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The Importance of Acoustic Quality in Classroom

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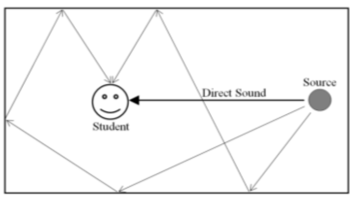
Graphical abstract



Abstract

An effective learning process in a classroom with good speech intelligibility requires good acoustic quality. Low acoustic quality may cause frequent speech repetition and consequently leads to several emotional disorders among the students. The purpose of this study is to improve the acoustic quality of the classroom for a better learning process. Two classrooms at Faculty of Civil Engineering, Universiti Teknologi Malaysia have been selected for this study. Reverberation time is the most important factor in acoustics, which was determined using theoretical calculations and simulations. A Dass-21 of self-report questionnaires was used to measure the levels of depression, anxiety, and stress among the students. The results showed that reverberation times of the classrooms were more than 1 second and 34% of the students have suffered from severe and extreme anxiety. The acoustic quality can be improved through the replacement of a painted concrete wall with high sound absorption material made of kenaf fiber in order to ensure reverberation time does not exceed the limit.

Keywords: Acoustic quality; room acoustics; reverberation time; kenaf fiber

1.0 INTRODUCTION

Classroom acoustics are currently gaining attention among educators because acoustic quality is one of the key factors for an effective learning process. Good classroom acoustics provide speech intelligibility between the students and teachers and it is very important to improve the academic performance of students. The importance of a classroom having a design that takes speech intelligibility into consideration has been discussed by previous researchers.[1-4] The most important factor is reverberation time,[5] which is considered as the quality of classroom acoustics.[6] The length of reverberation time can cause a person to feel angry or uncomfortable, thereby possibly affecting the emotional status of the students and lecturer.[7-13] Furthermore, according to some studies,[14-17] the noise in the classroom can lead to disorders such as depression, anxiety, and stress.

Reverberation time depends on several factors, such as the volume, sound frequency, and absorption level in the classroom.[18] It is required to reduce reverberation time in large room.[19] If reverberation time decreases, speech intelligibility will increases.[20-21] In recent years, many countries use a specific standard for classroom design.[22] The World Health Organization has also given some suggestions for schools to reduce noise and reverberation in the classroom through important classroom acoustics standard, ANSI S12.60-2002.[23] The standard recommends a good practice is to limit the reverberation time in a classroom to a maximum value of 1.0 second. It was reported that a reverberation time of 0.4-0.5 second produced a high signal-to-noise ratio, which is good for the learning process.[24] There are two ways to reduce reverberation time: (1) increasing sound absorption and (2) reducing the volume of classroom.[25]

The main purpose of this study is to improve the quality of acoustic quality of the classrooms at Faculty of Civil Engineering, Universiti Teknologi Malaysia in order to avoid emotional disturbances among the students. Improvement in acoustic quality is one of the ways toward achieving green building. Green building can be defined as a high-performance property that may reduce its impact on environment and human health.[26] In order to achieve this goal, the objectives of the study were to determine reverberation times of the classrooms as well as the levels of depression, anxiety, and stress among the students and to suggest ways to improve the acoustic quality of the classrooms.

2.0 METHODOLOGY

2.1 Determination of Reverberation Time

Two classrooms were selected: (1) classroom 1, which was newly constructed, and (2) classroom 2, which was built more than 20 years ago. Reverberation is based on the following analogy:

students hear sound directly from the lecturer's voice and also multiple reflections of the lecturer's voice that are delayed a few seconds. Reverberation is produced when a sound is reflected on many surfaces before reaching the student (Figure 1), and it leads to the damage of sound, such as "hello-oo-oo". Reverberation time is the time for the sound to disappear after the source ceases from producing sound. In room acoustics, the standard reverberation time is the time required by the sound to fall by 60 dB from its initial value (RT60). RT60 is one of the acoustic quality indicators for an enclosed room.[27]

