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. There were evaluated the Level III NICU, the laundry service, a physical space destined for a service of evoked potential and a neonatal incubator under working conditions. The measurements were performed with a type II sonometer (CENTER 322) and it was also used an incubator analyzer (FLUKE INCU) for the incubator. The average values obtained were of 63.6 dBA for the NICU, 82.5dBA for the laundry room, 52.7 dBA for the evoked potential room and 62.8 dBA in the inside of the incubator under 64 dBA in the outside. The reports were documented in compliance with the appropriate standards.

1. Introduction
It can be said 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 [1]. 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. The clinical engineer is, by education and training, a problem solver, working with complex human and technological systems [2].

One of the tasks that should be performed in a regular PM schedule, at any health institution, is the control of the acoustic pollution in different indoor environments. There are many sounds present in hospital environments, including those from beepers, alarms, machines, air-conditioning, staff activities, conversations, and medical equipment, among other sources. These can be severely irritating and at times harmful to patients, depending on their current conditions like age, hearing ability, medication intake, cultural background, and some psychological variables [3, 4]. But, not only indoor sources are present. In some cases outdoors sources like traffic, especially in big cities, should
be analyzed. Therefore, the acoustic pollution in healthcare environments is complex and requires a careful, strategic design and continuous control. Actually, acoustic pollution, or simply NOISE, is a component of new healthcare design guidelines and there are many studies trying to identify strategies to improve this matter.

But what would be considered as noise? Sound arises when fluctuations in air pressure give rise to pressure waves which travel through the atmosphere. As they travel they interact in various ways with their surroundings. Noise is a word which is normally applied to unwanted sound. Another way to understand Sound is by defining it as any pressure variation that the human ear can detect. Compared to the static air pressure ($10^5$ Pa), the audible sound pressure variations are very small ranging from about 20 μPa ($20 \times 10^{-6}$ Pa) to 100 Pa, being 20 μPa the average threshold of normal person’s hearing. A sound pressure of approximately 100 Pa is so loud that it causes pain and is therefore called the threshold of pain. The ratio between these two extremes is more than a million to one. Because of this, plus the ear logarithmic frequency response, the scale to represent acoustics parameters should be logarithmic. This logarithmic ratio is called a decibel or dB. The frequency range for a young, healthy human ear, is from 20 Hz to 20 kHz. In terms of sound pressure level, audible sounds range from the threshold of hearing at 0 dB to the threshold of pain which can be over 130 dB. There are many tables that represent different levels of sound pressure and human response, one of the most popular is table 1 [5].

<table>
<thead>
<tr>
<th>Common sounds</th>
<th>Noise Level [dB]</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rocket launching pad (no ear protection)</td>
<td>180</td>
<td>Irreversible hearing loss</td>
</tr>
<tr>
<td>Carrier deck jet operation</td>
<td>140</td>
<td>Painfully loud</td>
</tr>
<tr>
<td>Air raid siren</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Thunderclap</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Jet takeoff (200 ft)</td>
<td>120</td>
<td>Maximum vocal effort</td>
</tr>
<tr>
<td>Auto horn (3 ft)</td>
<td>110</td>
<td>Extremely loud</td>
</tr>
<tr>
<td>Pile driver</td>
<td>100</td>
<td>Very loud</td>
</tr>
<tr>
<td>Rock concert</td>
<td>90</td>
<td>Very annoying</td>
</tr>
<tr>
<td>Garbage truck</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Firecrackers</td>
<td>70</td>
<td>Telephone use difficult</td>
</tr>
<tr>
<td>Heavy truck (50 ft)</td>
<td>60</td>
<td>Intrusive</td>
</tr>
<tr>
<td>City traffic</td>
<td>50</td>
<td>Quiet</td>
</tr>
<tr>
<td>Alarm clock (2 ft)</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Hair dryer</td>
<td>30</td>
<td>Very quiet</td>
</tr>
<tr>
<td>Noisy restaurant</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Freeway traffic</td>
<td>10</td>
<td>Just audible</td>
</tr>
<tr>
<td>Business office</td>
<td>0</td>
<td>Hearing begins</td>
</tr>
</tbody>
</table>

Although an increase of 6 dB represents a doubling of the sound pressure, a human ear requires an increase of about 10 dB before the sound subjectively appears to be twice as loud. The smallest change
that can be perceived is normally about 3 dB. This is a direct consequence of the human frequency response.

