New approach to evaluate Acoustic Pollution in hospital environments

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Abstract. There are many different services within a hospital. This means different types of noise which can be considered as acoustic pollution. Knowing that preterm infants exposed to high amounts of noise in the NICU are at a much higher risk because of their neurologic immaturity and physiologic instability, that excessive levels of noise also affect the persons and it can also impede some studies on patients, it was proposed to evaluate the Sound Pressure Level in some services of the Instituto de Maternidad, Tucumán, Argentina. During SABI 2011, this workgroup presented their first results in this matter. In this paper, there were evaluated the new Level III NICU –with new facilities in a different physical space in the hospital-, the laundry service and the attenuation factor (AF) of the cabinet cover in a neonatal incubator. The measurements were performed with two type II sonometer –CENTER 322, Cirrus CR832C) and it was also used an incubator analyzer (FLUKE INCU) for the incubator. The average values obtained were of 64.3 dBA for the NICU, and 80.8 dBA for the laundry room; the AF was between 2.88-3.09 and 3.43 –both under different conditions.

1. Introduction
During SABI 2011, this workgroup presented their first results in this matter. Those results were based in data collected in Hospital Maternidad de Tucumán in compliance with standards and legal regulations [1]. During 2012 there were important changes in the hospital facilities, creating a new Level III NICU, and new complementary resolutions to the National Law of Health and Safe at Work No 19587 were issued [2, 3, 4].

The Instituto de Maternidad is a public institution considered as Reference, in its specialty, in the northwest of Argentina. It is classified “Level 3” according to the Organization and Functioning of Neonatology and NICUs services guidelines of the National Ministry of Health –R.M. 306/02- and is the last step before to derive, the most complex cases, to Hospital Juan Garrahan in Buenos Aires, Argentina. This hospital has a family-centered policy, this fact reflects a shift from the traditional focus on the biomedical aspects of a child’s condition to a concern with seeing the child in context of their family and recognizing the primacy of family in the child’s life. This philosophy has a legal and ethic context in which the child and its families are the real owners of this institutions, each family is considered unique and they will be the experts on the child’s abilities and needs. The Tucuman Public Health System has a birth rate of about 25000 per year; half of them are attended in the Hospital Maternidad and proximately 1000 pregnant women per day are attended in all services. This hospital has 35 baby incubators, 25 infant radiant warmers, 4 transport incubators and 2 Advanced Life
Support ambulances. For adult patients it has 147 beds –93 for the Obstetric service with its own infant beds, 24 in the service of gynecology, 23 for High-Intermediate Risk, 4 in the service of oncology and 3 for Differential Coint Joint Hospitalization-, and it also has 60 hospitalization units for neonatology.

It’s well known that Preventive Maintenance (PM) is a set of tasks performed by personnel for the purpose of maintaining equipment and facilities in satisfactory operating condition by providing systematic inspection to avoid failures either before they occur or before they develop into a major one, according to selected guidelines or standards [5]. The professional that takes care of these policies in a health institution is the Clinical Engineer. The American College of Clinical Engineering (ACCE) defines the Clinical Engineer as “A professional who supports and advances patient care by applying engineering and managerial skills to healthcare technology.” -ACCE Definition, 1992-. As clinical medicine has become increasingly dependent on more sophisticated technologies and the complex equipment associated with it, the clinical engineer, as the name implies, has become the bridge between modern medicine and equally modern engineering [6].

Today, all over the world, Noise is considered as a modern plague. In Hospital Environments there are many sounds including those from beepers, alarms, machines, air-conditioning, staff activities, conversations, and medical equipment, among other sources. These can be severely irritating and sometimes harmful to patients, depending on their current conditions like age, hearing ability, medication intake, cultural background, and some psychological variables [7, 8]. Therefore, the acoustic pollution in healthcare environments is complex and requires a careful, strategic design and continuous control. This fact implies new healthcare design guidelines and there are many studies trying to identify strategies to improve this matter; therefore, any health institution must perform a regular control of the acoustic pollution in different indoor environments and it should be included in any PM schedule.