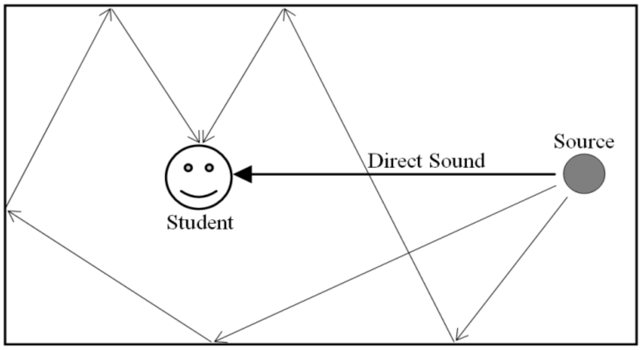


Figure 1 Multiple reflections in the classroom due to hard surface walls

In this study, reverberation time was determined by using theoretical predictions and simulations. For theoretical predictions, the calculation was made using the Sabine theory (Equation 1), which requires information on the room's sound absorption materials and the surface area of the building materials. Therefore, in this study, dimensions of wall such as the length, height, and width or any elements cover the classroom were measured, and the absorption coefficient of material that impede by the sound were estimated based on the previous researches.

$$RT_{60} = 0.163\ (v/\Sigma s\alpha) \quad (1)$$

where v is the volume of the classroom, s is the surface area, and α is the surface absorption coefficient. Dimension of classroom 1 was shown (Figure 2).

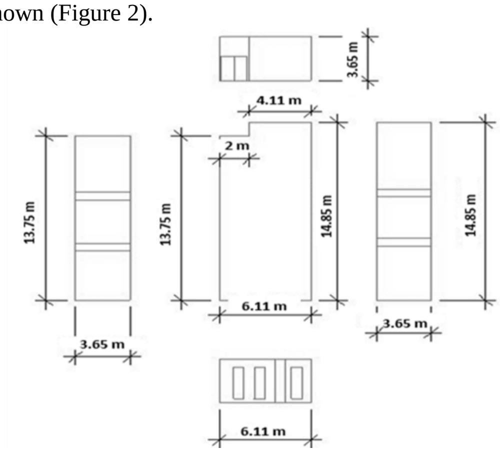


Figure 2 Dimensions of Classroom 1

The surface of each item such as the wall, floor, windows, chairs and other has α values of less than 1. A surface area with α has the ability to absorb α% of sound, while the remaining (1-α)% of the sound is reflected back into the classroom. In order to have a good reverberation time, absorptive materials can be added or removed from the space.

After the calculation of reverberation time using the Sabine theory, the next step is to calculate reverberation time using the room acoustics simulation software known as Computer Aided Room Acoustics (CARA). It was used for the calculation and optimization of room acoustics through sound source imaging methods in combination with a backtracking procedure. Through this software, various classroom modifications can be proposed to improve the quality of classroom acoustics by comparing the reverberation time of the original rooms with that of the refurbished ones.

2.2 Effects on Depression, Anxiety and Stress among the Students

A Dass-21 of self-report questionnaires was used to measure the levels of depression, anxiety, and stress[28] among 250 students attending two specific classes from the Faculty of Civil Engineering, Universiti Teknologi Malaysia. Through this self-report questionnaire, the emotional status of the students who have experienced learning environment in the classroom can be known. This test produces a short version of self-report data, and the Statistical Package for the Social Sciences (SPSS) software version 19 was used to analyze the data and perform a descriptive analysis.

3.0 RESULTS AND DISCUSSION

3.1 Reverberation Time

Interior conditions and CARA modeling simulations of classroom 1 and 2 were shown (Figure 3a-f). The materials used in these two classrooms were also tabulated (Table 1). Besides having a different materials of the floor, room volume of classroom 2 is three times larger than classroom 1. With a larger volume, the classroom 2 has more number of plastic chairs where their absorption coefficient of 0.04-0.08. Meanwhile, the sound absorption coefficient of the ceramic floor of 0.01-0.02 is less than the rubber-based vinyl flooring of 0.02-0.05. Painted concrete block walls also caused excessive reflections as compared to unpainted walls. The calculation of reverberation times for classroom 1 and comparison of reverberation times obtained from theoretical calculations and simulations were also shown (Table 2 and Table 3).