The sound level meters can acquire the sound level pressure and perform several different types of processing. It is well known that our hearing is less sensitive at very low and very high frequencies. In order to account for this, weighting filters can be applied when measuring sound. The signal may pass through a weighting network which is relatively simple to build by applying an electronic circuit whose sensitivity varies with frequency in the same way as the human ear. This has resulted in three different internationally standardized characteristics termed the "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 conform approximately to the response of the human ear. A “C-weighting” curve is also used, particularly when evaluating very loud or very low-frequency sounds. The Noise can be classified as continuous, intermittent or impulsive. When measuring noise, we need to know the type of noise in order to set the parameters to measure, the equipment to use, and the duration of the measurement. Some sonometers may have an octave or one-third octave band filter attached or integrated into the instrument; in this case, they are called Octave Band Analyzers [5, 6].

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 particular, in this preliminary study, the selected services were the level 3 neonatal intensive care unit, laundry, evoked potential facilities and a neonatal 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 [7, 8].

**Laundry:** This is a typical case of noise at work and an occupational point of view can be used for its analysis. The Argentine’s standards and laws to be applied are the IRAM 4079-1//2 (Maximum admissible levels at occupational environments to prevent hearing impairment. Relationship between noise exposure and hearing threshold permanent displacement), IRAM 4113-1//2 (Description, measurement and assessment of environmental noise), IRAM 4060-2 (Estimation of Equivalent Continuous Sound Pressure Level A-weighted with hearing protectors), National Law of Health and Safe at Work No 19587 and its complementary resolutions [9, 10]. 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 not the result of an accident or an illness, it is usually an easily recognized process, indicated by basic symptoms such as the need for words to be repeated, misunderstandings in conversation, difficulty in understanding a conversation in certain circumstances, etc. But it should be noted that when these symptoms are present, there is a very high probability of an irreversible process. Unfortunately, there are no low-cost solutions to reduce this problem, although the modern medicine has demonstrated that injuries appear at sound pressure exposure levels lower than those accepted by standards few years ago. In fact, in Argentina since 2003, the maximum Equivalent Continuous Sound Pressure Level (L.Aeq) for an 8 h working-day or 48 h working-week, has been reduced 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 few years ago.

**Noise evaluation of a physical space destined for a service of evoked potential.** In this case, the hospital authorities required a noise evaluation in order to implement a new Visual Evoked Potential
service. Evoked potentials are used to measure the electrical activity in certain areas of the brain and spinal cord. Electrical activity is produced by stimulation of specific sensory nerve pathways. These tests are used in combination with other diagnostic tests to assist in the diagnosis of neurological disorders. Evoked potentials are used because they can indicate problems along nerve pathways that are too subtle to show up during a neurologic examination or to be noticed by the patient. The disruption may not even be visible on MRI exam. There are different types of potentials, i.e **Visual Evoked Potentials (VEP):** This test requires that the patient observes a flashing checkerboard pattern projected on a monitor, this procedure takes up approximately 60 minutes to be completed; **Auditory Evoked Potentials (AEP):** This examination involves listening to clicking noises generated in a set of headphones, this exam may take 60 minutes to complete. There are many other types of evoked potential [11]. In this case, the evaluation was performed according to IRAM 4026 (auditory cabin) and IRAM 4113-1 (Description, measurement and assessment of environmental noise. Basic quantities and assessment procedures) standards.

