Original Research Article

Determination of reverberation time and sound pressure level of selected lecture halls in University of Agriculture, Makurdi-Benue State, Nigeria.

ABSTRACT

***Aim**: Designing a lecture hall acoustics is a prestigious task which demands high accuracy of acoustical measures such as Reverberation time (T), Sound pressure levels (SPL) among other numerous parameters. In Nigeria however, little is considered about the acoustical environment on stages in lecture halls and how the design of environments are perceived by the users even though most international standards set optimum values of these parameters with respect to room volume and designed purposes.*

***Study Design:** This research has been conducted to examine the values of T and SPL of six selected unoccupied lecture halls in the University of Agriculture, Makurdi. Place and Duration: Department of Physics/ College of Science Federal University of Agriculture, P.M.B.2373 Makurdi-Benue State, Nigeria, between July 2017 to February 2018.*

***Methodology:** The linear dimensions (length,breadth and height) of each lecture hall and the surface areas of the absorbent materials per each lecture hall was measured using the measuring tape . The AutoCAD software was then used for volume computations.*
To measure the sound pressure levels (SPLs), equivalent sound pressure levels were registered at each selected point of the halls using a calibrated digital sound level meter (model Extech 407780) at wall distance of 1.00 m and intervals of 10 s in between.

***Results:** Reverberation Time values were calculated using Sabine's method. The mean value of T_{60} was found to be 1.66 s with a standard deviation of 0.36 s. The calculated SPL values were found to have a least value of 63.68 dB (A) in L4 while L6 has the highest value of a dispersion of 84.79 dB (A). In comparison with international guidelines, the reverberation time as well as SPL values found in these lecture halls were not within reference values of 0.40 ≤ T_{60} ≤ 0.80s and 35dB(A)≤ SPL ≤ 45dB(A) established by International Standard Organization (ISO) 3382, International Electro technical Commission (IEC) 60268 and World Health Organization WHO. Hence the results showed that the selected lecture halls do not meet the current standard of acoustic design set for public speech buildings.*

Keywords: reverberation time, sound pressure level, absorption coefficient.

1. INTRODUCTION

Reverberation time (T_{60}) is the period required by the reverberant sound to decay to one-millionth of its initial value. This naturally corresponds to a drop of 60dB [14]. The selection of correct interval of reverberation is called the optimum reverberation time and it depends on the use of the room [13]. If the reverberation time is too long, it results in overlapping of speech and if too short, it produces the effect of deadness [14]. Reverberation is caused by multiple reflections of sound waves from walls, ceilings, or windows. These reflections generate delays by slightly modifying or attenuating the spectral copies of the original source signal. This reduces and further degrades speech intelligibility in quiet and noisy situations [13]. Nowadays, most of the lectures in Nigerian Universities occur in lecture halls (enclosed spaces), where the sound waves are reflected from the walls, window panes, ceilings, and floor giving rise to the phenomena of reverberation [11]. Reverberation time varies between positions in a room, so it is usually measured at several positions. The average then gives an overall assessment which indicates the acoustic quality as a function of location [4]. In view of the significant benefits to acoustics of auditoria, reverberation time is strongly influenced by the absorption coefficients of the surfaces [6] as well as the volume of the room [1,2,3,7,13,14]. Reverberation time should be negligibly small in a good lecture hall. Previous research works showed that typical reverberation time ranges from about 0.4 s to 4.0 s in lecture halls and more in concert halls or churches [12]. Since architectural design in institutions of learning often do not consider these values, it is pertinent to investigate the acoustic parameters of lecture halls in University of Agriculture Makurdi, as these remotely affect the outcome of a learning process.

1.1 Sound Intensity

The intensity of sound is the flow of sound energy per unit of time through unit area. Frequency is a measure of the quality of sound energy. The intensity of sound is purely a physical quantity which can be accurately measured since the human ear cannot perceive low-and-high frequency sounds. [14].The intensity of sound is measured on a logarithmic scale due to its wide range of variations.

Equation 1 gives the sound intensity levels in decibels.