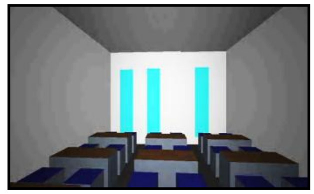
The results show that both classrooms have reverberation times greater than 2.0 second for all frequencies except for frequency of 250 Hz. Thus, the classrooms have high reverberation time values. This implies that each classroom should be remedied to achieve a good acoustic quality with a reverberation time less than 1.0 second. Sabin Theory was derived by taking into account a continuous process, which means the classroom in a diffuse state. CARA simulation software is able to calculate and evaluate the acoustic ambience of the classroom, recommend classroom modifications to improve the acoustic quality and compare the acoustic ambience of the original and modified room.


a) Classroom 1


b) Classroom 2


c) Front wall of Classroom 1


d) Front wall of Classroom 2


e) CARA simulation of Classroom 1

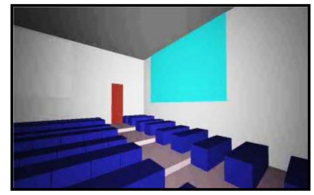

f) CARA simulation of Classroom 2

Figure 3 Dimensions and simulations of the classrooms

Table 1 Properties of the classrooms

Classrooms	1			2		
Items	**Material types**	**Surface area, S (m^2)**	**Absorption coefficient, α**	**Material types**	**Surface area, S (m^2)**	**Absorption coefficient, α**
Floor	Ceramic tile	88.58	0.01-0.02	Vinyl	202.40	0.02-0.05
Rear wall	Painted block concrete	22.30	0.04-0.10	Painted block concrete	49.38	0.04-0.10
Front wall	Painted block concrete	22.30	0.04-0.10	Timber (sawtooth)	44.10	0.05-0.20
Sidewall	Painted block concrete	108	0.04-0.10	Painted block concrete	111.91	0.04-0.10
Door	Solid timber	3.57	0.05-0.10	Solid timber	1.71	0.05-0.10
Ceiling	Gypsum	88.58	0.04-0.20	Gypsum	202.40	0.04-0.20
Windows	Glass	5.60	0.02-0.06	Glass (blinder)	19.23	0.02-0.06
Board	Linoleum	2.16	0.02-0.03	Linoleum	-	0.02-0.03
Whiteboard	Plane	2.14	0.01-0.02	Plane	-	0.01-0.02
Chair	Span/cloth/silk	0.36	0.30-0.60	cloth/silk	5.00	0.30-0.60
Chair	Plastic (41 no.)	12	0.04-0.08	Plastic (261 no.)	112.40	0.04-0.08
Screen	Plastic	10	0.10-0.20	Plastic	5.75	0.10-0.20
Lecturer's table	Timber	1.09	0.05-0.20	Timber	3.16	0.05-0.20
Stage	-	-	-	Thin carpet	16.23	0.05-0.70
Room volume (m^3)	322.96			813.07		

Table 2 Theoretical calculation using the Sabine theory for classroom 1

Item	**Properties**	**Surface Area-S (m^2)**		**Item**	**Properties**	**Surface Area-S (m^2)**		**Item**	**Properties**	**Surface Area-S (m^2)**		**Item**
Floor	Ceramic tile	88.58	0.01	0.88	0.01	0.88	0.01	0.88	0.02	1.77	0.02	1.77
Wall at the back	Painted block concrete	22.30	0.10	2.23	0.04	0.89	0.05	1.11	0.06	1.33	0.08	1.78
Wall at the front	Painted block concrete	22.30	0.10	2.23	0.04	0.89	0.05	1.11	0.06	1.33	0.08	1.78
Wall at the left	Painted block concrete	54.17	0.10	5.41	0.04	2.16	0.05	2.70	0.06	3.25	0.08	4.33
Wall at the right	Painted block concrete	54.17	0.10	5.41	0.04	2.16	0.05	2.70	0.06	3.25	0.08	4.33
Door	Plane solid timber	3.57	0.05	0.17	0.06	0.21	0.08	0.28	0.10	0.35	0.10	0.35
Ceiling	Gypsum	88.58	0.20	17.71	0.10	8.85	0.06	5.31	0.04	3.54	0.04	3.54
Board	Linoleum	2.16	0.03	0.06	0.03	0.06	0.03	0.06	0.03	0.06	0.02	0.04
Glass windows	Glass plate	5.63	0.02	0.11	0.03	0.16	0.04	0.22	0.05	0.28	0.06	0.33
Whiteboard	Plane	2.60	0.01	0.02	0.01	0.02	0.01	0.02	0.02	0.05	0.02	0.05
Chair	cloth/silk	0.36	0.30	0.10	0.40	0.14	0.50	0.18	0.60	0.21	0.60	0.21
Chair	Plastic	12	0.04	0.48	0.05	0.6	0.07	0.84	0.08	0.96	0.08	0.96
Screen	Plastic	10	0.10	1	0.10	1	0.10	1	0.20	2	0.20	2