But, how do we define noise? We will consider as Noise any unwanted sound that exceeds the standards recommendations beyond any physical consideration. The unit used to measure Sound or Noise is decibel (dB), it is a logarithmic unit that indicates the ratio of a physical quantity relative to a specified reference level. It is well known that human hearing is less sensitive at very low and very high frequencies and requires an increase of about 10 dB before the sound subjectively appears to be twice as loud even when an increase of 6 dB represents a doubling of the sound pressure. The smallest change that can be perceived is normally about 3 dB. This is a direct consequence of the human frequency response.

When a noise evaluation is to be performed, the first step is to identify the type of noise in order to select the instrument –sound level meter-, noise parameters and the duration of the measurement [9]. The sound level meters, also known as sonometers, can acquire the sound level pressure and perform several different types of processing. The signal may pass through an electronic weighting network whose sensitivity varies with frequency in the same way as the human ear. There are three different internationally standardized characteristics termed "A", "B" and "C" weightings. The most common frequency weighting in current use is “A-weighting”, it provides results often denoted as dB(A) which conforms to the response of the human ear. The “C-weighting” curve is applied when very loud or very low-frequency sounds are present. In some cases, Regulations may require an objective measurement of tonal content as well. In practice, this will be performed with an octave or one-third octave band filter attached or integrated into the instrument; in this case, they are called Octave Band Analyzers [9, 10].

What about the measurement report? It is common to report only dB values. This makes the report difficult to understand and turns it into a source of information of little or no use at all. Standards and recommended practices are a great help to make a measurement report, the level of detail must be consistent with its purpose and it is also important to write it in an easy-to-understand, readable style. ISO 1996-1:2003 states the minimal information to be recorded and also gives some recommendations. In Argentina, during January 2012 it was issued the Res. 85/2012 complementary to the National Law of Health and Safe at Work No 19587. This new resolution plus Res. 295/2003,
also complementary, states the entire legal context for Noise and Vibration. In 2003 the maximum Equivalent Continuous Sound Pressure Level (L(Aeq)), for an 8 h working-day or 48 h working-week, was reduced by the Res. 295/2003 from 90 dB to 85 dB, according to international standards. In other words, this means to recognize that the ear is affected at levels four times lower than the ones accepted years ago. This resolution also gives a theoretical framework leading to classify the type of noise before making any data collection. The measurement protocol and its report form, including an explanation of every item, are stated in Res. 85/2012; many of the suggestions, given by ISO 1996-1:2003, were taken into account—although there is no item for photos, a good practice is to complement the report with a set of them describing the working conditions-[2, 3, 4, 11].

In this context, the objective of this paper is to measure Sound Pressure Levels at some services of the Instituto de Maternidad y Ginecología Nuestra Señora de las Mercedes, Tucumán, Argentina in compliance with the appropriate standards and regulations. In particular, in this preliminary study, the selected services were the new level 3 neonatal intensive care unit and the laundry. Also, it will be evaluated the Attenuation Factor for the cabinet cover of an infant incubator.

Why were these services selected?

Neonatal Intensive Care Unit (NICU): Numerous studies have documented the continuous noise exposure of infants associated with NICUs. Noise levels are often related to the new modalities of respiratory therapy such as high-frequency oscillatory ventilation and high-frequency jet ventilation, devices alarms, visitors (patient’s family), among other sources. The exposure of medically fragile and low birthweight infants to NICU noise has been related to anoxia and bradycardia and has a negative impact on blood pressure, heart rate, perfusion, oxygen saturation and cerebral blood flow. Consequently, preterm infants exposed to high amounts of noise in the NICU are at a much higher risk because of their neurologic immaturity and physiologic instability. The Committee on Environmental Health of the American Academy of Pediatrics recommend a maximum noise pressure of 45 db(A) in daytime and 35 dB(A) at night [12, 13]. During 2012, new facilities were inaugurated; therefore, the objective is to compare those results obtained in 2009-2011 with those obtained in March 2013 at the new facilities. In this case, the report will be made following the ISO 1996-1:2003 and IRAM 4113-2:2010 [11, 14]. Figure 1 shows the floor plan of the old LEVEL III NICU while Figure 2 shows the floor plan of the new LEVEL III and LEVEL II facilities.

