
Full Paper

SPEECH INTELLIGIBILITY OF LECTURE THEATRES IN OBAFEMI AWOLowo UNIVERSITY, ILE-IFE, NIGERIA

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ABSTRACT

This work measured the speech intelligibility of lecture theatres in Obafemi Awolowo University (OAU), Ile-Ife, Nigeria using the Rapid Speech Transmission Index (RASTI) and Speech Transmission Index for Public Address (STIPA) methods. These methods are objective speech intelligibility measurement methods and they have been used in this work to determine definite and quantitative speech intelligibility values of lecture theatres in OAU unavailable before. RASTI is known to overestimate values when public address systems are involved and this was also observed to be true in this work. STIPA values are therefore recommended for making decisions related to speech intelligibility of the lecture theatres while RASTI values were evaluated for record purposes. Lecture theatres with architectural designs that minimize reverberation in addition to good interior acoustic enhancements were observed to have higher RASTI and STIPA values than lecture theatres with poor architectural design and poor acoustic enhancements.

1. INTRODUCTION

Other factors apart from the loudness level of speech can affect the comprehension of words by listeners. The major factors that affect comprehension of speech are noise and reverberation time. While noise is due to the presence of other sound sources (and/or external bodies), reverberation is due to the reflection of the original speech waveform by the walls and other structures in a room. Greenland, Shield and Dockrell (2009) stated that "design criteria for speech intelligibility in enclosed spaces are widely expressed as combinations of maximum background noise levels, and maximum mid-frequency reverberation times, assuming that students are quiet and listening to

the teacher during lessons". Noise and reverberation times should be closely observed in the evaluation of speech intelligibility in a room designed for receiving lectures.

The measure of how well speech is understood or comprehended is termed *Speech Intelligibility*. Speech intelligibility is also defined as the score attained by live listeners to a live talker over a sound system (Davis and Patronis, 2006). When noise level is high and reverberation time is long in a room, the speech signal will be coloured by these interfering signals, making it difficult for listeners to comprehend what is being said. If the ambient noise level in a space is only 15dB below speech level, most listeners will have no trouble understanding the message, but many of them will complain about the noise level (Eargle and Foreman, 2002). Even though the noise level might be at an acceptable level for good word recognition in a room, the reverberation due to the make-up of the room might be excessive, leading to poor speech intelligibility in that room. Therefore, there is a need to measure the speech intelligibility in a room designed for teaching regardless of the noise level, in order to determine the suitability of the room for teaching. The speech intelligibility measurements obtained can be used as a basis for deciding on the need for improvement in acoustic enhancements in the room or otherwise.

This work measured the speech intelligibility of lecture theatres in Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria using two objective methods: Rapid Speech Transmission Index (RASTI) and Speech Transmission Index for Public Address (STIPA).

2. SPEECH INTELLIGIBILITY MEASUREMENT TECHNIQUES

Formerly, speech intelligibility was measured only by using lengthy word-lists and a group of live listeners. However, today there are accurate and rapid methods of measuring intelligibility using acoustic instruments (Davis and Patronis, 2006). Intelligibility measurement and assessment techniques can be divided into two categories: subject based measures and objective acoustic measures of a parameter or parameters that correlate with some aspect of perception (Ballou, 2002). In subjective methods, trained speakers and listeners are used in the estimation of speech intelligibility. The speakers may be required to pronounce phonemes, syllables, words and/or sentences while the listeners respond. The response may be open or closed, for the open response case, the listener is required to respond to what he believes he heard. While, the listener must choose from a fixed number of options in the closed case, even when he presumably heard something not included in the options. At least four speakers and listeners are required for a useful estimation of speech intelligibility. This implies that a total of 16 speaker/ listener pairs are required.

A typical form of subjective testing is the syllabic testing. Syllabic testing is an accurate but tedious procedure (Eargle and Foreman, 2002). Intelligibility also depends on the acuity of individual listeners' ears; this makes it difficult to reproduce similar results for the same room when different sets of individuals are used for the test.

Objective methods are machine-based measurements of speech intelligibility. Speech intelligibility is estimated by using an

equipment that observe changes in certain features of the speech signal on reaching the listener position, and specifies the speech intelligibility value based on the observed changes. Usually, a sound source is placed at the speaker position while the intelligibility equipment is placed at the listener position.

One of the earliest objective methods of measuring speech intelligibility is the Articulation Index (AI) method. AI is based on the principle that the response of a speech communication system can be divided into twenty different bands. Each band has a distinct contribution to the overall speech intelligibility of the system. The contribution of each band is computed from a weighted value of the signal-to-noise ratio in that band. The overall speech intelligibility is the average of intelligibility taken over the twenty bands. Speech intelligibility is measured from 0 (completely unintelligible) to 1 (perfect intelligibility). AI does not account sufficiently for reverberation and other time-domain distortions. It has therefore been replaced by newer methods like the Speech Transmission Index (STI) method.

Speech Transmission Index (STI) is a machine measure of speech intelligibility that utilizes a speech-like test signal derived from a combination of 98 different waveforms. The 98 STI waveforms are generated by modulating (100% amplitude modulation) seven waveforms (one from each of seven octave bands ranging from 125 Hz to 8 KHz) by 14 different sinusoidal waveforms with frequencies ranging from 0.63 Hz to 12.5 Hz. The loss of modulation, known as the Modulation Transfer Function (MTF) is evaluated in each of the waveforms by comparing the received signal with the test signal and converting the MTF values into signal-to-noise values which are then averaged and normalized. The speech intelligibility is also measured from 0 (completely unintelligible) to 1 (perfect intelligibility).