Sound pressure level, denoted L_p and measured in dB, is defined by:

$$L_p = 20 log_{10}(\frac{P}{P_0}) \text{ dB} \quad (1)$$

where

p is the root mean square *sound pressure*

p_0 is the *reference sound pressure*;

The commonly used reference sound pressure in air is:

$P_0 = 20\mu P_a$

1.2 Sound Pressure Level

Sound pressure level (SPL) is the ratio of the absolute, sound pressure and a reference level usually the threshold of hearing. SPL is measured in decibels (dB), because of the incredibly broad range of intensities human can hear. The human ear cannot perceive low-and-high frequency sounds as they perceive sounds between 3000Hz and 4000Hz hence the reason that frequency response of human hearing changes with amplitude. Therefore, two weightings for measuring sound pressure levels have been set as A and C, where A - weighting applies to SPLs up to 55 dB and C-weighting applies to SPLs above 55 dB. In order to distinguish the different sound measures, a suffix is used: A-weighted SPL is written as dB (A) or LA and C-weighted SPL is written as dB(C) or LC. Other sound measuring instruments use "Z" to indicate linear SPL. In situations of ambient environmental measurements of "background" noise, distance need not be quoted as no single source is present. However, measurement of noise level of specific equipment needs distance specification. A minimum distance of 1.00 m from the source is commonly used. Thus, the equivalent SPL can be calculated using (2)

$$L_{eq} = 10\log\left[\frac{1}{n}\sum 10^{P_i/10}\right] \text{ dB(A)} \quad (2)$$

where L_{eq} is the equivalent sound pressure level in dB(A); P_i is the sound pressure level measured at each moment "i", in dB(A); n is the total number of measurements [14].

1.3 Theory of Reverberation Time

Reverberation time measurement is used to estimate the required time for the sound signal to "fade away". That is for the sound pressure to reduce by a predefined value. T_{60} is the standard reverberation time measurement and is defined as the time it takes for the sound pressure level to reduce by 60dB, measured from the moment the generated test signal is shortly ended [13] Reverberation time can be estimated using various methods such as; ray tracing method, Eyring's method, Sabine's Method among others. The famous Sabine's formula for estimation of reverberation time (T_{60}) in rooms [13] as used in this work is stated in equation 3.

$$T_{60} = \frac{0{,}161 . V}{A} \quad (3)$$

where v is the room volume (m^3) and *A – is acoustic absorption of the room.*

2. MATERIALS AND METHODS

2.0 Materials

The materials used for measurements in this research work are:

Measuring tape (YUE BAO: 0-30 m), Samsung galaxy stops watch (model SM G920I), Sound level meter (Extech 407780-EN v 2.3), Microphones, Tripod, Thermometer (0-100℃), AutoCAD software, D.C source (AAA 1.5 volts × 4), Global positioning system.

2.1 Study Area/Sample Space

The research was carried out in the Federal University of Agriculture, Makurdi using six (6) lecture halls. The selected lecture halls are listed in Table 1 with their respective location within the University.

Table 1: Selected Lecture halls in University of Agriculture, Makurdi

Code	Lecture Hall	Capacity (seats)	Location
L1	Science Lecture Theatre	1000	N 7.7677°, E 8.6218°
L2	Engineering Lecture Theatre	1000	N 7.7921°,E 8.6188°
L3	Engineering Auditorium	510	N 7.7903°, E 8.6201°
L4	Aper Aku Auditorium	811	N 7.8000°, E 8.6163°

L5	Block A91	180	N 7.7659°, E 8.6211°
L6	Block B19	154	N 7.7656°, E 8.6219°

2.1.1 Lecture halls descriptions

The lecture hall L1 has a seating capacity of 1000 seats with 100 tables and designed for courses. The shape is an irregular hexagon with height of 6.65 m, and the interior partitions are double plaster wall. The room contained a large white board (2.40 m x 1.20 m) and large windows (2.38 m x 1.75 m); small windows (2.38 m x 1.15 m) on the side walls. The lecture hall also contained suspended particle board ceiling (0.60 m x 0.60 m) however 23 pieces have removed. It has 34 ceiling fans. The floor is covered with a concrete (terrazzo).

The lecture hall L2 is of the same designed, dimensions and description with L1 but has 24 pieces of the particle board ceilings removed thereby creating more empty spaces in it than L1.

