Acoustical Quality Assessment of Lecture halls at Lund University, Sweden

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ABSTRACT

Noise control in buildings should aim at reducing disturbances caused by speech noise (i.e., improve speech privacy, speech intelligibility). Room acoustics can be controlled with high room absorption, high screens and bookcases, and sufficient masking sound. This research concerns as important aspect of room acoustic metrology, the ability to quantify the most relevant room acoustic parameters for academic purposes. In this proposed study we will focus on the lecturing rooms of Lund University, of which some have designed quite recently while others were constructed many years ago. As the use of audio- visual equipment as well as the use of enabling techniques for disabled students is continuingly increasing. Lecture halls, which have not been explicitly designed for the use of such equipment, are being fitted with an assortment of audio-visual fixtures. This can lead to far less environment profoundly impacts the outcome of the learning process it is performance to assess the current state of the situation with respect to the acoustic performance of lecture halls at Lund University.

Keywords: Room acoustics, Reverberation time, Speech clarity, Sound strength

1. INTRODUCTION

Noise pollution has become another deleterious outcome of modern civilization, to be added to the others pollution of our environment. Many of the aspects that appeared with the evolution of the modern era served to deteriorate the acoustic environment of classroom. Today every student owns a mobile phone and other electronic devices that tend to make the classroom environment noisy and hindering its major purpose. Most studies performed on classrooms have been shown that excessive noise [1] and late reverberation time degrade speech clarity and hence has a significant effect of student's learning process and wellbeing [2]. More knowledge and information about the importance of classroom acoustic are found in [3, 4].

As the acoustic performance of the environment impacts the outcome of learning process, it is important to assess the situation and promote the lecture halls environment which makes everyone's interest in listening and being involved in communication. The main objective of the present study was to evaluate the acoustic comfort of lecture halls in Lund University, Sweden and briefly introduces the room acoustic parameters of these lecture halls relevant to each other. The acoustical parameters evaluated were reverberation time, sound strength, clarity and speech intelligibility according to international standard ISO 3382-1 [5].

2. MEASUREMENTS METHODOLOGY

2.1 Classrooms Descriptions

The lecture hall P1 has a seating capacity of 25 seats with 13 tables and has designed for courses.

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The shape is ordinary rectangular classroom with a height of 3 m, and the interior partitions are double wooden wall. The room contained a large blackboard (4.80 m × 1.20 m) and large windows (7.2 m × 1.8 m) on the other side wall. All the other walls were concrete. The classroom contained suspended ceiling (20 mm glass wool, 200mm air gap, 7.50 m × 4.70 m). A photograph of teaching room P1 can be seen in Figure 1.

Figure 1 – Classroom P1

The lecture hall N1 has a seating capacity of 36 seats with 16 tables and has designed for courses. The shape is ordinary rectangular classroom with a height of 3 m, and the interior partitions are double wooden wall. The room contained a large blackboard (4.80 m×1.20 m), large windows (9.6 m×1.8 m) on the other side wall and a sink. All the other walls were concrete where on one of these walls; there are two doors (2m ×1 m for one). The classroom contained suspended ceiling consisting of 20 mm glass wool, 200 mm air gap (10.2 m × 4.80 m). A photograph of teaching room N1 can be seen in Figure 2.

Figure 2 – Classroom N1

The classroom Navet is situated at Navet building. It was empty and hosts a variety of events, such as conferences, courses and presentations by students and its walls are not parallel with height 3.35 m and there are three glass doors at one wall and two at other wall. A photograph of Navet room can be seen in Figure 3. All information about the classrooms is illustrated in table 1.

Table 1 – Data for the measured classrooms

Classrooms	Volume, m^3	Seats	Volume/Seat m^3
P1	169	25	6.76
N1	220	36	6
Navet	575	…..	…..

Figure 3 – Classroom 'Navet'

2.2 Measurement Setup

The aim of this work was to verify the acoustic quality of Lund University classrooms according to standard design for university building. All measurements are carried out according to international standard ISO 3382-1 [5] with respect to the source and microphone positions in the room. The sound source was placed at two different positions in each classroom at teacher's position, with 1.5 m above the floor, about 1.5 m from the corners of the classroom, and excited by white noise signal through a power amplifier and five microphone positions for each source at a typical ear height of 1.5 m which means ten microphone positions in each room. These positions were selected in the main seating area covering the typical range between teacher and students in the classroom. The measurement equipment is NOR 140. Every measurement were recorded for ten seconds to ensure that the recorded time was sufficiently long to enable determination of background noise. The acoustic parameters were measured according to ISO 3382-1 [5]. All windows and doors were closed and the air conditionings were switched, and the measurements were carried out during the day.

