ACOUSTIC EVALUATION OF THE SCHOOL ENVIRONMENT: MEASUREMENT AND SIMULATION

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Abstract. *The academic quality is strongly related the interest of students to the classes, as well as the interaction between them with their teachers. The problem that can disturb this formation is the noise interference, which could complicate the understanding of the classes developed within the school context. In a classroom, are considered noise, the sounds that disturb the speech understanding of teachers by students, or affect the verbal response given by students to the teacher. Are also considered noise, sounds that distract the concentration causing the lost of the focus in the class. The unwanted sounds can permanently damage the health of students and teachers because they need to raise the tone of voice, which may cause damage to your vocal cords and / or their hearing systems. The quality acoustics of classrooms is recommended by INMETRO by ABNT NBR 10152:1987, which specifies the sound pressure levels that case if they exceeded, impair the health and education in classrooms. Thus, it is essential to the acoustic of the school environment to be able to know the sources of noise and from the results obtained, seek solutions to solve that problems. After reviewing the literature about the subject, will be made measurements of sound pressure level at various places within the school to be compared with the levels recommended by the rule. From the results obtained by the measurements made, this study wants to examine and suggest some solutions to the adequacy of environments that are outside the rule.*

Keywords*: Acoustic, noise, classrooms, school environments*

1. INTRODUCTION

In a classroom ther should be interaction between teachers and students so that the lesson is clearly developed, benefiting the understanding of course content by students. Among the factors that contribute to this objective is achieved is the acoustic quality of the environment. The physical structure of the room should be adequate as the norms in order to provide acoustic comfort for its occupants. Undesirable sounds within an environment are called noises are the sounds inside a classroom hinder the understanding of talking or distracting, thereby corrupting the focus of the class. It is therefore of great importance to know the sources of noise, monitor their sound intensities and control them so they do not affect the learning environment. These activities are related to metrology and are regulated by national authorities.

Metrology is the science that covers the practical and theoretical aspects related to measurements, whatever the uncertainty in any field of science or technology (Inmetro, 2010). Measurement procedures are designed to determine the momentary value of a physical quantity based on an agreed unit as standard. Thus the object of measurement called the measurand is given as a fraction or multiple of the unit standard that must be recognized internationally.

Brazil had its first law promulgated in the molds of metrology in the 1930s, but only since the 1960s there was an implant metrology control at the national level, with the creation of the National Weights and Measures (INPM). In 1973, Law 5966 and officially established the National System of Metrology, Standardization and Industrial Quality (Sinmetro) whose function is to formulate, organize and execute activities related to metrology in Brazil. The Sinmetro is composed of a regulatory body, the Conmetro, and another executive, Inmetro.

The Council of Metrology, Standardization and Industrial Quality (Conmetro) is the body's regulatory Sinmetro. It is responsible for ensuring the uniformity of units of measurement used in the country, establish criteria and procedures for certification of quality of industrial products and also for imposing penalties for violations of legislation (Albertazzi and Sousa, 2008).

The National Institute of Metrology, Standardization and Industrial Quality (Inmetro) is the executive organ of Sinmetro and aims to promote quality of life of citizens and the competitiveness of the economy through metrology and quality. It is responsible for providing the Brazil national metrological standards, structuring and managing the national metrological reference system, and monitor and verify the measurement instruments, systems manage Brazilian accreditation and Calibration Laboratory Tests and win international recognition of the Brazilian system metrology, accreditation of laboratories and inspection bodies and certification.

In its evaluations and inspections Inmetro checks the product or work environment has accordingly. According Inmetro, conformity is the procedure that aims to provide adequate level of confidence in a product, subject to compliance requirements defined in standards or technical regulations. Among the certification bodies accredited by Inmetro can highlight the Brazilian Association of Technical Standards (ABNT), whose mission is to provide systematic knowledge of Brazilian society, through normative documents, which enables the production, sale and use of goods and services in a sustainable and competitive in domestic and foreign markets, contributing to the scientific and technological development, environmental protection and consumer protection.

2. LITERATURE REVIEW

2.1.1. Metrology Concepts

No matter how good the quality of the measurement system, for more caring and who is the operator and the influences of environmental conditions, yet a greater or lesser degree, the measurement error is present (Albertazzi and Sousa, 2008). The measurement error is considered as the difference between the actual value of the measured and the amount determined in the measuring devices.