STI has gained international acceptance as a useful measure of the ability of a transmission path to faithfully transmit speech intelligibility (Leembruggen, Hippler and Mapp, 2009). However, the standard STI takes about 15 minutes to be evaluated. Fortunately, simplified versions of the STI are now available that can be evaluated in about 15 seconds. These versions use fewer waveforms than the standard STI and the most common are Rapid Speech Transmission Index (RASTI) and Speech Transmission Index for Public Address (STIPA).

RASTI is a subset of STI. The RASTI method only considers the two octave bands 500 Hz and 2 kHz and each band is modulated with four and five frequencies respectively, making a total of 9 combinations (Bjor, 2009). The RASTI test signal is therefore a composite signal comprising 9 waveforms. Speech intelligibility is also obtained by computing MTF for the waveforms and mathematically combining these values to obtain a single value between 0 and 1. STIPA is a more comprehensive subset of STI than RASTI. The STIPA test signal is also a composite signal like the RASTI test signal, but the 9 waveforms in this case span all the octave bands from 125 Hz to 8 KHz specified for the full STI measurement.

When noise that is present is not correlated to the octave bands at which RASTI is calculated the modulation is not influenced and this leads to overestimation of the speech intelligibility (Zeilstra, 2009). RASTI does not account for distortion in time domain which can be present with the use of public address systems. It is best suited for person-to-person communications. For these reasons, STIPA which is more comprehensive and accurate than RASTI is recommended for making decisions pertaining to speech intelligibility of the lecture rooms. However, RASTI values were also evaluated for record purposes. STIPA handles reverberation in the room and distortions commonly found in public address systems. It delivers results closer to the values obtained by the full STI method (Bjor, 2009).

3. EXPERIMENTAL PROCEDURE

The speech intelligibility tests – RASTI and STIPA – were carried out using proprietary equipment called *Sencore SP495 Sound Pro Audio Consultant* in 14 different lecture theatres. The Sencore SP495 Sound Pro Audio Consultant (shown in Fig.1) is a high quality audio

and acoustic analyser for design and consultation. It provides over 25 multiple audio analysing features including speech intelligibility, noise curves, signal generation, sound pressure level and impulse recorder. All functions, filters, and processing of the SP495 Audio Consultant are implemented in DSP firmware algorithms. The SP495 Audio Consultant can operate over the frequency range of 20 Hz to 22 KHz with a level resolution of 0.1 dB.

The speech intelligibility tests were carried out with a loudspeaker connected to a laptop (playing the RASTI or STI-PA test signal) acting as the sound source. For every reading taken, a measurement microphone connected to the Audio Consultant (placed at the listener position) received the sound signal. The Audio Consultant computes the Modulation Transfer Function (MTF) for each constituent waveform from the received signal and displays the RASTI or STIPA value. Two readings were taken for both RASTI and STIPA measurements in each lecture theatre. The readings were taken at the middle and back of the rooms with the sound source situated at the front of the rooms as suggested in the Audio Consultant Manual and also done by Zeilstra (2009).



Fig. 1. Sencore SP495 Sound Pro Audio Consultant

3.1. RASTI Measurements

RASTI values were estimated at the middle and back of each lecture theatre according to the following procedures:

1. The RASTI test signal CD was inserted into the CD drive of a laptop connected to a loudspeaker. The location of the loudspeaker was termed the “speaker location”.
2. The Audio Consultant was placed at the listener location and a microphone was connected to it. The microphone received the sound signal from the loudspeaker and converted it to the corresponding electrical signal which is the input signal to the Audio Consultant.
3. The sound level of the test signal received at the listening location was set to fall between 75 – 85dB (this is the nominal listening level) by using the Sound Pressure Level (SPL) meter function on the Audio Consultant. Slow averaging was used for the SPL measurements as it averages the transients and provides the best indication of the sound level that the human ear hears (Sencore Operational Manual).
4. The RASTI function was then selected on the Audio Consultant menu to compute the RASTI value.
5. The ON/OFF field was selected to change “OFF” to “RUN” to evaluate the speech intelligibility value.
6. After some seconds, the RASTI value was displayed on the screen.

3.2. STIPA Measurements

STIPA values were also estimated at the middle and back of each lecture theatre using similar procedures to that used for the RASTI evaluation, except that the test signal was the STIPA test signal.

4. ARCHITECTURAL DESCRIPTION AND ACOUSTIC TREATMENT OF LECTURE THEATRES

4.1. The Ajose Lecture Theatre (AJSLT)

The essentially pentagonal shape of this auditorium (shown in Figs. 2 and 3) has been modified by converting the flanks into accordion-fold sections of alternating window and wall segments. This design articulation ensures there are no runs of parallel walls (which would have negatively impacted on the acoustic environment).

Acoustic treatment concentrates on ceilings and walls of the podium area, as well as the rest of the hall. In the podium area, wall treatment consists of 45mm-wide hardwood timber slats with 40 mm in-between spacing, on a plywood base; while the rear flanks and end wall, feature similar slats on mineral-wool ("fuzz") cladding. Ceiling treatment over the podium consists of triangularly-shaped acoustic panels, angularly suspended over the area. In the rest of the auditorium, polished timber panels are arranged in groups, with each group angularly-sloped and alternating with other groups sloping in the opposite direction. At the rear, the panels are beveled and also perforated. With these provisions, it was envisaged that there would

be adequate absorption and appropriate reflection of sound for effective speech intelligibility.

4.2. Science Lecture Theatres

The Science Lecture Theatre complex features two auditoria, similar in design, but of varying capacities; the study analysed PY 102, the smaller of the two. It is a rectangular structure with severely raked seating, a stage area with exaggerated headroom, and a sitting area with parallel wall runs; the podium is flanked by short runs of angular walls (as shown in Figs. 4 and 5).