3. RESULTS AND DISCUSSION

There are many important parameters that one should consider during studying room acoustic quality such as reverberation time T20, strength of sound G, clarity C50 and speech intelligibility STI. Measurements and analysis of these parameters are reported in the current study and compared to recommendations.

3.1 Reverberation time for Classrooms T20

Figure 4 shows that, the reverberation time measurements for Classrooms at different volumes, P1=169 m^3, N1=220 m^3 and Navet=575m^3. To summarize the measurement results of all classrooms in a comparative study, the average reverberation time T20 for each classroom is presented. This figure illustrates that the values of T20 increases as the volumes of classroom were increased and decrease with the amount of absorption in it where the maximum reverberation time is obtained with Navet classroom. The mid–frequency region from 500-2000 Hz usually provides a relative indication of the listening conditions in classrooms. The average value of T20 for classroom P1 and N1 were around 0.62 s and for Navet is 1.29 s. The differences in T20 of classrooms attributed to the different building materials employed. The average value of T20 of Navet classroom was found to be greater than 0.6 s that is considered the optimal and a target value for reverberation time for optimal classroom design. It shows along reverberation time at low frequencies (125 -500 Hz) greater than 1.0 s that is considered the optimal upper limit for speech intelligibility and for good speech intelligibility, T20 values at low frequencies should remain flat [6]. Therefore the Navet classroom can be said to have a high value for T20 when unoccupied. When compared results of classrooms with World Health Organization [7], only the classroom P1 and N1 fall within the established range 0.4-0.8s and Navet classroom above the range. So reverberation time for P1 and N1 offer better condition than do in the Navet classroom. This is due to low sound absorption in Navet classroom.

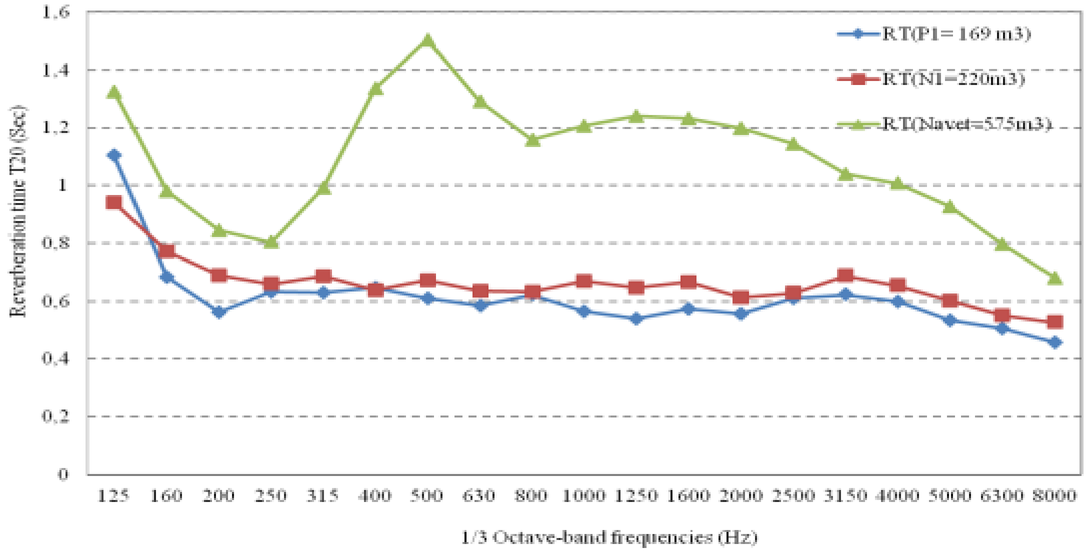
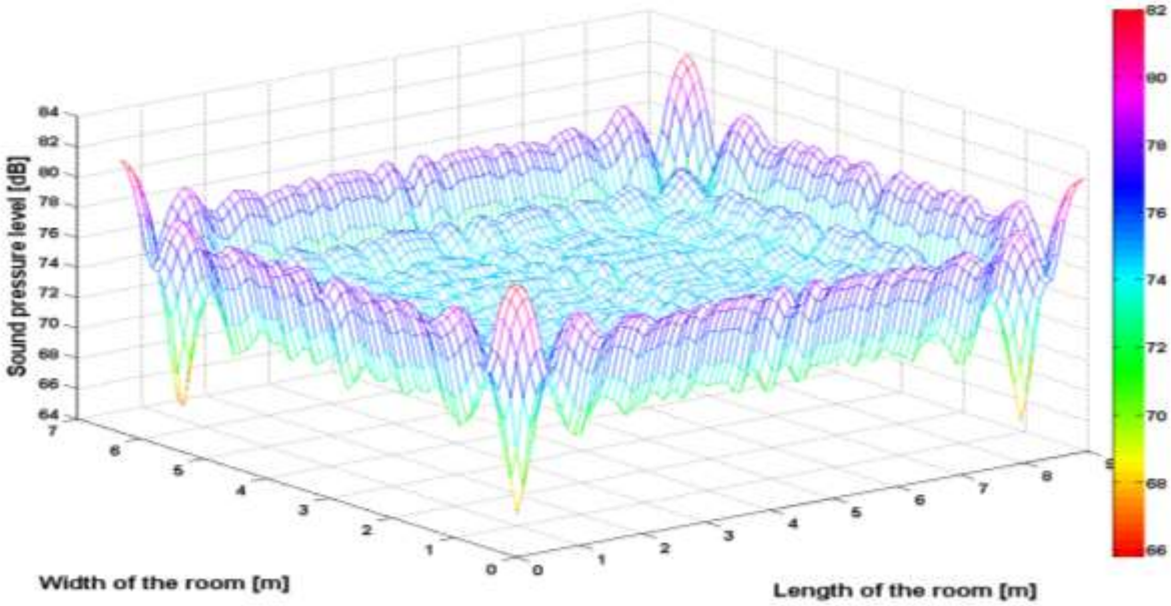