![Figure 1. Floor plan of the old neonatology LEVEL III - green box-](image)
Laundry: This is a typical case of noise at work and an occupational point of view can be used for its analysis. Occupational Safety and Health (OSH) can be important for moral, legal, and financial reasons. We should note that OSH can also reduce employee injury and illness related costs, including medical care, sick leave and disability benefit costs. OSH may involve interactions among many subject areas, including occupational medicine, occupational hygiene, public health, safety engineering, industrial engineering, among other disciplines. In Argentina, the standards and laws to be applied are the IRAM 4113-1:2009, IRAM 4113-2:2010, IRAM 4079:2006, National Law of Health and Safe at Work No 19587 and its complementary resolutions Res. 295/2003 and Res. 85/2012 [2, 3, 4, 14, 15, 16]. Occupational noise-induced hearing loss is one of the causes responsible for numerous occupational ailments and injuries. When the loss or reduction of hearing ability is present, there is a very high probability to be in presence of an irreversible process. Unfortunately, there are no low-cost solutions to reduce this problem; therefore, this task should be included in a MP schedule.

Neonatal Incubator: The objective is to evaluate the noise attenuation factor for the cabinet cover. The parameters to be measured are sound pressure, inside and outside the baby compartment.

This is a major challenge because of the complex conditions proper of level III NICUs. The IEC 60601-2-19:2009 defines the Compartment as an environmentally-controlled enclosure intended to contain an infant and with transparent section(s) which allows for viewing of the infant. The subclause 201.9.6.2.1.101-Sound level within the compartment- states that it is unwise to keep preterm infants in an environment with ambient sound level above 50 dBA and with alarm impulses as high as 80dBA [17]. All the infant incubators in the neonatology service are in compliance with IEC 60601-2-19:2009; but it should be noted that other institutions may have infant incubators in compliance with older standards than those from 2009 which accepted sound level, within the compartment, < 60 dBA.

2. Materials and Methods
The environment sound pressure level was measured with two type II sonometers. One of them was a CENTER 322 with data-logger, certified on June 2012. It was calibrated with a Sound Level Calibrator (TES-1356) at 94dB according with the manufacturer’s instructions. The instrument autonomy is about 36 h when it is powered by a 9V alkaline battery.

The sonometer parameters were set to:
- Level Range: Auto 30-120 dB; Frequency Weighting: A; Time Weighting: Fast
- Sampling time was programmed depending on the environment under evaluation

The recorded data were downloaded to a notebook, via an USB-RS232 cable adapter managed by the TestLink SE322 software, for Sound Level Meter, provided by the manufacture’s sonometer. Furthermore, they can be also saved as a “csv” file format to be processed in any spreadsheet.

It was also used a sonometer Cirrus CR:832C Class 2 with 1:1 & 1:3 Octave Band Filters, certified on February 2012. It was calibrated with a Acoustic Calibrator (CR:514) according with the
manufacturer’s instructions. The instrument autonomy is about 36 h when it is powered by a 9V alkaline battery.

The sonometer parameters were set to:
- Level Range: 30-100 dB
- Frequency Weighting: A
- Time Weighting: Fast
- Sampling time was programmed depending on the environment under evaluation

**Neonatal Intensive Care Unit (NICU):** The sound level pressure was recorded during 24 h, the sampling time was set to 5 sec and the sonometer was placed as part of the life support system of a baby incubator, as closely as possible of the incubator, in order to get data of the nearby environment under working conditions. Figure 3 shows a general view of the corridor, between the two hospitalization sectors, and the north beds area - light blue and green box in figure 2 floor plan-. Figure 4 shows the sonometer as part of the life support set. Figure 5 show a general view of the south beds area. It was asked to the personnel “to ignore the presence of the new instrument” in the service and it was explained that it does not record voices or conversations.

![Figure 3. Level III NICU. General View: a- corridor between two hospitalization sectors; b- north beds area. Light blue and green box in figure 2.](image)

![Figure 4. Sonometer as part of the life support set](image)

![Figure 5. General View of the south beds area](image)

**Laundry:** The sound level pressure was recorded using the CENTER 322 sonometer, during 5 min and the sampling time was set to 1 sec. It was asked to the personnel “to ignore the presence of the instrument” in the service and it was guaranteed that the device does not record voices or conversations. The sonometer was placed in the centre of the engine room, inside a foam rubber bag to avoid vibrations, with the microphone pointing to the noise sources. Figure 6 shows the engine room; Figure 7 shows the sonometer inside the foam rubber bag.
Neonatal Incubator: This test was performed in two different places. A first set of tests were performed inside a room placed at the old LEVEL III NICU under harder environment noise conditions than usual working conditions; at the outside; there was personnel, remodelling the existing facilities, using power tools like hammer drills, sanders, grinders, etc. Figure 8 shows the incubator under test and Figure 9 shows a view of the area under remodelling.