**Neonatal Incubator:** This is a major challenge because of the complex conditions proper of level III NICUs. The Instituto de Maternidad de Tucumán, is one of the 5 main hospitals in the province, it is Reference Center for the north-west region in Argentina and also the last step before deriving the most complex cases to Hospital Juan Garrahan in Buenos Aires, Argentina. In this case, the authorities require the implementation of a protocol to evaluate the performance of the incubators in working conditions. One of the parameters to be evaluated is sound pressure within the baby compartment. Other parameters available to evaluate are air flow, temperature –both radiant and convection-, relative humidity. The tests were performed in compliance with IEC 60601-2-19:2009 and IRAM 4220-2-19:1995 standards.

### 2. Materials and Methods

In all cases, the environment sound pressure level was measure with a type II sonometer (CENTER 322) with data-logger. It was calibrated with a Sound Level Calibrator (TES-1356) at 94dB according with the manufacturer’s instructions. The instrument autonomy is about 48 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, 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.

**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 in a corner between 2 incubators, with patients, trying to get data under the worst conditions.

**Figure 1.** General view of the level III NICU and the sonometer placed in the corner
The personnel were asked “to ignore the presence of the new instrument” in the service and it was explained that it does not record voices or conversations. Figure 1 shows a view of the level III NICU and the sonometer placed in the corner.

**Laundry:** The sound level pressure was recorded during 5 min, the sampling time was set to 1 sec. The personnel were instructed “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 2 shows two pictures of the engine room, Figure 3 shows the sonometer inside the foam rubber bag.

![Figure 2. Two pictures of the engine room of the laundry service](image1)

![Figure 3. Sonometer inside the foam rubber bag](image2)

**Noise evaluation of a physical space destined for a service of evoked potential:** The sound level pressure was registered during approximately 40 min; the sampling time was set to 1 sec. The sonometer was placed in the centre of the room, inside a foam rubber bag to avoid vibrations. The door was closed and there were no personnel during the record. The data were recorded during a high level of people circulation in the hall at approximately 10 am. Figure 4 shows the hall, the entry and the room interior.

![Figure 4. Hall, the entry and interior of the room destined for VEP](image3)

**Neonatal Incubator:** This test was performed in the hall between Level III & Level II NICUs as the service had no incubator available. Thus, it was decided to evaluate the incubator under worse conditions than those within the room, the ambient temperature being 24°C. This is showed in Figure 5. In this case, the test was performed with both, a sonometer and an incubator analyzer (Fluke Incubator Analyzer-INCU). The INCU is a portable device designed to verify the proper operation and environment of infant incubators. This unit focuses on the record in parameters important to the care of infants over time, 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, the user selects the desired record time/interval via the software and then initiates the start of the test from...
the INCU. 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
Sample interval: 1 min

![Figure 5. Incubator under test](image)

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. A previous study, performed in the same service in 2009, showed an average noise of 64.8 dBA [12]. In this case, we try to carry out the evaluation under the worst possible conditions. Figure 6 graphs the recorded data.

![Figure 6. Level III noise measurement](image)

The statistics values obtained are the following (24 h format):
- Start Time: 11/05/2011 10:23:23
- End Time: 12/05/2011 10:55:13
- Sampling Rate: 3 sec
- Data: 29449
- Maximum: 85.4 dBA@12/05/2011 2:01:59
- Minimum: 58.0 dBA@11/05/2011 23:41:08
- Average value: 63.6 dBA

If we compare these results with those obtained in 2009, even though the present values seem to be lower, it is possible to conclude that the working conditions 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 [13, 14].
Laundry: This is the first time that this type of evaluation is performed in this service and the personnel were pleased for being taken into account. Figure 7 graphs the recorded data.

![Figure 7. Laundry noise measurement](image)

The statistics values obtained are the following (24 h format):
- Start Time: 10/05/2011 9:48:32
- End Time: 10/05/2011 9:54
- Sampling Rate: 1 sec
- Data: 312
- Maximum: 83.8@10/05/2011 9:52:56
- Minimum: 81.8@10/05/2011 9:51:34
- Average value: 82.5 dBA

Even when the average value seems to be high, it is lower than the maximum fixed by the law which is 85 dB.

Noise evaluation at a physical space destined for a service of evoked potential: The hospital needs a new Visual Evoked Potential service. Currently, the room destined for this matter is in a hall with an important people circulation. Even when the sound-noise is not the stimulus for the patient under evaluation, the environmental noise could interfere. Figure 8 graphs the recorded data.