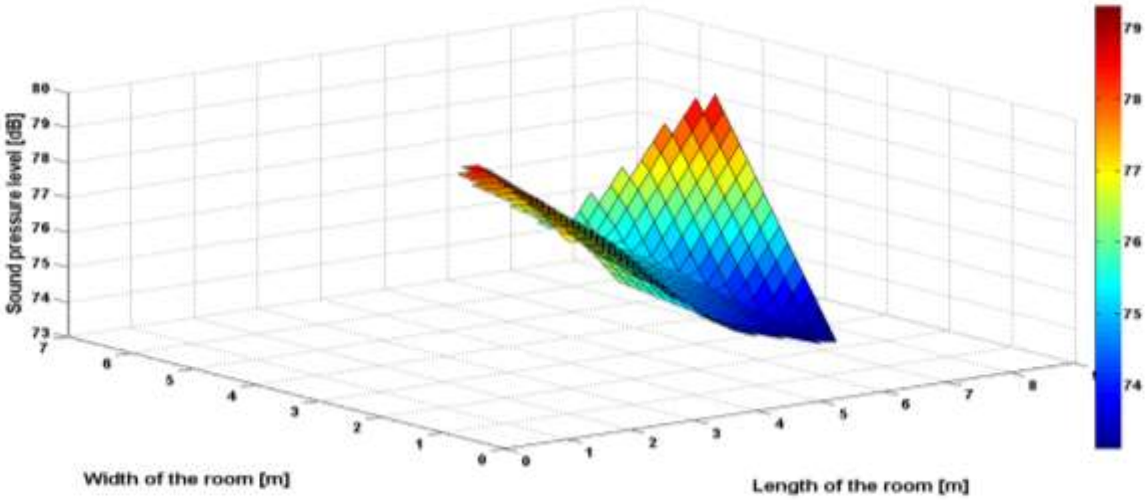
Figure 4 – Reverberation time T20 against frequency for all classrooms

For one of the classrooms P1 a local minimum of the reverberation time can be observed at the third-octave band with the centre frequency of 200 Hz. For the classroom Navet a local minimum can be observed at 250 Hz and a maximum at 500 Hz. One hypothesis is that the phenomena are related to room resonance. Therefore a resonance frequency analysis has been carried out for the third-octave bands in question. A Matlab code was generated to calculate the model frequency and to plot the modes of the classroom based on the dimensions of the room, which will be used to compare theoretical room modes values with the measured values of sound pressure in the classroom. The mode combinations studied in this work were nx=0:25, ny = 0:25and nz =1.5.