The stage area is panelled with 300 mm wide plain plywood planks, encompassing the flanking walls, and up to above the two front doorways into the auditorium. The rear and main flanks are treated with 50mm x 12mm studs (bevelled from bottom up), on a fibre-board base, with 35mm in-between spaces. Acoustic treatment of the ceiling is uniform over the whole hall, and consists of 300 x 300 mm corrugated chipboard tiles on 50 x 100 mm hardwood noggins, at 300 mm centres. The acoustic treatment of the walls and ceilings of this room minimize multiple reflections that can adversely affect speech intelligibility by absorbing sound energy impinging on them.

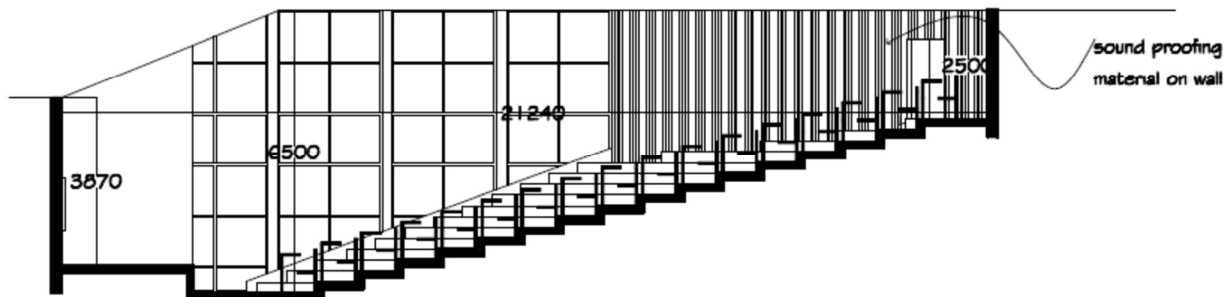


Fig. 2 Ajose Lecture Theatre Section

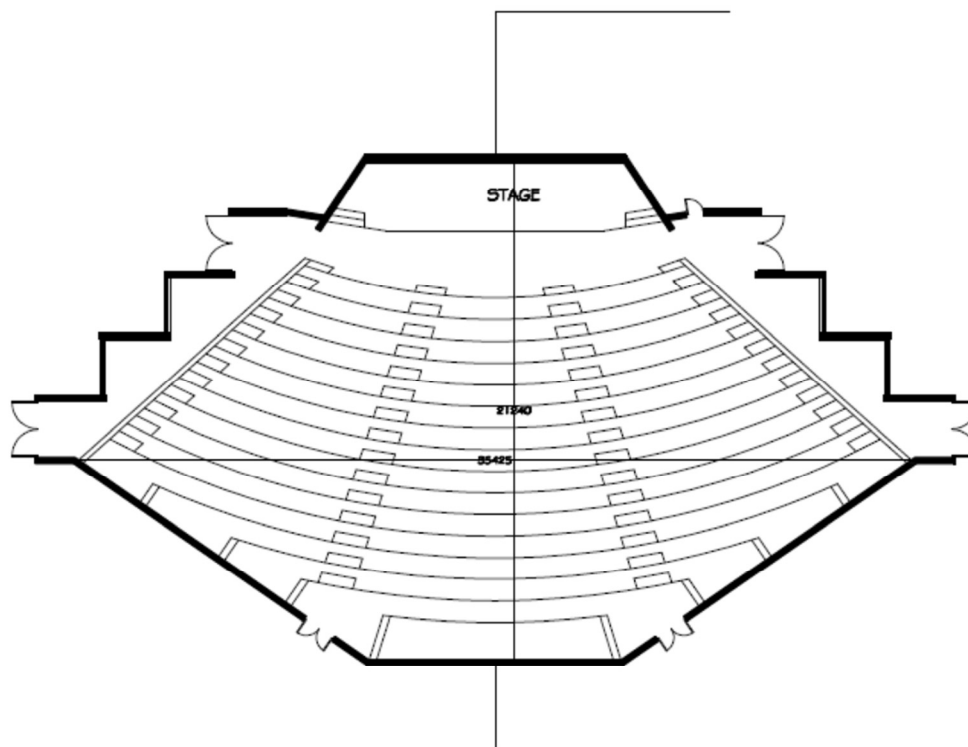


Fig. 3: Ajose Lecture Theatre Plan

4.3. Biological Sciences Lecture Theatres



The complex features three octagonal lecture theatres, of varying seating capacities; the largest, BOOC (shown in Figs. 6 and 7), was the subject of the study. In each case, the octagon is irregular, with the flanks, front and rear walls slightly longer than the remaining four wall-segments. This arrangement produces limited lengths of parallel-running walls – limiting the possibility of reflected sound that could worsen intelligibility.

Acoustic treatment of the stage area is the same as that of the rear wall of the auditorium, and comprises hardwood-timber plank panelling, grooved into 75mm slats.

The ceiling over this area consists of hardwood, overlapping slats, sloping upward from the blackboard, to meet a suspended ceiling over the central area of the auditorium.

The 1,200 x 1,200mm asbestos-cement sheets on timber noggins, constitute the finish to this suspended ceiling in which installations

for artificial sound amplification are embedded. There are floor-to-ceiling louvre windows in the two flanking walls. Unfortunately, the remaining four walls defining the framework of the auditorium have been denuded of acoustic treatment. Nevertheless, it is apparent that, initially, the walls were once finished with timber slats on some fabric (presumably felt) base.