Also according to Sousa and Albertazzi (2008), an error can be considered systematic or random. The systematic error corresponds to the mean error of measurement, while the random error corresponds to the plot unpredictable measurement error, values responsible for wide variation among themselves in repeated measurements.

Therefore, it is evident that before drawing conclusions about the measurements is necessary to have an assessment as to the values found in such activities in order to determine how the values behave and show approximate values or random. Thus, if any perceived disparity between the measured values, this error is applied to the appropriate statistical method to fix your suffering.

To correct an error it is necessary that the source is acknowledged. This source can be internal to the meter and / or being influenced by external operator or the environment. The internal error may occur due to the technology of the device, the imprecision of measuring scales, with material that is built for long wear and use. Influenced by external errors are due to operator inexperience in handling measuring equipment.

To mitigate the errors by employees apparatus meters, they must be calibrated. According to Sousa and Albertazzi (2008), calibration can be defined as the set of operations that establish, under specified conditions, the relationship between values indicated by an instrument or measuring system or values represented by a material measure or a reference material and the corresponding values of the quantities set by standards. It is necessary so that the devices are calibrated meters during measurements to allow for a minimum of error.

The calibrations are performed in specialized laboratories accredited by the inspecting Inmetro, which together with the regulatory body the way the Conmetro Sinmetro which is the agency responsible for Metrological System Sterling. For a laboratory to receive the seal of approval, must conform to standards (NBRS) established by the agencies already mentioned, so as to act independently in order to product quality and defending the consumer.

When performing a calibration, the laboratory checks the meter by comparing its value to a standard measure. If there are discrepancies, the apparatus has been modified in a way that presents the values closest to the default value, thus leading to adjustment of the device. There are two methods of calibration, the direct and indirect. The direct method is done by comparing the values of the equipment meters with the default values that can be materialized. The indirect method is to generate the standard size for an auxiliary device and then compare with the value measured by the device.

With use, the meter will suffer wear that creates uncertainties in their measurements, so it is important to follow the rules which determine the time intervals in which a particular apparatus must be calibrated. The NBR 10151/2000 recommends that the sound pressure level meter and acoustic calibrator should have the calibration certificate of the Brazilian Calibration Network Inmetro or renewed at least every two years. The NBR 17025/2005 states that the calibration certificate shall not contain any recommendation on the calibration interval except if combined with the customer.

2.1.2. Standards used

The ABNT NBR ISO/IEC 17025:2005 specifies the general requirements for the competence of testing and calibration laboratories. The standard is applicable to all organizations that perform testing, calibration and sampling, and used in developing the management system for quality, technical and administrative operation of the laboratories.

The ABNT NBR 10151:2000 deals with the evaluation of noise in populated areas, to ensure the comfort of the community. The standard sets out the conditions required for assessing the acceptability of noise on communities, specifying the method for measuring noise and patching levels measured, if the noise present special features. This method involves measurements on the equivalent sound pressure level in decibels belonging to the weighting curve "A" which represents the sensitivity curve of human hearing in relation to frequency and sound pressure level. Figure 1 shows the weighting curves A and C standard. The C curve is almost flat and represents the sound environment without the use of filters, widely used for measuring noise. The big difference between the two curves is the attenuation for low frequencies.