Figure 5(a and b) show the surface graph of the measured and theoretical value of sound pressure level at frequency of 200 Hz in classroom P1 with different microphone positions (student positions). The x-axis and y-axis represent the length and the width of classroom P1 ranging from 0:8.9m, 0:6.33m respectively, and z- axis represents the sound pressure level inside the classroom at 200 Hz. It was seen that from this figure, the sound pressure seemed to decrease in intensity as the microphone position got further away from the loudspeaker (Teacher position) where the sound pressure level at the first microphone position(x=3.3m,y=1.6) was 76.1dB and for the last microphone position(x=7.3, y=2) was 73 dB for the first position of the loudspeaker .In the same time for the second position for loudspeaker, we found also the sound pressure at the first microphone position higher than others. This means that, the students in the first rows will hear more clear and louder than those are seating in the last rows. These differences in the sound pressure level attributed to the multiple reflections with the walls that are out of phase with direct speech and each other. This late reflections of sound degrade the speech clarity. From the theoretical graph Figure 5b, it was seen that the sound pressure level reach at the highest values in the corner (red points) and the sound pressure varies from one position to another. This means that the value of sound pressure is not constant at all positions which agree with experimental graph.



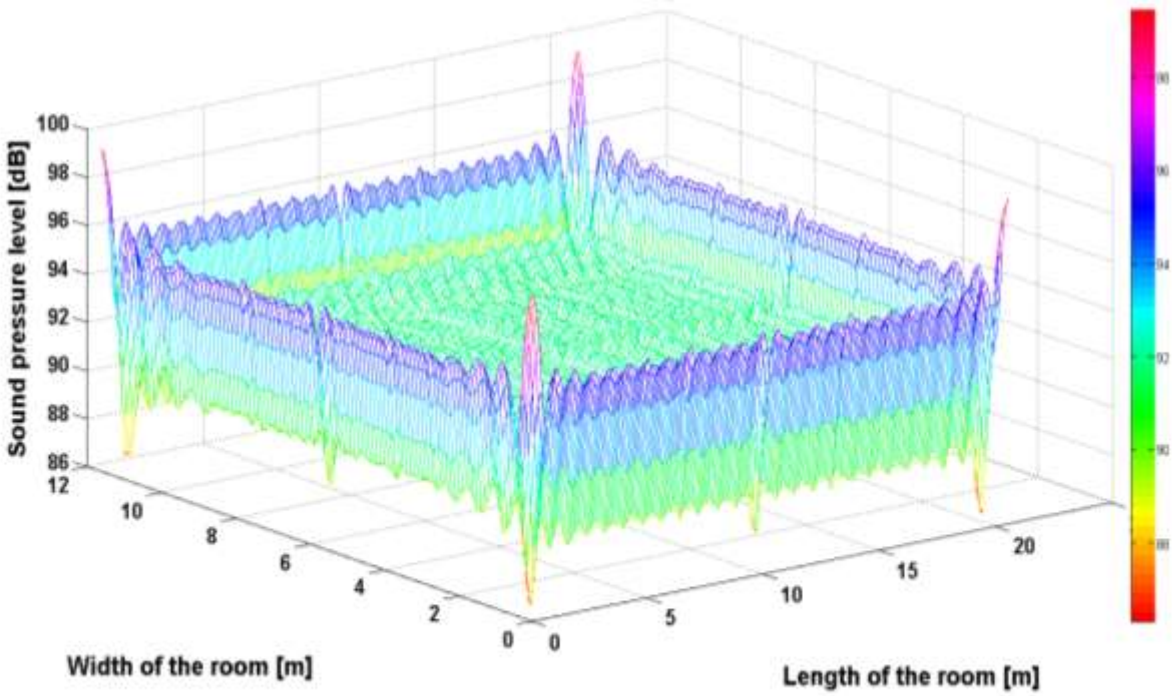
(a)



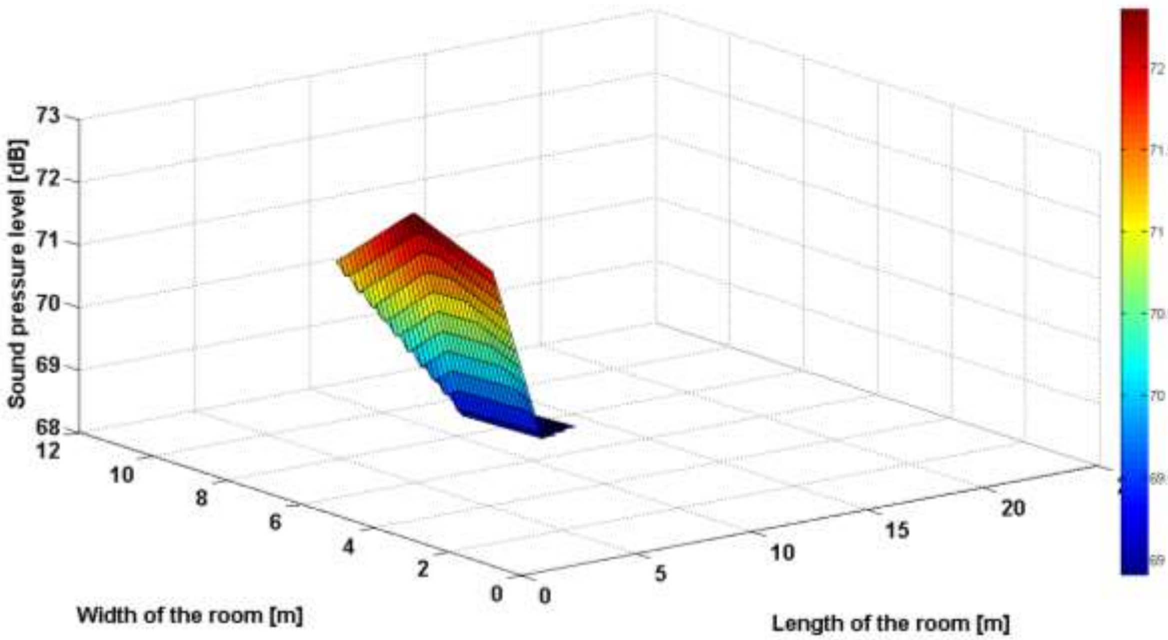
(b)