The lecture hall L3 has a seating capacity of 510 seats with 54 tables and designed for courses. The shape is an irregular hexagon with height of 5.24 m, and the interior partitions are double plaster wall. The room contained a large white board (2.45 m x 1.24 m) and a plastic board (1.40 m x1.20 m); large windows (3.20 m x 2.32 m), semi-large windows (3.20 m x 1.80 m), medium windows (3.20 m x 1.16 m), small windows (1.80 m x 1.70 m), two large doors (2.00 m x 1.32 m) and two small doors (2.00 m x 0.85 m) on the side walls. The lecture hall also contained suspended particle board ceiling (0.60 m x 0.60 m). The floor is covered with a concrete (terrazzo). A photograph of L3 can be seen in Figure 1.

Figure 1: Picture of L3

The lecture hall L4 has a seating capacity of 811 seats with 55 tables and designed for courses. The shape is an irregular octagon with height of 8.99 m, and the interior partitions are double plaster wall except the side opposite the white board/ stage which is a wooden wall (14.10 m x 5.30 m). The room contained a white board (1.84 m x 1.26 m) and a trace board (1.60 m x1.20 m); large windows (2.10 m x 1.26 m), semi-large windows (1.50 m x 1.46 m),small windows (1.45 m x 0.60 m), and rover windows (1.22 m x 1.22 m); it has six metal doors (2.50 m x 1.70 m) and two small doors (2.00 m x 0.85 m) on the side walls and trapezoidal wooden stage of area 32.02 m^2 comprising of wooden staircase (1.90 m x 0.20 m). The lecture hall also contained suspended particle board ceiling (0.60 m x 0.60 m) however 10 pieces of this dimension have been removed. It has 21 ceiling fans. The floor is covered with a concrete (terrazzo). A photograph of L4 can be seen in Figure 2.

Figure 2: Picture of L4

The lecture hall L5 has a seating capacity of 180 seats with 30 tables and designed for courses. The shape is ordinary rectangle with a height of 3.00 m, and the interior partitions are double plaster wall. The room contained a large white board (2.40 m x 1.20 m), large windows (4.65 m x 1.50 m), small windows (1.50 m x 1.50 m), and two metal doors (2.35 m x 1.50 m). The lecture hall also contained suspended Brazilian ceiling (0.60 m x 1.20 m for one). The floor is covered with a concrete (terrazzo) and has 8 ceiling fans.

The lecture hall L6 has a seating capacity of 154 seats with 22 tables and designed for courses. The shape is ordinary rectangle with a height of 3.40 m, and the interior partitions are double plaster wall. The room contained a large white board (2.40 m x 1.20 m), large windows (4.85 m x 1.20 m), two other windows (4.30 m x 1.20 m), and two metal doors (2.10 m x 0.90 m). The ceiling is a double concrete plaster of area 104.36 m^2 with 8 ceiling fans. The floor is covered with concrete plaster (terrazzo).

2.2 Methodology

Volume and area measurements

To evaluate the volume of each lecture hall, measuring tape was used to measure their linear dimensions. The AutoCAD software was then used for volume computations.

Reverberation time computation

The reverberation time (T) in each hall was evaluated using (3): $T_{60} = \frac{0,16 .V}{A}$

The respective absorption coefficients (α) of the material surfaces were adapted from ISO 3382-1, 2009 [14].

Measurement of sound intensity level

To measure the sound pressure levels (SPLs), equivalent sound pressure levels were registered at each selected point of the halls using a calibrated digital sound level meter (model Extech 407780) at wall distance of 1.00 m and intervals of 10 s in between. SPL was then calculated using equation (2).

Sound pressure level-SPL computation

The SPL values were measured in each lecture hall and equivalent SPL (L_{eq}) in each hall calculated using equation (2): L_{eq}=10log $[\frac{1}{n}\sum 10^{P_i/10}]$ dB (A)

3. RESULTS AND DISCUSSION

3.1 Results

In this section, the results of the measured items and computed values per each lecture hall selected are presented. Table 2 gives the summary of the measured surface areas, volumes and total absorptions in these halls.