4.4. Humanities Lecture Theatres (Auditorium I & II)

Each of the two Humanities auditoria (AUD I and AUD II) has a rectangular floor plan, with the usual lecturer’s podium in front, and a projection-room at the rear (Figs. 8 and 9). Wall treatment is varied in form (though not significantly in material). In the stage area, the section above the chalk-board is paneled in plain plywood;

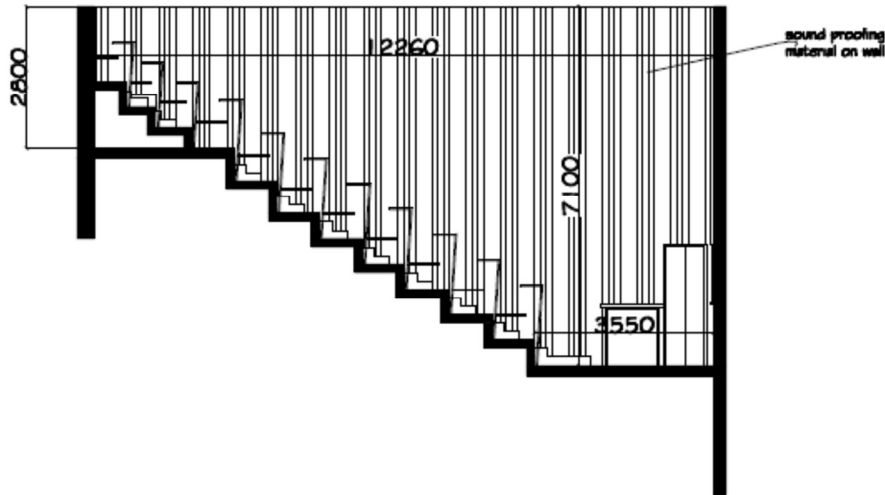


Fig. 4: Physics (PHY 102) Lecture Theatre Section

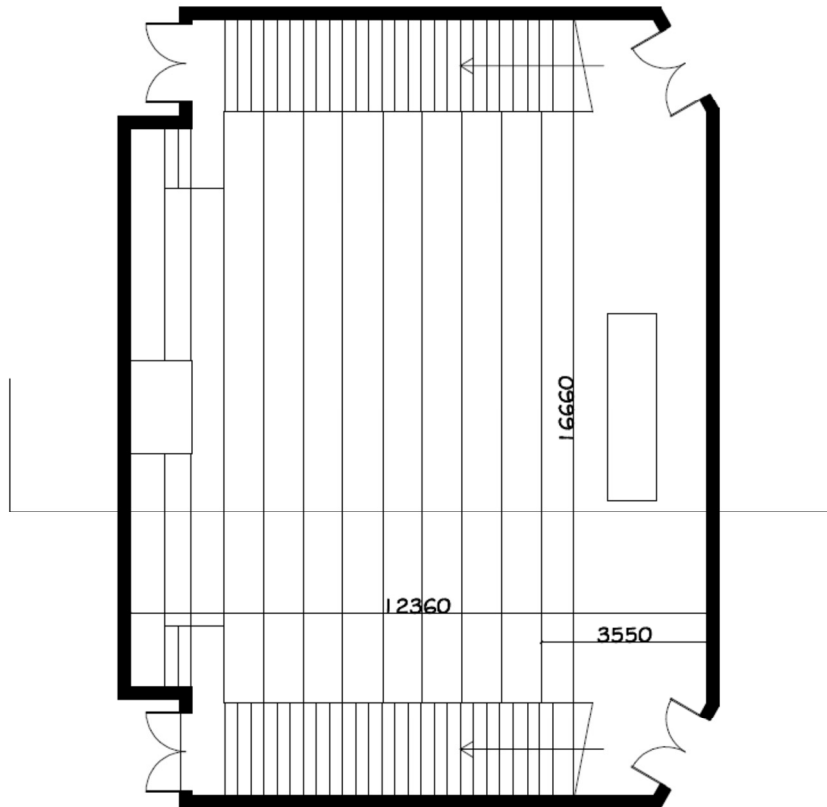


Fig. 5: Physics (PHY 102) Lecture Theatre Plan

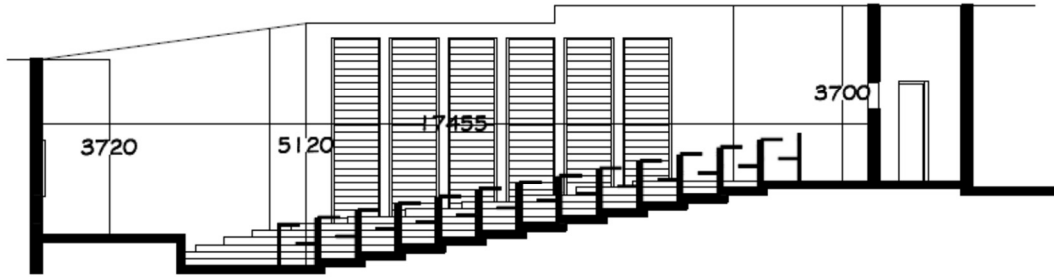


Fig. 6: BOOC Lecture Theatre Section

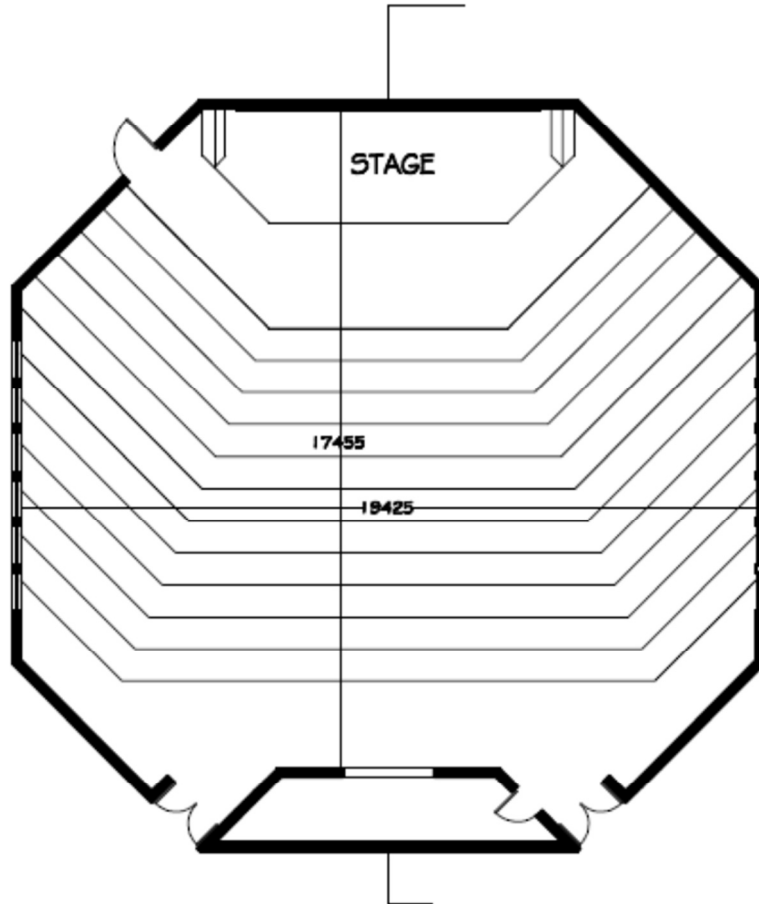


Fig. 7 BOOC Lecture Theatre Plan

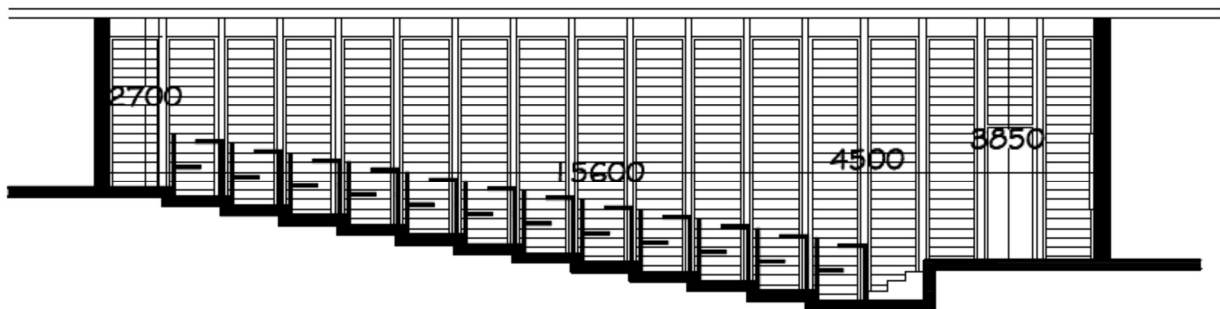


Fig.8: AUD I and AUD II Lecture Theatre section

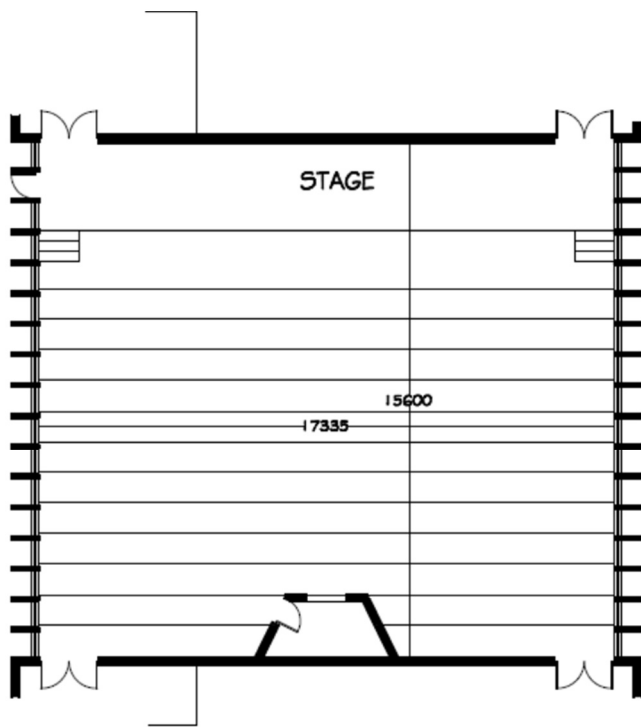


Fig. 9 AUD I and AUD II Lecture Theatre Plan

below, the finish is veneer-covered plywood. At the back of the hall – and excluding the projection-room area – 600mm-wide plywood panels provide cladding for the wall; paneling for the projection-room area comprises 150mm timber panels.

With 17 sets of floor-to-ceiling louvre windows on the flanks (separated by 100x 900mm reinforced concrete fins), the architectural configuration approximates a covered, but un-enclosed (tent) setting. The peculiar acoustics of this class of form is complemented by the use of glossy and reflective poly-vinyl chloride (PVC) slats as ceiling finish.

4.5. Oduduwa Lecture Theatres

The two Oduduwa Lecture Theatres are converted facilities in the Obafemi Awolowo University teaching spaces pool. Unlike the other lecture theatres (which were purpose-built teaching facilities), the ODLT auditoria were created by adapting free space under the raked seats of the Oduduwa Hall amphitheatre complex. As such, in general articulation, each of the two theatres is a-typical of the typology and characterized by unique vestigial features such as a tiered concrete ceiling and intervening concrete supports. Basically, these features constituting the structural supports of the amphitheatre above, define the spatial configuration of the lecture space (as shown Figs. 10 and 11). With the above seating area sloping down to the stage area, the headroom here is unusually low, and somewhat inadequate; the supporting beams of the raked seating above, converge on this area with a writing surface which is necessarily curvilinear (to reflect the orchestra area in the amphitheatre above); the tyrolene wall finish undoubtedly has implications for acoustic perception. Fan-shaped flanking wall segments consist of sandcrete block partitions, with matt-textured paint finish; louvre windows complement these wall sections. The rear of the fan-shaped hall comprises 12 window sections, framed by textured sandcrete party-walls.