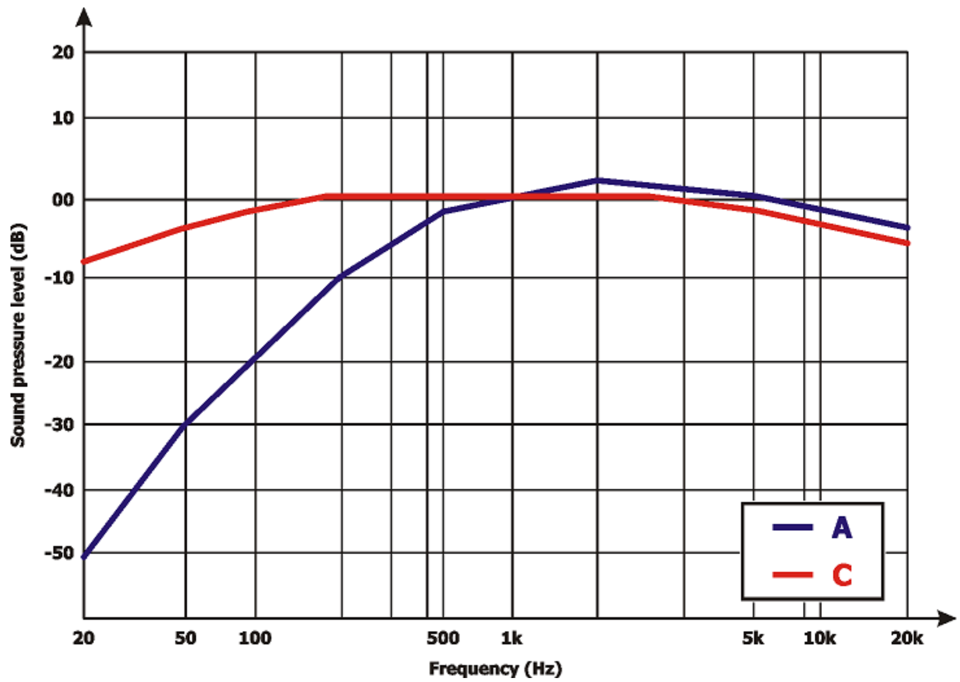

Figure 1. Curves A and C weighting standardized by ISO

The ABNT NBR 10152:1987 addresses the noise levels for acoustic comfort. The standard fixed values to the noise levels compatible with the acoustic comfort in various environments, including in the school environment.

Even following the rules, mistakes can occur in the design and measurements. These errors can not be ignored, since they can cause problems that can affect health in a particular environment. Therefore it is important to understand the mistakes, find their sources and studying the causes for which you can apply the necessary correction, or if the error is inevitable, live with it getting reliable information from a measurement process.

2.2. Fundamentals of acoustics in enclosed

2.2.1. Reverberation Time

Indoors, two fields are produced by a sound source: one is the direct field diverging from the source and the other is the reverberant sound field (Gerges, 2000). A receiver will receive the first direct sound, which travels the shortest path and soon after, the sounds reflected by walls, ceilings and objects within the environment. According Zwirtes (2006), the human ear can not distinguish two sounds that are spaced at a time of approximately 0.06 s. As the reflections tend to be faster than the threshold of perceptibility, the reflections are meant as an extension of the original sound.

The reverberation time (RT) is defined as the time required for the sound pressure level in a room decrease by 60dB after being stopped at the emission source (Harris, 1994).

There are many formulas for calculating the reverberation time, studies by Bistafa and Bradley (2000) and Neubauer (2001) show that there is great precision in most of the results, they are only approximations of the real model that does not take into account some essential parameters such as objects included in the room and air absorption.

The most widely used equation for calculating the RT was prepared by the American physicist Wallace Clement Sabine, and is given by:

$$RT = \frac{0.161V}{A}(s) \tag{1}$$

where:

RT = Reverberation Time (s)
V = Enclosure Volume (m^3)
A = Equivalent sound absorption area (m^2)

The equivalent sound absorption area is given by the following formula:

$$A = \sum_{i=1}^{n} \alpha_i S_i (m^2) \tag{2}$$

where:

αi= absorption coefficient of each construction element
Si= surface area of each building element

Hohmann et al. (2004) suggest a supplement in the Sabine formula relating the sound absorption equivalent, including in the area formula of the functional elements of the room (chairs, tables and people, etc..) Covering including noise attenuation air. Thus, the area of sound absorption will be calculated by the formula:

$$A = Ab + Ae + Ap + Al \tag{3}$$

where:

A = equivalent sound absorption area (m²)
Ab = Area of the equivalent sound absorption walls (m²)
Ae = equivalent sound absorption area of objects (m²)
Ap = equivalent sound absorption area concerning persons (m²)
Al = equivalent sound absorption area of the air in the room (m²)

A study by Zannini et al. (2005) showed that the results obtained with the modified formula of Sabine obtained results closer to the actual values measured in situ.

2.2.2. Geometric Model

The theory of sound waves is not applicable for the analysis of medium and high frequency, because a large number of modes appears in the course of its development, so the theory of geometric model appears more feasible to be applied. Although not completely describe all phenomena in the environment, the model represents very well the most important aspects of practical standpoint. This model assumes that the rays leave evenly acoustic source mirroring the environment. This leads to reflections and every surface that the rays come in contact will suffer attenuation.