![Figure 8. Visual evoked potential room measurement](image)

The statistics values obtained are the following (24 h format):
- Start Time: 10/05/2011 9:01:01
- End Time: 10/05/2011 9:38
- Sampling Rate: 1 sec
- Data: 2200
- Maximum: 72.0@10/05/2011 9:01:02 (opened door)
- Cursor A: 55.1@10/05/2011 9:01:42 (closed door)
- Cursor B: 53.5@10/05/2011 9:36:59 (closed door)
- Max. Between A and B: 70.7@10/05/2011 9:12:59 (closed door)
- Min. Between A and B: 44.6@10/05/2011 9:09:50 (closed door)
- Avg. Between A and B: 52.7 (closed door)
It should be noted that, for a correct noise evaluation of this service, the noise has to be divided into its
general frequency components. Unfortunately, when this evaluation was performed, the octave band analyzer
was not available and the room did not have any type of acoustic sound conditioning; therefore, only a
general environmental noise evaluation was performed. Figure 9 shows the maximum values expected
in compliance with IRAM 4026 standard.

![Figure 9. Maximum admissible Sound Pressure Level in audiometric cabin. Reproduced from IRAM 4026 standard](image)

**Neonatal Incubator**: The real intention 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 under analysis in many institutions [15]. Our preliminary results show that the attenuation factor is very poor; for an external noise of 64 dBA, the inside shows 62.8 dBA. These values are shown in Figure 10.

![Figure 10. Noise inside the cabinet. The mark points the instant when the instrument is put outside over the incubator](image)

The INCU also performed 4 temperature records according the diagram showed in Figure 11 and in compliance with IEC 60601-2-19:2009 and IRAM 4220-2-19:1995 Standards. Figure 12 shows the graphic report of the INCU air sensors. Temperature Sensor T1 is used for convection measurements.
and could correspond to point B in Figure 11; Temperature Sensor T2 is used for Convection or Radiant measurements and corresponds with point M in Figure 11; Temperature Sensor T3 is used for convection measurements and could correspond with point C in Figure 11; Temperature Sensor T4 is used for Mattress Temperature measurements (made by conduction) and it does not have any correspondence with any point in Figure 11.

![Figure 11](image)

**Figure 11.** Positioning of air temperature sensors. Reproduced from IEC 60601-2-19:2009

The standard states that:
- During steady state condition, the INCUBATOR TEMPERATURE shall not differ from the AVERAGE INCUBATOR TEMPERATURE by more than 0.5°C (1°C transportable) during at least 1 hour at the control temperatures of 32°C and 36°C
- ... in each point A,B,C,D,E, shall not differ from the AVERAGE INCUBATOR TEMPERATURE (test at a set T of 32°C - 36°C) by more than ±0.8°C (±1.5°C transportable).
- The warm-up time of the equipment shall not differ by more than 20% from the warm-up time specified in the instructions for use. INCU: Check the difference between the time stated by the manufacturer and the time to raise the temperature by 11°C, starting at the environmental conditions with a setting temperature 12°C above the ambient.
- After adjusting the temperature from 30°C to 34°C or Transit 32°C to 36°C, the overshoot in the incubator temperature shall not exceed 2°C.

![Figure 12](image)

**Figure 12.** Temperature values inside the baby compartment. The mark points the instant when the instrument is put outside over the incubator.

The results showed in Figure 12 verify the standards requirements. Air flow and its average value 0.22 m/s, lower than the max fix by the standard which is 0.35 m/s were measured as well.
4. Conclusion
Environmental noise data is often used in legal proceedings. In fact, we should always collect data with the assumption that it may someday have to be examined in court testimony. Therefore it is of utmost 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 ISO 1996 that states the information must be recorded. It is also important to write the report in an easy-to-understand, readable style. Depending on the target audience, the use of graphics, sketches, and illustrations can sometimes help to explain the data. In other cases, text and figures will suffice [5].

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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