Figure 5(a and b) – Theoretical and measurement values for sound pressure level in classroom P1 at 200Hz

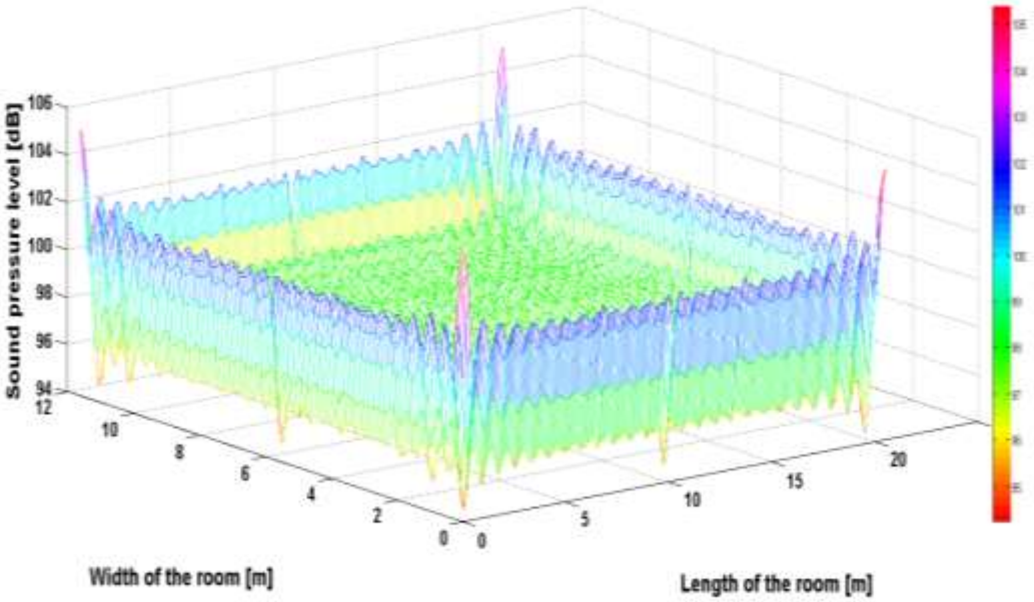
Figure 6 (a, b, c, and d) show the surface graph of the measured and the theoretical value of sound pressure level at frequency of 250 Hz and 500 Hz in Navet classroom. The x-axis and y-axis represent the length and the width of Navet classroom ranging from 20.5m, 11.65m respectively with knowing that the walls of this classroom are not parallel and the last coordinates represent the largest length and the largest width of this room. From this figure, it can be seen that the sound pressure depend on the position inside the room. The maximum values for the measured sound pressure were achieved at the nearest microphone position from the loudspeaker (teacher position) for both frequencies 250Hz and 500Hz and the minimum values for the measured sound pressure levels were achieved far away from the loudspeaker position. From the theoretical graphs (a and c), it is clear that the sound pressure level changes with the same rate and it can be observed is almost constant in the middle of the room exception at the region near to the walls. From these figures it can be concluded that, the deviations in the measured sound pressure values return to the configuration and the wall construction of the classrooms.