Table 2: Selected lecture hall surface areas, volumes and total absorptions

Lecture hall	Volume/m^3	Volume/seat m^3	Absorption surfaces with their areas in m^2												Total absorption m^2-sabin
			Doors	Windows	Switches	White board	Table Tops	Ceilings	Floor area	Lecture's stand	Walls	Distribution boards/change over	Speakers	Ventilators	
L1	4853.04	4.85	22.00	111.65	1.57	2.88	136.00	809.64	942.34	-	5654.04	0.58	-	-	394.2694
L2	4853.04	4.85	22.00	111.65	1.57	4.35	136.00	809.28	942.34	6.42	5654.04	2.54	0.41	-	391.0615
L3	2093.65	4.11	8.72	95.24	5.51	3.04	76.14	398.79	398.79	-	2392.74	12.52	0.41	-	191.9704
L4	8206.94	10.12	28.9	117.4	1.73	4.24	93.57	912.89	880.88	-	7419.49	-	0.74	8.79	712.9500
L5	547.73	3.04	7.05	36.68	0.28	2.88	54.08	182.58	182.58	9.59	479.7	-	-	-	91.5100
L6	354.83	2.30	3.78	21.96	0.19	2.88	35.36	104.36	104.36	6.42	349.28	2.88	-	-	39.4900