4.6. Social Sciences Lecture Theatre (SSLT)

The Social Sciences Lecture Theatre (SSLT) (shown in Figs. 12 and 13) is a relatively small lecture hall, integrated into the ground floor of the Social Sciences general offices/ classrooms complex. It is

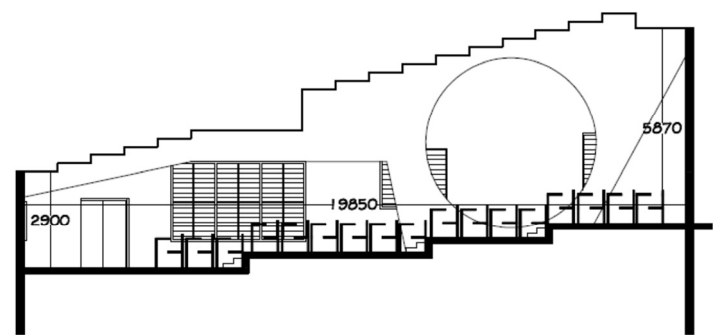


Fig. 10 ODLT Lecture Theatre Section

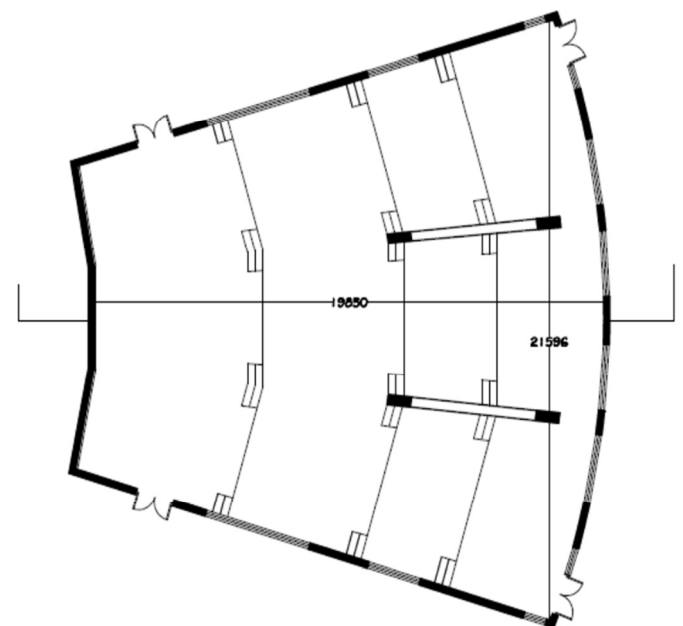


Fig. 11 ODLT Lecture Theatre Plan

rectilinear, with a volume that constitutes a rectangular pyramid frustrum i.e. the flanking walls slope inwards from bottom, halfway upwards, with louvre windows making up the rest of the wall segments; these walls are bare of any acoustic treatment.

In the stage area, 600mm-wide plain plywood panels constitute soffit treatment. At the rear of the theatre, 450mm timber slats alternate with 400mm gaps featuring some fabric-covered mineral-wool base. Ceiling treatment throughout the hall comprises 35mm timber slats on a plain plywood base.

4.7. Health Sciences Lecture Theatres (HSLT)

Similar in spatial configuration to the octagonal Biological Sciences lecture theatres, HSLTC (shown in Figs. 14 and 15) is the largest of three teaching spaces in the Health Sciences complex. The stage wall constitutes one end of the space, and the opposite end the entrance. The two parallel flanks – of an equal run as the other wall segments – provide floor-to-ceiling fenestration, with the glazing interrupted by 100 x 900mm reinforced concrete fins.

The walls are totally devoid of any acoustic treatment. The only consideration given to non-electronic acoustic performance appears to be with respect to the elaborate suspended, “egg-crate ceiling”, uniformly provided over the whole auditorium; this is expected to produce differential reflection of sound. The egg-crate comprises perpendicular timber frames (of about 1,500 x 1,500mm), criss-crossed by diagonals; the timber panels are 750mm-deep, with the diagonals recessed to accommodate fluorescent tubes, providing artificial lighting with minimum glare.

