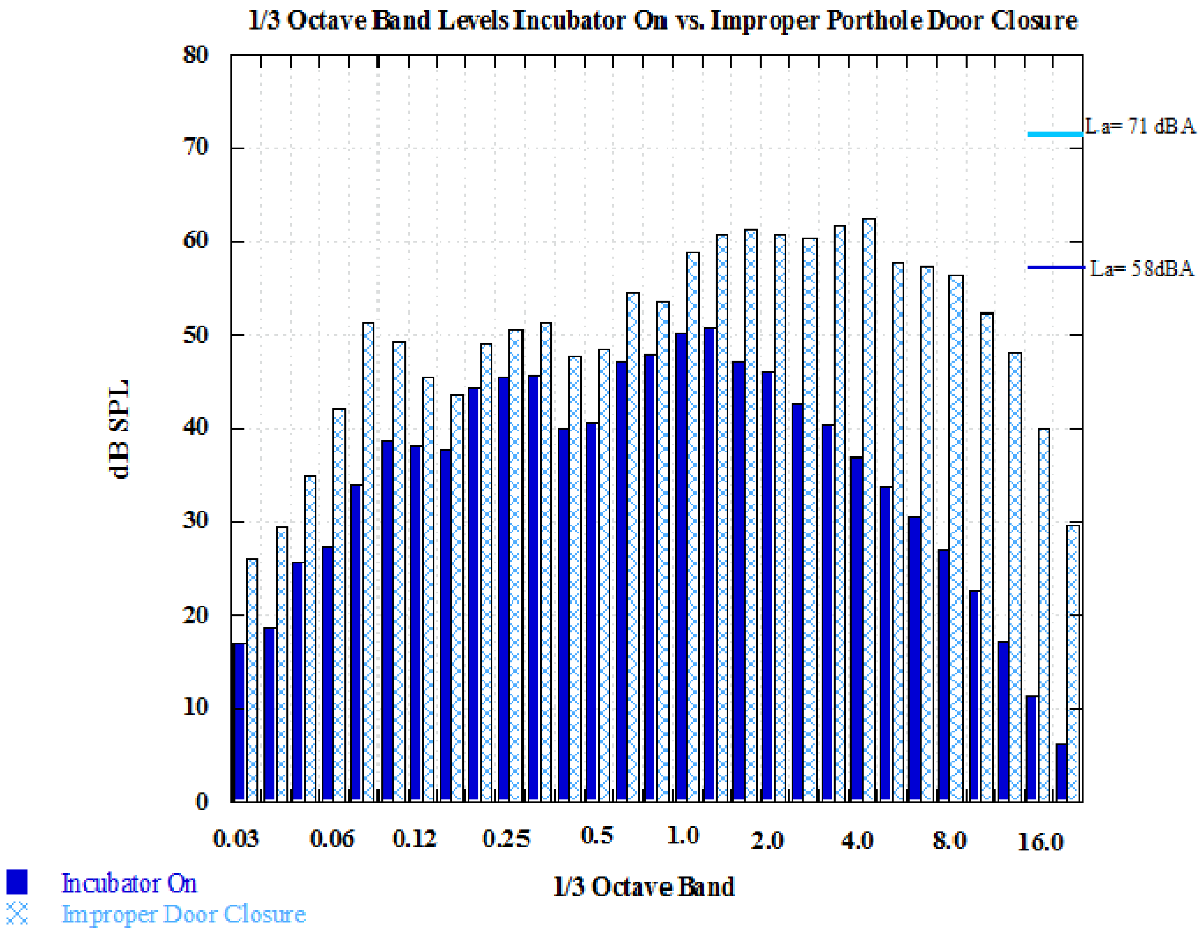

Figure 18 1/3 Octave Band Levels Incubator On vs. Proper Door Closure

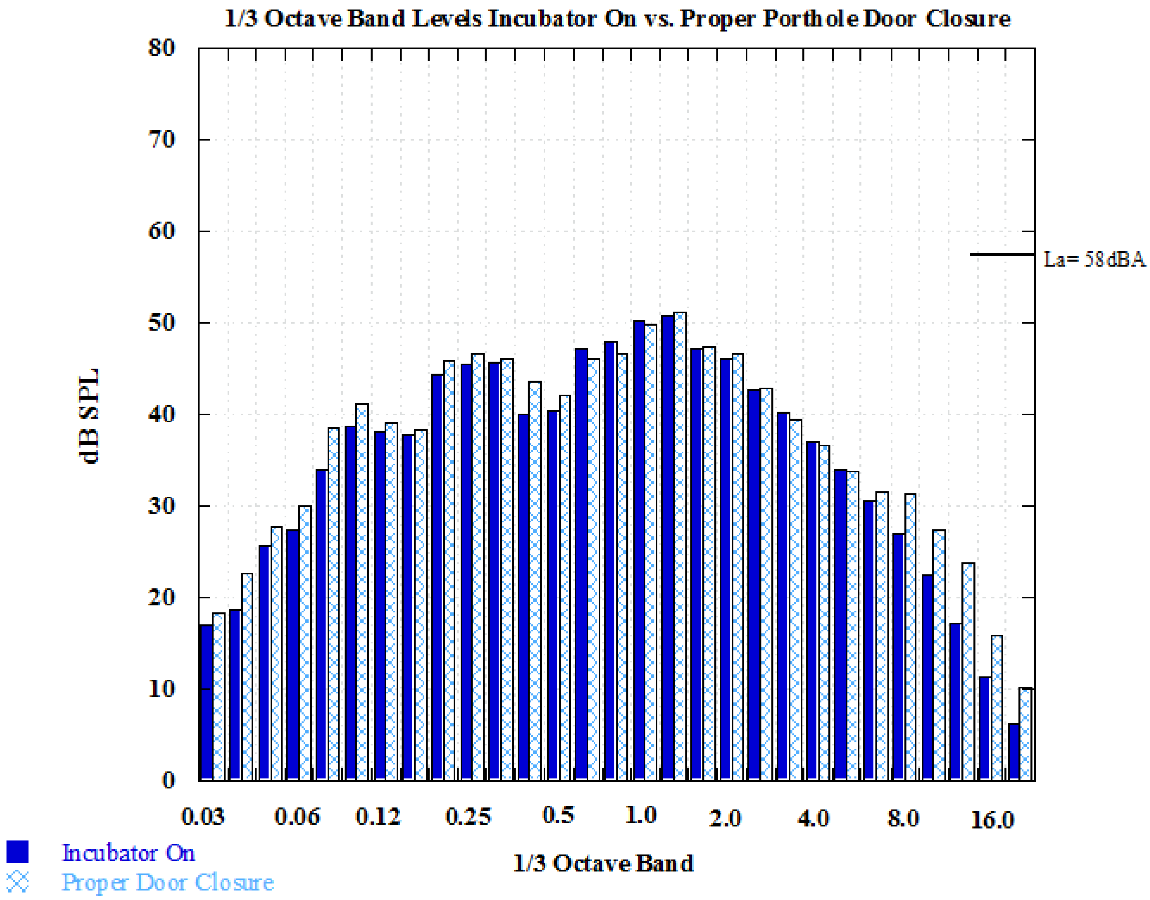