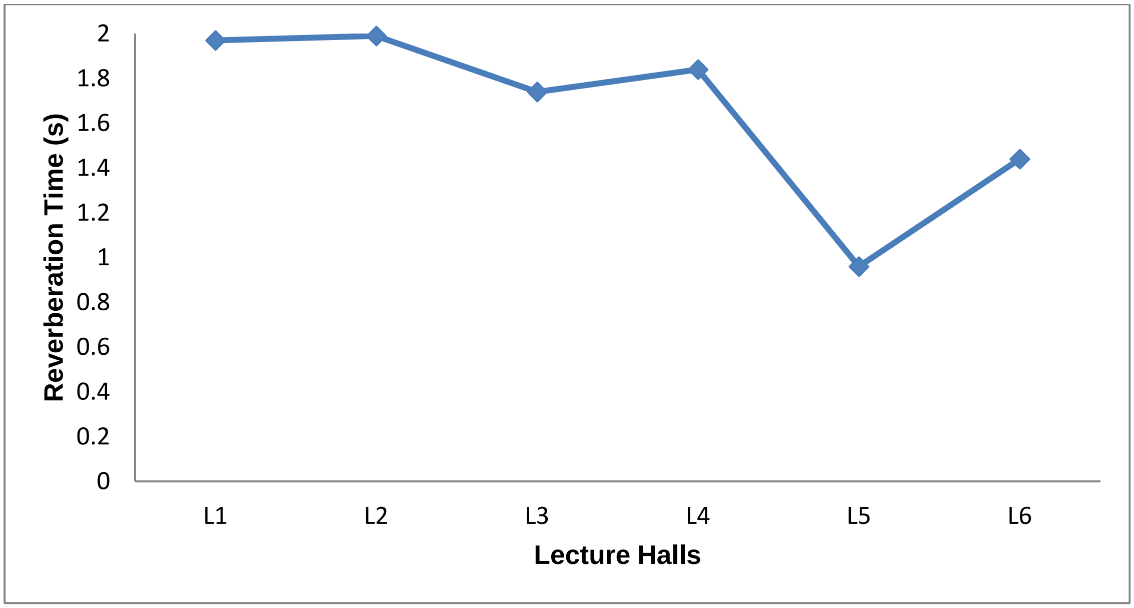

Figure 3: Reverberation Times calculated per Lecture Halls

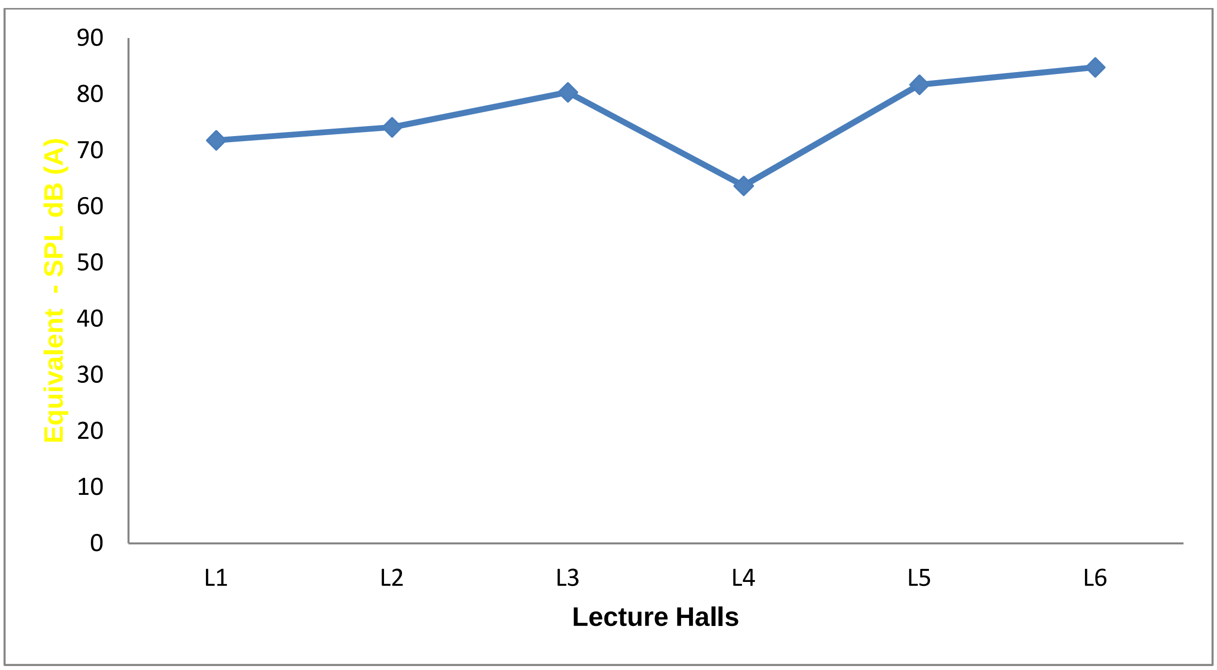

Figure 4: Equivalent SPL measured in Lectures halls

3.2 Discussion

Figure 3 shows the reverberation time values in each selected lecture hall. These values were found to range 0.96 s and 1.99 s with L2 having the highest value of 1.99 s and L4 having the lowest value of 0.96 s. The mean value $\bar{T}$ of this range is 1.66 s and the standard deviation of 0.36 s was recorded indicating dispersion. These values are above the values set by ISO3382 and IEC 60268 for lecture hall design. The result also conform with similar works of [8] in which their study result gives the maximum value of reverberation time (T) as 1.29 s above the WHO range of 0.4 s – 0.8 s recommended standard values of T for lecture halls while evaluating the acoustic comfort of lecture halls in Lund University, Sweden. The mean value, 1.66s of T is also above [9] values of T which establishes the range 0.4 s- 0.6 s for 'good' intelligibility to normal speech and normal hearing to be achieved in lecture halls. Hence, these values provide a relative indication of poor listening conditions in these halls. Their value differences are attributed to high level of background noise and different absorbing materials employed.

The equivalent sound pressure level (SPL) results in Figure 4 show a range between 63.68 dB(A) and 84.79 dB(A) with L4 having the least value of 63.68 dB(A) and L6 having the highest value of 84.79 dB(A). Therefore, regarding parameters set by ISO 3382, IEC 60268 and WHO; values of SPL found in each lecture hall were above the recommended set standard values in the range 35 dB(A) – 45 dB(A) for lecture hall environment.

4. CONCLUSION

In this work, lecture hall acoustic parameters relating to reverberation time (T) and sound pressure level (SPL) have been determined in six selected lecture halls of the University of Agriculture, Makurdi. The results obtained were compared to the design goal. The method of Sabine was used in computing reverberation time and from the results only L4 offers a relatively closer reverberation time of 0.96 s with respect to ISO3382 and IEC 60628. This is due to greater amount of absorbent materials employed in the surface finishing of L4 as compared to the other lecture halls. However, improvement in the absorption of materials still needs to be done in L4 and other lecture halls in order to meet the acceptable set range of 0.4 s – 0.6 s in lecture hall design [15]. Sound pressure levels (SPL) values found from this research in each lecture hall are all above the recommended values set by ISO 3382, IEC 60268, WHO and NBR 10150/2000 which establishes values in the range 35-45 dB(A) during day times in schools. This high level of unwanted background noise is the possible predominant cause of speech masking which decreases speech intelligibility in these lecture halls. Finally, the results obtained from this study show that the presence of acoustic treatment was not noted as of the time of designing the lecture halls in the Federal University of Agriculture, Makurdi as recommended by international standard bodies. However, the designers care much about ventilation since each lecture hall has wider window openings as our region is tropical.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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