sound proofing
material on ceiling
and rear wall

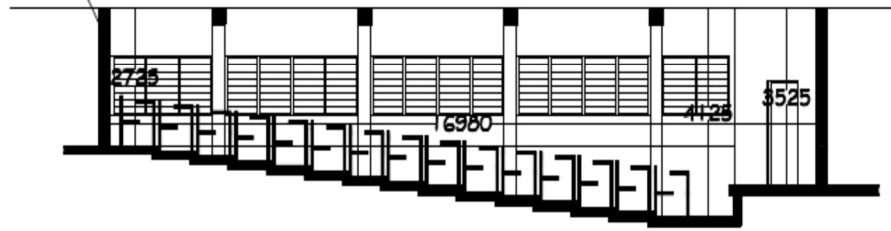


Fig.12 SSLT Lecture Theatre section

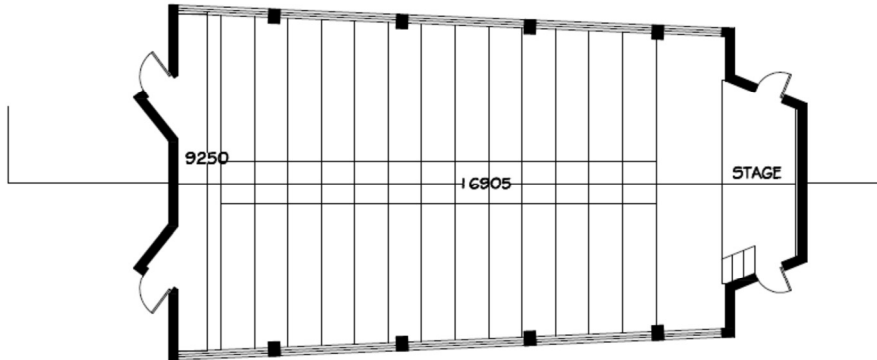


Fig.13 SSLT Lecture Theatre plan

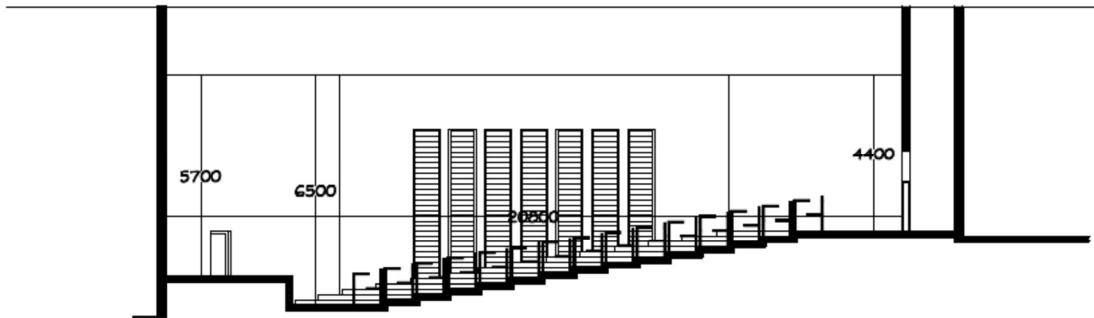


Fig.14 HSLTC Lecture Theatre section

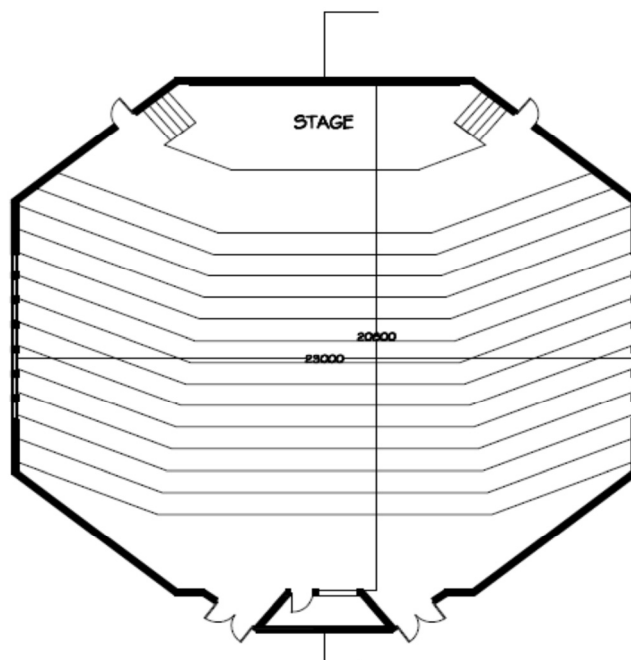


Fig.15 HSLTC Lecture Theatre Plan

5. RESULTS AND DISCUSSIONS

RASTI and STIPA test values are usually decimal numbers between 0 and 1. Table 1 shows the guideline for interpreting the RASTI speech intelligibility test values. STIPA values are also interpreted in a similar way as shown in Table 2. RASTI and STIPA speech intelligibility measurements were taken in 14 lecture theatres as mentioned earlier. The values obtained for each lecture theatre are given in Table 3.

STIPA values were found to be higher at the middle of the lecture theatres than at the back as shown in Fig. 16. This is also true for RASTI values. This is expected since speech intelligibility of public address systems decreases with the distance from the loudspeaker which was placed in front of the room. This can be further explained by the reduction in the strength of the direct wave from the sound source (due to attenuation) as distance from source increases.

It was also observed that the RASTI values are higher than corresponding STIPA values at the middle of the lecture theatres as shown in Fig. 17. RASTI values are also higher than STIPA values at the back of the lecture theatres (see Table 3). This is due to the overestimation tendencies of RASTI mentioned earlier. Hence STIPA values should be used to specify the speech intelligibility capability of the rooms while the RASTI values can be kept for record purposes.

The dimensions of the lecture theatres were found not to be the main factor that determines the ratings of intelligibility in the rooms. Some large rooms were observed to have better speech intelligibility values than smaller rooms. For example, AJSLT has better speech intelligibility ratings than the ODLT lecture rooms which are smaller rooms. It is how well reverberation is handled in the rooms that determine whether reflections in the rooms would affect intelligibility or not, not just the sizes of the rooms.

Rooms with good intelligibility values are those that were well-designed to minimize reverberation from walls and ceilings. The architectural design and wall cladding of AJSLT and BOOC help to prevent excessive reverberation, while PY102 and CH102 lecture theatres have walls with acoustic cladding that absorbs sound, preventing reflection and reverberation from the walls. Such rooms have higher speech intelligibility ratings than rooms with poor architectural design and poor or no wall cladding (like HSLTC, HSTLB, HSLTA, ODLT I and ODLT II lecture theatres).

For the lecture rooms with poor speech intelligibility, one approach to improve the STI ratings is to implement good acoustic treatments for the walls and ceilings. It will be an arduous and costly task to change the architectural configurations of the rooms, so this option may have to be left out. For rooms with parallel louvre windows forming part of the walls, the windows should be kept open to reduce reflection of sound waves in the room thereby reducing the possibility of reverberation, leading to improvement in the speech intelligibility in such rooms.