Sound pressure level [dB]
100
98
96
94
92
90
88
86
Width of the room [m]
12
10
8
6
4
2
0
Length of the room [m]
0
5
10
15
20

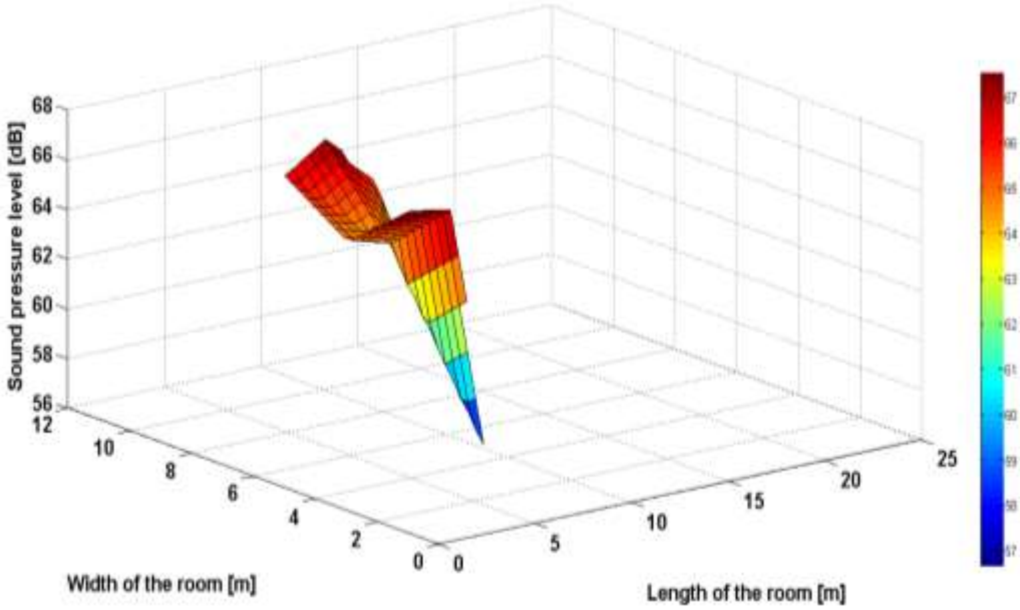
(a)


Sound pressure level [dB]
73
72
71
70
69
68
Width of the room [m]
12
10
8
6
4
2
0
Length of the room [m]
0
5
10
15
20
72
71.5
71
70.5
70
69.5
69

(b)



(c)



(d)

Figure 6(a, b, c, and d) – Theoretical and measurement values for sound pressure level in 'Navet' classroom at 250Hz and 500Hz

3.2 Clarity of Speech C50

The clarity of speech is defined as the logarithmic energy ratio between the early arriving sound within 50ms and late arriving sound [5]. So it is important to know the amount of energy arriving at microphone positions (student positions) within the first 50ms which consider a better indicator of perceived reverberance and strengthens the early sound. In order to achieve a good quality in classrooms, it is important to keep the amount of direct sound arriving at certain positions more than the reflected sound. The early arriving reflections make the direct sound louder while the later arriving reflections degrade the speech of sound and make the spoken message unclear. The following Figure 7 illustrates the measured clarity C50 for all classrooms. From this figure, it was seen that the speech clarity increased as the frequency increased. This change means that more sound is received in the first 50ms. The increase of speech clarity is important to improve the classrooms speech development. On the same figure, the speech clarity decreased as the volume of classrooms increased and also decreased for unoccupied classrooms as in Navet classroom. This means that the speech clarity depends on the reverberation time where the reverberation time is high for Navet classroom. The Navet classroom showed a low level in clarity especially between 125-2000 Hz. These frequencies are important for speech and almost Navet classroom showed negative numbers as an indication of bad intelligibility. Above these frequencies, the clarity of speech is a bit more than other frequencies. From this figure, it was noticed that speech clarity has the same behavior of reverberation time for each classroom.