The acoustic ray theory believes that the sound propagates in the form of a ray, with properties similar to those found in the geometrical optics (Gerges, 2000). This simplification can be assumed that the wavelength is extremely smaller than the dimensions of the room where it occurs. However, this consideration may not be satisfactory at low frequencies.

A cutoff frequency accepted by many specialists, above which the acoustic ray theory is valid, the frequency of Schroeder (Gerges, 2000), given by:

$$f_c = 2000\sqrt{T/V} \tag{4}$$

where:

T = Reverberation Time (s)
V = Room’s Volume (m³)

2.2.3. Image-Source

The Image Source algorithm is the most commonly used in rectangular environments such as schools, offices and homes. The accuracy of the solution increases with increasing rigidity of the walls of these environments.

This algorithm treats each reflection as a virtual source, which is out of the environment and consists of the source image, across the wall. The image suffers loss of sound energy corresponding to the sound absorption coefficient of the wall.

With the Image-Source is possible to obtain good temporal resolution, however, the computational time increases exponentially, in addition, the algorithm does not take into account the diffusion effects of reflections or mirroring caused by irregular surfaces.

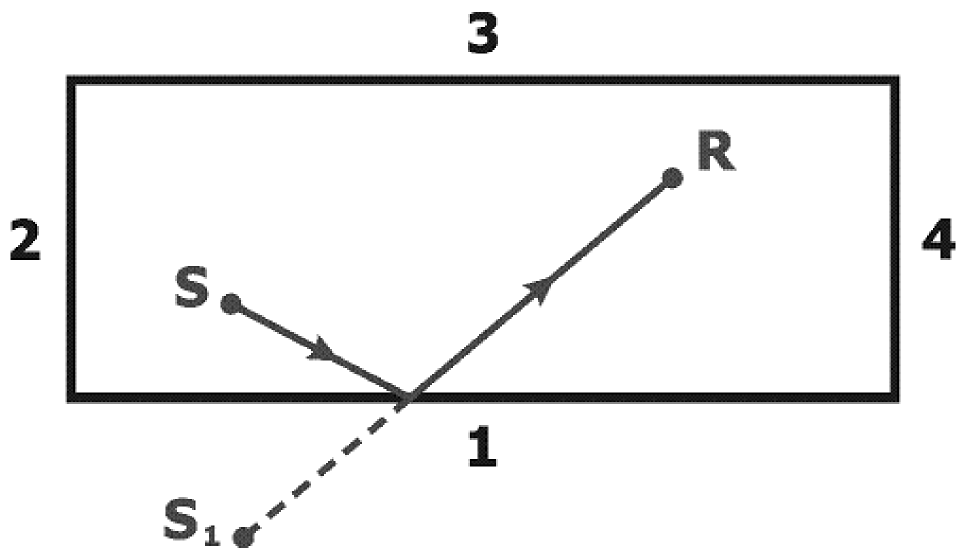

Figure 2. Representation of the virtual source outside the room (Gerges, 2000)

2.2.4. Ray-Tracing

The Ray-Tracing algorithm boils down to accompany the sound beam, respecting Snell's law for reflection. The method takes into account the diffuse reflections and requires a computational time only proportional to the length of the impulse response, but does not provide results with good temporal resolution.

A sound beam can reflect on a specular or diffuse. By Snell's law as reflected in a mirror, the incident ray and reflected ray are in the same plane, and angle of incidence is equal to the angle of reflection. As shown in Fig. 3.Diffuse reflection occurs when the reflected beam delivers its energy in all directions. As shown in Fig. 4.