Table 1: Guideline for Interpreting RASTI Speech Intelligibility Test Values

Rasti Values	Rating
0.2	Bad
0.25	Bad
0.30	Poor
0.35	Poor
0.40	Poor
0.45	Fair
0.50	Fair
0.60	Fair
0.65	Good
0.70	Good
0.75	Good
0.80	Excellent
0.85	Excellent
0.90	Excellent
0.95	Excellent
1.00	Excellent

Source: Sound Pro Audio Consultant Operational Manual

Table 2: Correspondence between STI or STIPA scores and perceived speech intelligibility

Subject Descriptor	Unintelligible	Poor	Fair	Good	Excellent
STI score	0 - 0.3	0.3 - 0.45	0.45 - 0.60	0.60 - 0.75	0.75 - 1.0

Source: Nestoras et al (2007)

Table 3: Speech Intelligibility Values of Lecture Theatres of Obafemi Awolowo University, Nigeria.

Lecture Theatre	Method	Location 1 (Middle)	Location 2 (Back)	
Ajose Lecture Theatre	AJSLT	STIPA 0.65	0.44	
		RASTI 0.64	0.57	
Physical Sciences	PY 102	STIPA 0.56	0.51	
		RASTI 0.65	0.58	
	CH 102	STIPA 0.50	0.48	
		RASTI 0.69	0.58	
Biological Sciences	BOOC	STIPA 0.68	0.57	
		RASTI 0.70	0.65	
	BOOB	STIPA 0.68	0.65	
		RASTI 0.70	0.68	
	BOOA	STIPA 0.68	0.62	
		RASTI 0.72	0.65	
Health Sciences	HSLTC	STIPA 0.31	0.29	
		RASTI 0.43	0.44	
	HSTLB	STIPA 0.34	0.33	
		RASTI 0.52	0.47	
	HSLTA	STIPA 0.29	0.29	
		RASTI 0.46	0.45	
Humanities	AUD I	STIPA 0.73	0.55	
		RASTI 0.90	0.73	
	AUD II	STIPA 0.64	0.43	
		RASTI 0.83	0.74	
	Oduduwa Lecture Theatre (Conversions)	ODLT I	STIPA 0.22	0.15
			RASTI 0.38	0.30
ODLT II		STIPA 0.12	0.07	
		RASTI 0.37	0.35	
Social Sciences	SSLT I	STIPA 0.56	0.51	
		RASTI 0.78	0.62	

6. CONCLUSION

The speech intelligibility of 14 lecture theatres was evaluated using RASTI and STIPA methods. Speech intelligibility values ranging from poor to good were obtained for the rooms, depending on how well they were designed and whether provisions were made for proper handling of reverberation in the room. Based on the stated findings, there is a need to enhance the acoustic features of lecture rooms with poor or fair ratings, in order to improve speech intelligibility. It appears that all the studied lecture spaces can still be improved upon, based on the RASTI and STIPA values, as no room could be rated to have excellent speech intelligibility at the back.

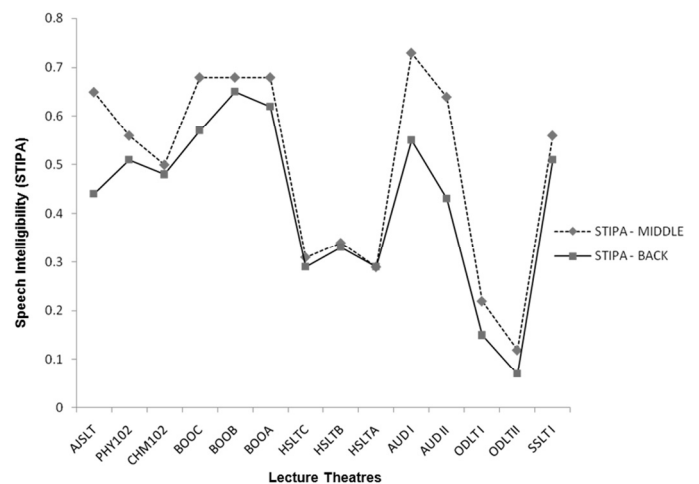


Fig. 16 Comparison of STIPA values at the middle and back of the lecture theatres

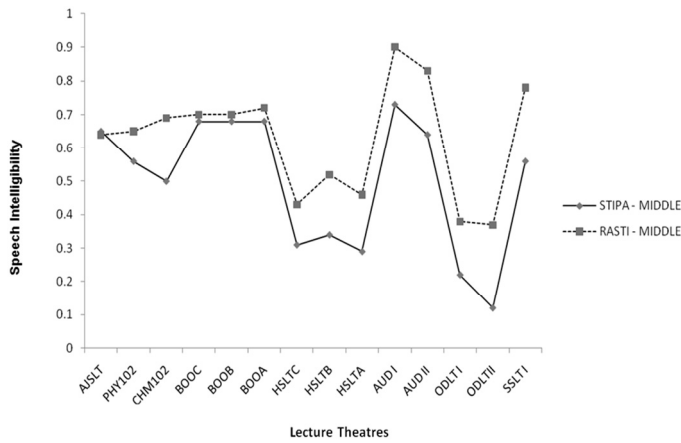


Fig. 17 Comparison of RASTI and STIPA values at the middle of the Lecture theatres

Garay-Vargas and Rodriguez-Manzo (2008) stated that “it is hard for architects to imagine how an architectural space will sound when there is not enough knowledge of the acoustic parameters, the behaviour of materials, the type of space, the dimensions, geometry, all of them are fundamental to define the sound characteristics of the space”. Hence, subsequent lecture theatre building projects should take cognizance of the need to incorporate speech intelligibility capability into the project and this can be done at the design stage of the buildings. Therefore, acoustic parameters and other important parameters that will affect the speech intelligibility of the lecture room should be considered.

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