Figure 19 1/3 Octave Band Levels Incubator On vs. Incubator Hood Open

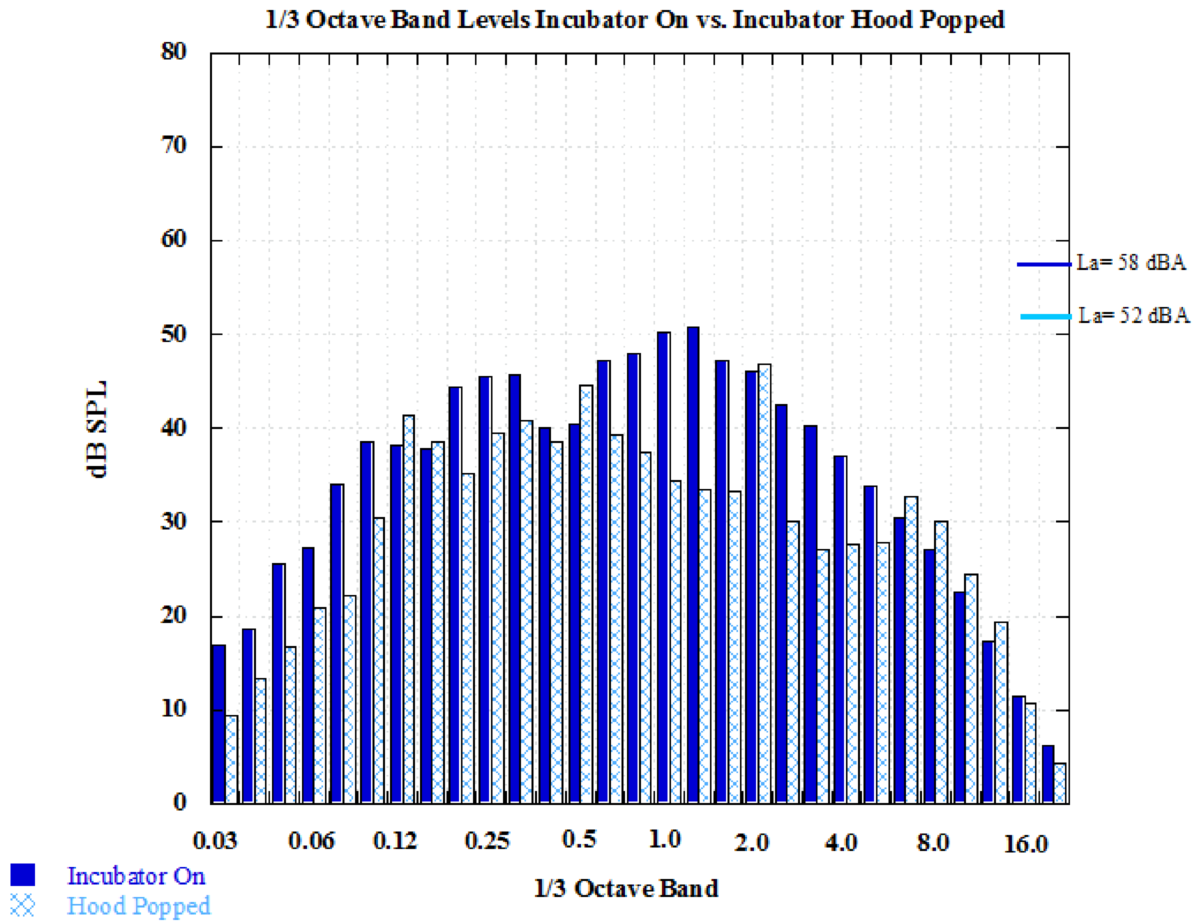

Figure 20 1/3 Octave Band Levels 8L Oxygen Facing In vs. Facing Out