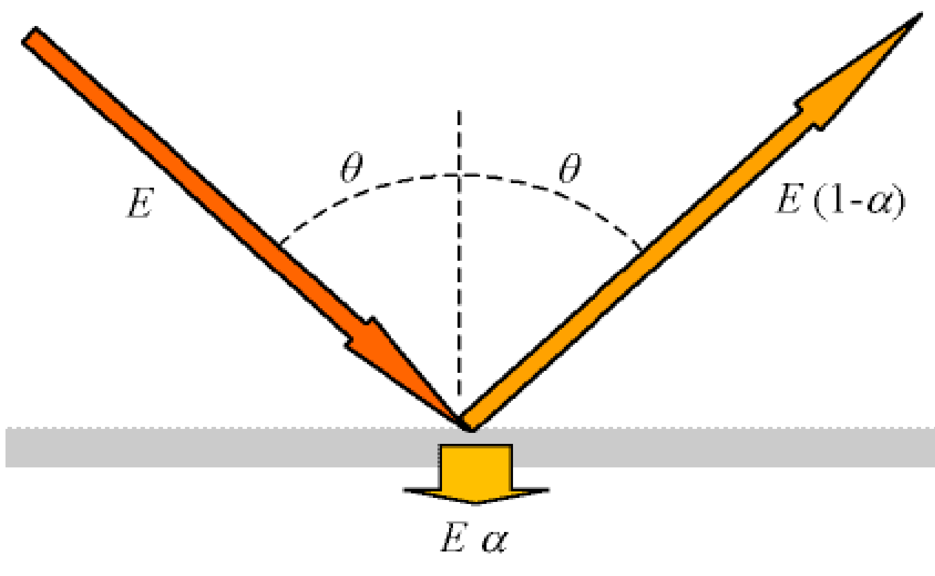

Figure 3. Representation of specular reflection (Tenenbaum and Camilo, 2004)

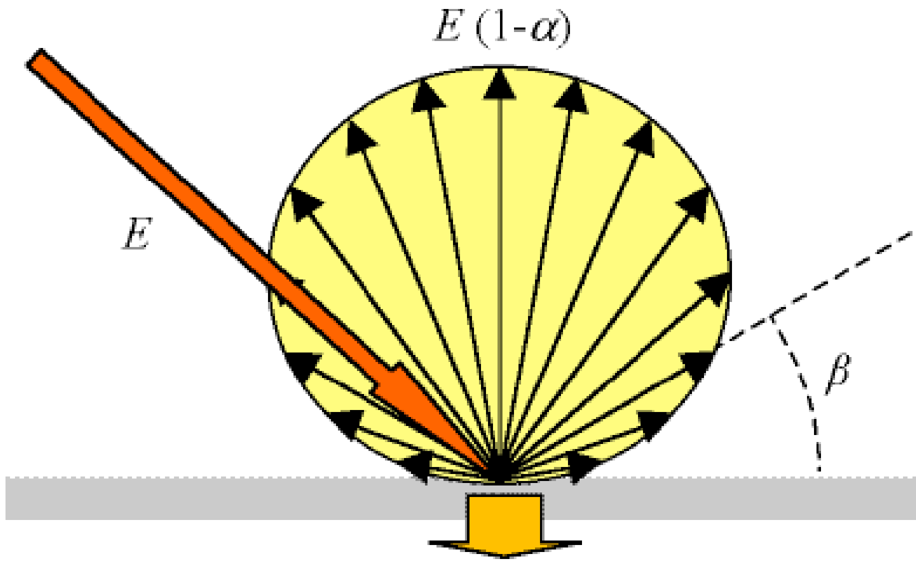

Figure 4. Representation of diffuse reflection (Tenenbaum and Camilo, 2004)

3. METHODOLOGY

The main objective is to apply the concepts of metrology in the evaluation of acoustical quality of classrooms of the institution CEFET-MG, Campus V. The campus has two buildings where there are classrooms. III in the building, there are nine classrooms. The building I have a room.

We then identified three types of room:

The model I understand the room 118 which is located in the building I Campus, previously scheduled to be part of the library was transformed into the classroom. Its dimensions are different from other rooms of the institution and has one of its walls mounted with removable dividers.

Model II includes 301 rooms, 303, 306, 308, 312, 314 and 323 that are located in the building of the Campus III. It has the standard model adopted in the construction of the building for classrooms.

Model III includes 310 rooms and 321 that are located in the building of the Campus III. They have the same dimensions as Model II, however, the rooms of this model have been designed for laboratories, therefore, have in one of its walls with a large glass.

For the acoustic analysis were calculated reverberation time and the measured sound pressure levels of the classrooms.

3.1 Calculation of Reverberation Time

The ANSI S12.60: 2002 states that for empty rooms with a total volume of less than 283 m³ ideal reverberation time corresponds to 0.6 seconds. Classrooms evaluated fall into this standard as shown in the table below.

Table 1. Measured values for the volume of each room.

Type of room evaluated	Volume (m³)
Model I	205.09
Model II	179.37
Model III	179.37

For each room were raised their construction materials and dimensions for application in Eq. (3).