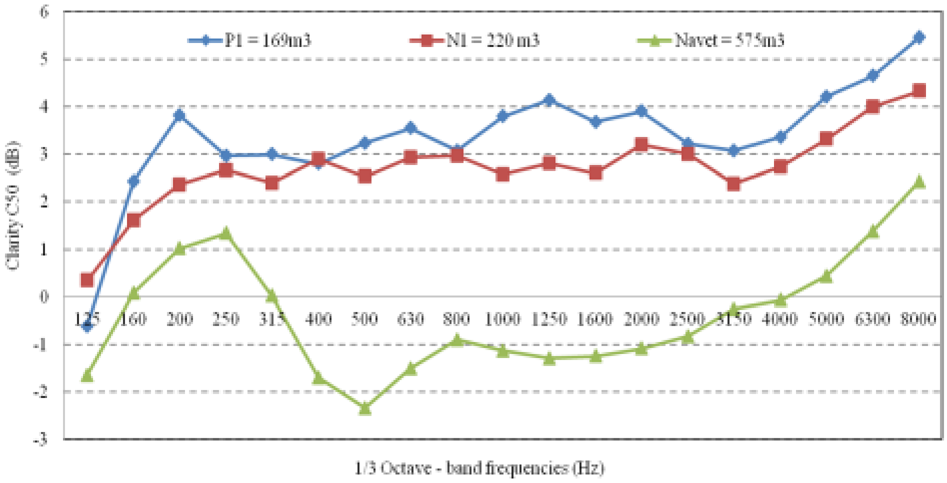


Figure 7 – Clarity C50 against frequency for all classrooms

3.3 Speech Transmission Index STI

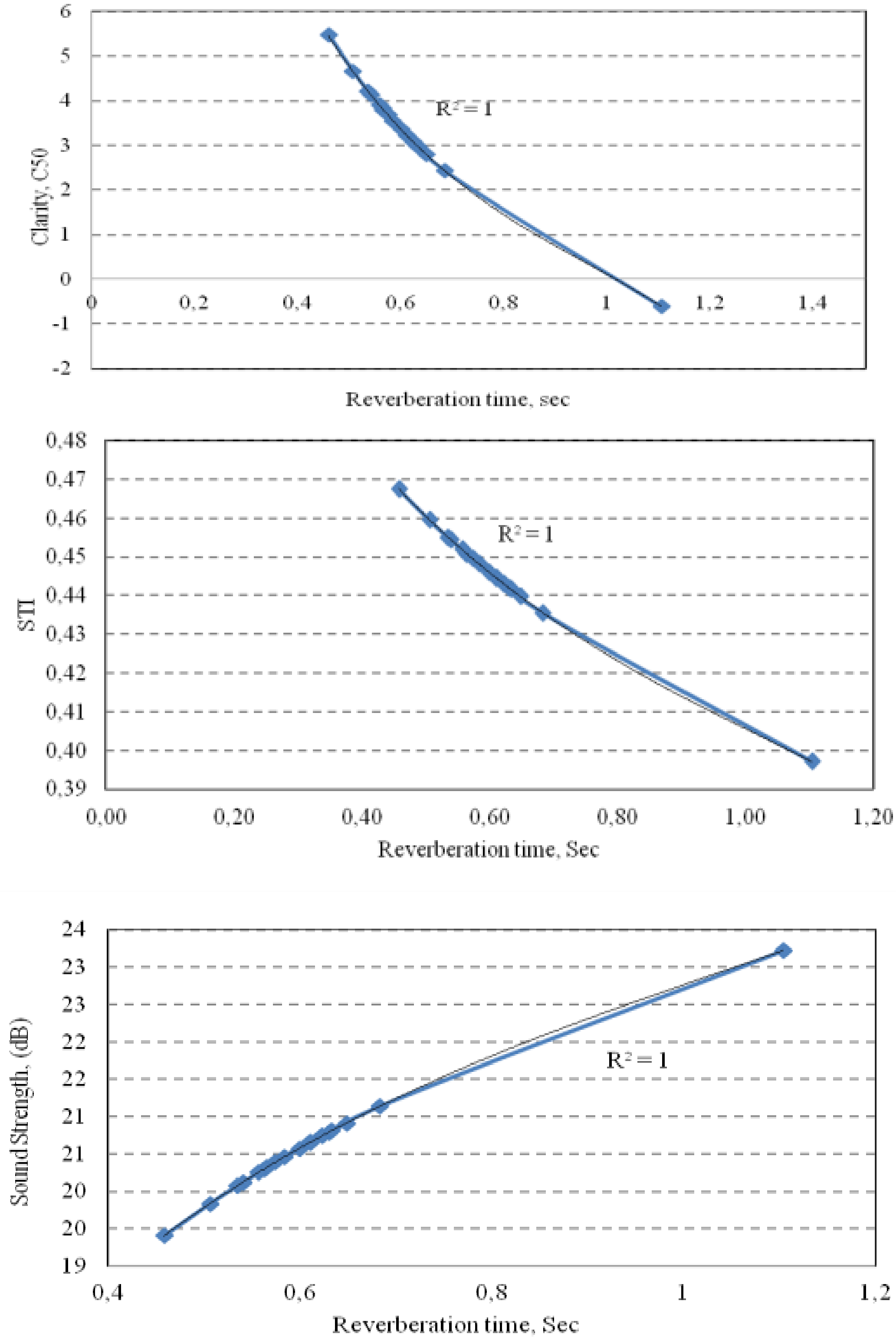
Speech transmission index (STI) is a physical correlate of speech intelligibility (SI). Speech transmission index was calculated from reverberation time, using a simplified version of a procedure proposed by Muller and Swen Mediro [8]. The intelligibility of speech depends upon its audibility as well as clarity. Audibility is affected by the loudness of speech relative to the background noise level. An increase in the background noise will cause lager masking of speech and hence will decrease intelligibility. From the Table 2, it was noted that the average value of STI over all the frequency range for classrooms P1=0.45, N1=0.46 and Navet 0.50 and STI varies between 0 and 1 where 0 means bad speech intelligibility and 1 means Excellent. The STI values evaluated in Table 2 indicated poor speech transmission index for all classrooms where the desired value for STI should be > 0.75 [9].