A second set of tests were performed inside the new neonatology facilities, at the corridor between both beds area shows in Figure 2 (light blue box) under normal conditions. In both cases, the ambient temperature was 24°C.

In order to evaluate the noise attenuation factor -for the cabinet cover- and the interior noise, there were used both sonometers, previously described, plus an incubator analyzer (Fluke Incubator Analyzer-INCU). The INCU is a portable device designed to verify the proper operation and environment of infant incubators recording important parameters of the incubator such as airflow, sound level, temperature (four individual measurement probes), and relative humidity. It can operate stand-alone and is programmed by a PC via an RS232 port; after the test is completed, the user uploads the data collected into the PC for display and analysis. The recorded data can be saved in a file or printed in a report. The INCU parameters were set to: Interval Time: 1 h 20 min with a Sample interval: 1 min.

The first test was performed without any external coverlet and the incubator was “ON” –Figures 8 and 9-. In the second test, the incubator was covered with an external coverlet, normally used to limit ambient light transmission into the inside –Figures 10 a and 10b-. In both cases, it was compared the INCU collected data –inside- against CENTER 322 data –outside-. The third test was performed, with and without different coverlets, while the incubator was OFF; the noise was recorded with the Cirrus sonometer –inside- and the Center 322 –outside-.
3. Results

**Neonatal Intensive Care Unit (NICU):** It is well known that the sound pressure levels in level III NICUs are higher than in the other levels I & II. Previous studies, performed in the same service in 2009 and 2011, showed an average noise of 64.8 dBA and 63.6 respectively [1, 18]. In this case, we try to carry out the evaluation under the worst possible conditions. Figure 11 graphs the recorded data during 24 h.

![Figure 11. NICU Level III noise measurement -24 h-](image)

The statistics values obtained are the following (24 h format):
- Start Time: 21/03/2013 11:05:56 a.m.
- End Time: 22/03/2013 11:32:26 a.m.
- Sampling Rate: 5
- DataNo: 17618
- Avg.: 64.3
- Maximum: 89.2 @ 21/03/2013 11:29:31 a.m.
- Minimum: 59.0 @ 22/03/2013 03:27:21 a.m.

If we compare these results with those obtained in 2009 and 2011, even though the present values were recorded at the new facilities, it is possible to conclude that ambient noise are similar but they should be improved if we take into account the American Academy of Pediatrics recommendations. But, when these results are compared to other real values, obtained in other institutions in our country and all over the world, it can be said that this is an acceptable result [19, 20, 21, 22].

**Laundry:** This is the second time that this type of evaluation is performed in this service and the personnel were pleased for being taken into account. Figure 12 graphs de recorded data.
Laundry

The statistics values obtained are the following (24 h format):
Start Time: 03/05/2013 10:46:01 AM    End Time: 03/05/2013 10:51 AM
Sampling Rate: 1 sec         Data: 300
Maximum: 93.6@3/5/2013 10:49:51 AM
Minimum: 78.2@3/5/2013 10:48:07 AM
Average Value: 80.8 dBA

These values are similar to those obtained in previous measurements [1]. Even when, the average value seems to be high, is lower than the maximum fixed by the law which is 85 dBA.

**Neonatal Incubator:** The goal of this test is to check if the cabinet cover has any noise attenuation factor. The actual model of incubators at level III NICU has a technical specification of “own noise” less or equal to 50 dBA, but there is no specification for cover attenuation factor. This matter is still under analysis by many groups [21, 22, 23, 24]. Preliminary results show that the attenuation factor for the ambient noise is 1.15, for an external noise of 64 dBA [1].