Another important item to be evaluated theoretically is the mean absorption coefficient of the environment. To calculate RT using the Sabine equation changed this ratio should produce values below 0.3. This condition also occurs in the halls evaluated as shown in the graphic below.

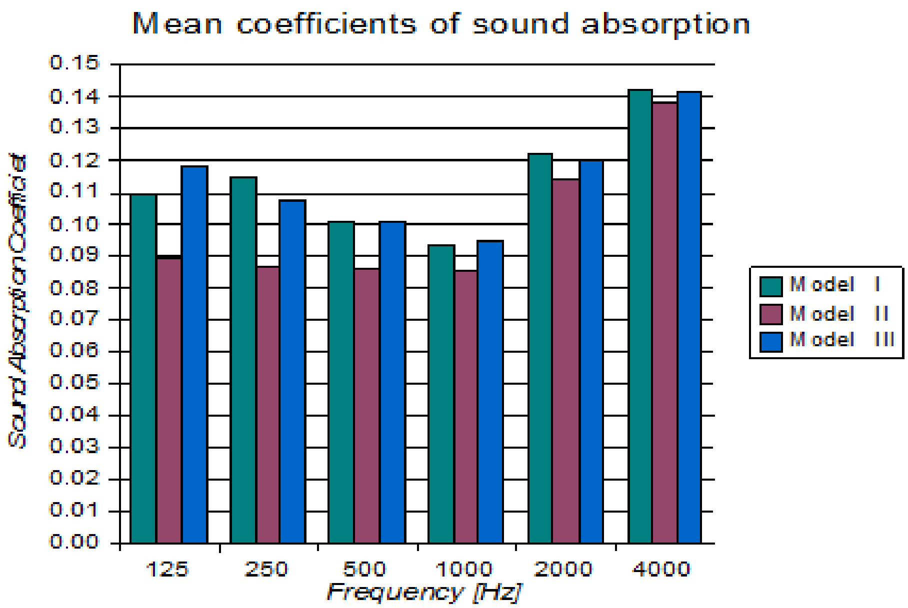

Figure 5. Average sound absorption coefficients for the three models of room

So, applying the modification suggested by Eq. (3) in Eq. (2) are found the values shown in Tab. 2.

Table 2. Values calculated by substituting the Eq. (3) in Eq. (2).

A = ∑ai*αi	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Model I	22.33	20.85	25.00	23.99	25.99	25.78
Model II	14.40	13.26	21.17	21.22	22.38	23.03
Model III	14.99	13.61	21.12	21.04	22.07	22.65

Applying the values shown in Tab. 1 and Tab. 2 in Eq. (1), are obtained the values for the reverberation time shown below in Tab 3.

Table 3. Values calculated by substituting the Eq. (3) in Eq. (2).

Reverberation Time	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Model I	1.48	1.58	1.32	1.38	1.27	1.28
Model II	2.01	2.18	1.36	1.36	1.29	1.25
Model III	1.93	2.12	1.37	1.37	1.31	1.28

You can see that the calculated values are well above those recommended by the standard.

Were also measured sound pressure levels in rooms of Model II for that, the rooms were divided into five points in an X, each point distant from each other by more than 0.50 m apart and all structural surfaces in more than 1.00 m. The equipment used was a decibel meter digital ICEL LD-4020, he was positioned 1.20 m high and made three measurements at each point in order to minimize errors. As a program signal generator software was used Sound Generator. The speakers were placed at the center of the room, the position of professor at a height corresponding to his mouth. With these data it can find the average sound pressure level of the rooms of Model II for each frequency value, the results are shown in Fig. 6.