Table 2 – STI values for classrooms

Classrooms	Volume, m^3	Average value of STI
P1	169	0.45
N1	220	0.46
Navet	575	0.50

3.4 Clarity C50, Speech transmission index STI, and Sound Strength versus T20

Figure 8(a, b and c) show the measured Clarity (C50), mean speech intelligibility (STI), and sound strength (G) versus reverberation time (T20) and the best fit third-order polynomial curves for classroom P1 for example. As the analysis of variance results indicate, there is an overall significant trend for speech intelligibility and clarity to increase with decreasing reverberation time (improving room acoustics). Further, the effects of room acoustics (G) are larger for larger T20. (i.e., there is a significant interaction effect). For the highest value of T20 (T20=1.1), there is only a very small effect of varied C50 and STI over the full range of likely room acoustics conditions. In order to evaluate the relationship between these parameters, a correlation analysis was conducted. This figure shows also these correlations, highlighting the strong association between these parameters and T20. There is a high correlation between these parameters and reverberation time and the correlation coefficient R square is 1 in all reverberation time range. The strong correlation that can be seen between these parameters and T20 is expected since according to the equations that are used for calculations of C50, STI and G are a function of T20.



(a) (b) (c)

Figure 8(a, b and c) – Clarity C50, STI and Sound Strength G against T20 for all classrooms

4. CONCLUSIONS

The room acoustic parameters related to reverberation time (T20), speech clarity C50, speech intelligibility STI and sound strength G have been measured in three lecture halls according to ISO 3382-1. Obtained results were compared to the design goal. As for reverberation times, it was found that the N_1 and P_1 classrooms offer better acoustic conditions than the Navet classroom, due to the furniture materials employed. The reverberation time relating to the mid frequency range usually provides a relative indication of the listening conditions in classrooms. The classrooms investigated in this study can be characterized by long sound decay at low frequencies especially for Navet classroom. This long decay degrades the speech clarity and hence affects the speech intelligibility. From the analysis of the resonance frequency we obtain the sound pressure level seemed to decrease in intensity as the microphone positions got further away from loudspeaker position indicating that the sound pressure levels are not the same in all positions.

Speech intelligibility in classrooms measured based on speech transmission index STI. It was verified that in all the classrooms, the index was in the range of 0.45-0.50, representing not fair intelligibility. This situation deserves a great attention where speech intelligibility reflects the understanding of communications. From the measured acoustic parameters, it was found also that clarity, speech intelligibility, sound strength and reverberation time are strongly correlated since the correlation coefficient is 1 in all frequency range.

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REFERENCES

1. J. Badly, R. Reich, and S. Norcross, “On the combined effects of Signal-to-noise ratio and room acoustics on speech intelligibility” J.Acoust.Soc.Am., Vol. 106 (1999).
2. J. Bradley and H. Sato, “The intelligibility of speech in elementary school classrooms”, J.Acoust.Soc.Am., Vol.123, (2008).
3. S.K Tang “Speech related acoustical parameters in classrooms and their relationships”, Applied acoustics, 69 (2008) 1318-1331.
4. Chris Di Marino, Dillon Fuerth, Devin Gignac, Adam Lunardi, Colin Novak, Robert Pikul and Anthony Simone “Acoustic Enhancement of Proposed Grand Lecture Hall using Computer Simulation”, Canadian Acoustics, 43-Vol.39 No.1(2011).
5. ISO – 1:2009, Acoustics – “Measurements of room acoustic parameters” – Part 1: Performance spaces.
6. H. Kutturf, “Room Acoustics”, Elsevier, London and New Yourk, (1991).
7. World Health Organization – WHO, “Noise in schools”, Geneva, (2001).
8. Muller, Swen Mediro STI (2005).
9. Ecophone2013:1,”http://www.ecophone.com/se/Akustik/room-AcousticPlanning1/Rumsakustiska-matt/Taltydlighet/”.