The first test was performed inside a room placed at the old LEVEL III NICU –under remodelling- in harder environment noise conditions than usual working conditions. A second test was performed at the corridor between the beds area. In both cases, the incubator was “ON”. The values obtained are showed in Table 1.

| Incubator is ON | Area under remodelling | Corridor |
|-----------------|------------------------|----------|
|                 | Inside | Outside | Inside | Outside |
| Leq dBA         | 59.5   | 59.5    | 63.5   | 62.3     |
| L min dBA       | 55.5   | 42      | 59.7   | 54.5     |
| L max dBA       | 73.6   | 78.9    | 70.3   | 74.9     |
| Sampling rate   | 60 s   | 60 s    | 60 s   | 60 s     |
| Interval Time   | 3 h    | 3 h     | 3 h    | 3 h      |

Table 1.

Both tests have many uncontrolled external variables but the attenuation factor is similar to the preliminary obtained in 2011. These results are very useful when we analyzed them; in the first test the fact to be noted are the minimum values, we can assumed that the L min for the inside is the own internal noise of the incubator, therefore it should be scheduled for a preventive maintenance. The values measured in the second test surprised us because we measured Leq inside > Leq outside. Fortunately, other group reported described similar results that suggest a reverberance effect in the interior space of the closed incubator due to lack of effective acoustic damping. In addition, it is apparent that the physical transmission loss of the plexiglass of the enclosure hood is negligible and this is supported by additional test results [21].
Based on these results, we decided to performed other two tests with the same incubator but in “OFF” state. The first one was performed while there were personnel talking “normally” closely to the incubator –normal conversation-, the second one was performed with music -closely to the incubator-; in both cases with and without an external coverlet. We assumed that the spectral frequency is different. These results are shown in Table 2.

| Incubator is OFF | Without coverlet | External coverlet |
|------------------|------------------|-------------------|
|                  | Normal conversation | Music | Normal conversation | Music |
|                  | Inside | Outside | AF | Inside | Outside | AF | Inside | Outside | AF |
| Leq [dBA]        | 49.8   | 59      | 2.88 | 54.9   | 64.7   | 3.09 | 47.8   | 58.5   | 3.43 |
| L min [dBA]      | 41.5   | 54.6    | 41   | 54.9   | 54.0   | 40.7 | 54.7   | 53.9   |      |
| L max [dBA]      | 77.4   | 76.6    | 82.4 | 77.1   | 75.2   | 75.6 | 81.3   | 80.4   |      |
| Sampling rate [sec] | 1 1    | 1      | 1    | 1      | 1      | 1   | 1      | 1      |      |
| Interval Time [min] | 10 10  |         | 10   | 10     | 10     | 10  | 10     | 10     |      |

Table 2. AF= attenuation factor

In this analysis we have to take into account some facts: a- a human ear requires an increase of about 10 dB before the sound subjectively appears to be twice as loud; b- an increase of 6 dB represents a doubling of the sound pressure; c- AF=1 means that (P outside = P inside); AF=2 means (P outside = 2* P inside) –this means 6 dB-; AF=3 means (P outside = 3* P inside) –this means 9.5 dB-. A baby cannot tell us if he can perceive or not any variation in loudness; therefore, we will consider an acceptable value if AF ≥2 and a good AF when this value is ≥3

4. Conclusion

Environmental noise data is often used in legal proceedings. In fact, we should recommend collecting data with the assumption that someday it may have to be examined in court testimony. Therefore it is of outmost importance that the conditions of the measurement be carefully documented in a formal measurement report. A comprehensive and carefully documented formal has the best chance in any legal proceedings or noise control negotiations settled out of court. All reports should be documented according to Res. 85/2012 -complementary to the National Law of Health and Safe at Work No 19587- and with ISO 1996-1:2003 recommendations. It is also important to write the report in an easy-to-understand, readable style [2, 3, 4, 11].

In the case of neonatal incubators, it is necessary to perform complementary tests, with octave analysis, to determine the frequency components in order to discriminate its own internal noise and the contribution of the external life support set. In 2012, a group of the Vibration and Acoustics Laboratories of Virginia Tech and the Department of Internal Medicine Eastern Virginia Medical School, obtained results that would indicate a significant level of low frequency sound particularly when devices such as ventilator pumps are employed [21]. In 2013, other group described a multidisciplinary design project, conducted in an academic setting, reflecting a systems-oriented, human-centered philosophy in the design of neonatal incubator technologies, proposing some tips to enhance the incubator performance [24].

We do not conclude anything new if we said that a PM schedule is a major task in any health institution, but we believe that a very significant contribution is to include in the schedule a regular control of the acoustic pollution all over the health institution.

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