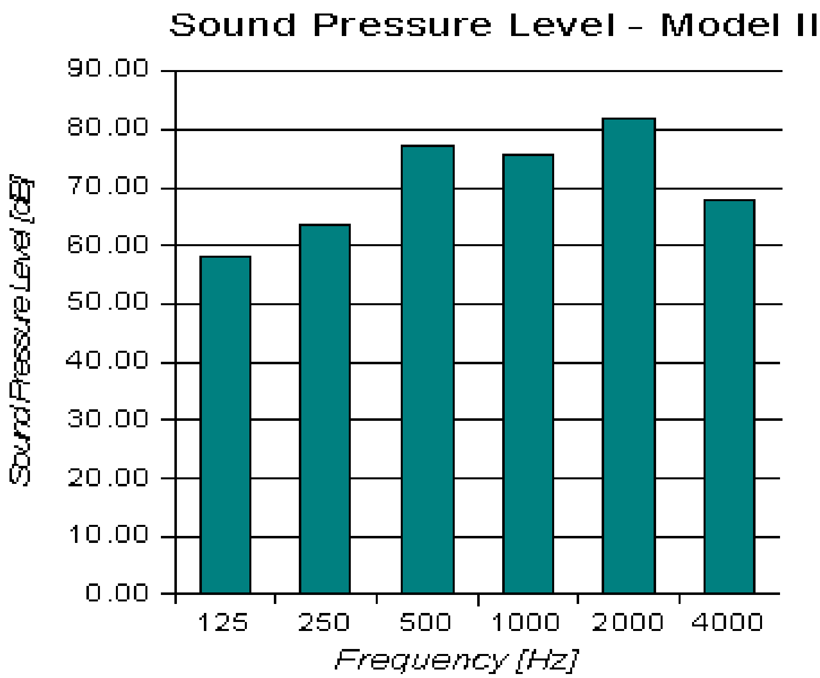

Figure 6. Average sound pressure level to the halls of the Model II

4. CONCLUSIONS

This paper presented a review of evaluation standards of acoustic environments, and also showed the theoretical calculation of the reverberation time of the classrooms of CEFET faculty, campus V. It was also the concepts of metrology involved in developing the project.

You can see that the values of the reverberation time calculated, shown in Tab. 3 are well above those recommended by the standard. These results may be related to the fact that classrooms were built with no thought to the acoustic quality of them and also because neither of them have been designed for the classroom.

The next step in the development of the project will determine whether there really has been a concern in the acoustic construction of buildings and a possible suggestion on how to improve the acoustic quality of these classrooms.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Albertazzi,A.G.Jr., Sousa, A.R.de, 2008, “Metrologia Científica e Industrial”, Ed. Manole, Barueri, Brazil, 428 p.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, NBR 10151: Acústica – Avaliação do ruído em áreas habitadas,visando o conrto da comunidade - Procedimento, Rio de Janeiro, 2000 , 4p.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, NBR ISO/IEC 17025: Requisitos gerais para a competência de laboratórios de ensaio e calibração, Rio de Janeiro, 2005, 31p.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, NBR 10152: Níveis de ruído para conforto acústico, Rio de Janeiro, 1987 , 4p.

Bistafa, S., Bradley, J., 2000, “Reverberation time and maximum background-noise level for classroom from a comparative study of speech intelligibility metrics”. Journal of the Acoustical Society of America, Vol. 107, No. 2, pp. 861-875.

Gerges, S.N.Y., 2000, “Ruído: Fundamentos e Controle”, 2nd ed., Ed. NR Colsultoria e Treinamento, Florianópolis, Brazil, 700p.

Harris, C. M., 1994, “Noise control in buildings”, Ed. McGraw-Hill Book Company, Nova York, U.S.A. .

Hohmann, R., Setzer, M. J., Wehling, M., 2004, "Bauphysikalische Formeln und Tabellen". 4th ed, Ed. Werner Verlag, Düsseldorf, German, 473p.

Inmetro, "Introdução", Instituto Nacional de Metrologia, Normalização e Qualidade Industrial. 15 Dec.2010 <http://www.inmetro.gov.br/metcientifica/>

Neubauer, R., 2001, "Classroom acoustics: do existing reverberation time formulae provide reliable values?", Proceedings of the Iinternational Congress on Acoustics, Vol. 17, Rome, Italy.

Tenenbaum, R. A., Camilo T. S., 2004, "Método Híbrido para simulação numérica de acústica de salas: Teoria, implantação computacional e validação experimental", I Seminário Música Ciência Tecnologia: Acústica Musical, São Paulo, Brazil.

Zannin, P. H. T., Ferreira, A. M., Zwirtes, D. P., Nunes, E. L.S., Stumm, S. B., Töws, M., 2005, "Comparação entre tempos de reverberação calculados e medidos", Ambiente Construído, Porto Alegre, Brazil, Vol. 5, No. 2, pp. 75-85.

Zwirtes, D.P.Z., 2006, "Avaliação do desempenho acústico de salas de aula: Estudo de caso nas escolas estaduais do Paraná ", Federal University of Paraná, Curitiba, Brazil, 141p.

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