Item	Properties	Surface Area-S (m^2)		Item	Properties	Surface Area-S (m^2)		Item	Properties	Surface Area-S (m^2)		Item
Lecturer's table	Plywood (19 mm (3/4"))	1.09	0.18	0.19	0.15	0.16	0.12	0.13	0.1	0.10	0.1	0.10
Student's table	Plywood (10 mm (3/8"))	18	0.22	3.96	0.17	3.06	0.09	1.62	0.1	1.81	0.11	1.98
∑ Sα				39.96		21.24		18.16		20.29		23.55
Reverberation time (RT60, Sabine theory), 0.161*(V/∑A)				1.30		2.44		2.86		2.56		2.20

Table 3 RT60 (s) for the Sabine theory and CARA simulation

Frequency (Hz)	Classroom 1			Classroom 2		
	Sabine theory	CARA simulation	Simulation after improvement	Sabine theory	CARA simulation	Simulation after improvement
250	1.30	1.10	0.58	1.74	1.58	0.97
500	2.44	2.20	0.55	2.78	2.41	0.91
1000	2.86	2.40	0.45	2.63	2.23	0.81
2000	2.56	2.00	0.46	2.38	2.01	0.81
4000	2.20	1.80	0.47	1.98	1.79	0.82

As stated before, an important step to reduce reverberation time is by replacing the existing material that radiates sound with sound- absorbing material. Sound-absorbing material shortens the reverberation time to avoid excessive reflections. The observations made in the two classrooms indicate replacing the large surface with sound-absorbing material. The CARA simulation reveals that sidewalls are ideally to be replaced with sound-absorbing material with absorption coefficients of 0.4 and 0.8 (Table 4) for frequencies between 200 Hz and 4000 Hz. Locally, kenaf fiber was used to cover only selected interior walls (Figure 4) in order to avoid the excessive absorption that can cause death classrooms, which is not appropriate for learning process. Kenaf fiber is one of the natural fibers that can be used as a construction material to replace synthetic fibre.[29]

Table 4 Sound absorption of Kenaf fiber

Frequency	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
α	0.48	0.74	0.91	0.86	0.83

Figure 4 Kenaf fiber

3.2 Levels of Depression, Anxiety and Stress among the Students

The frequency levels of depression, anxiety, and stress among 250 students with respect to the room acoustics conditions studied were illustrated (Figure 5). The surveys were performed when the students attended the lecture in Classrooms 1 and 2. It was found that the number of students who felt anxious in severe and very severe levels (36%) was the more than the same levels of depression and stress.

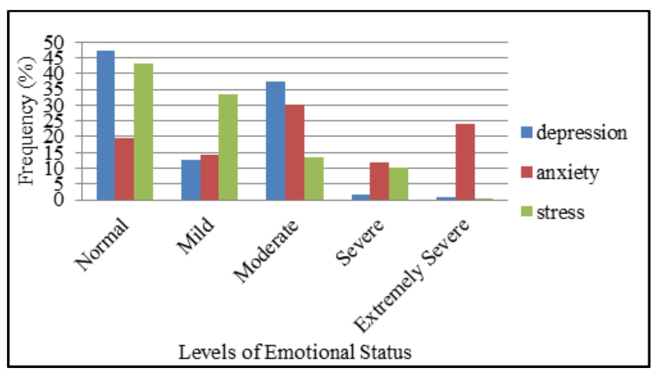


Figure 5 Frequency (%) of students according to their levels of emotional status

When a lecturer speaks, the sound reflects on the surface of the painted concrete block walls, floors, seats, ceiling, and other surfaces. Hard smooth surfaces reflect sound several times (Figure 3). For classroom 1, most of the surfaces are reflective. Sound that was absorbed into the surface of the materials will be lost where penetration occurs, and the sound is sent into the space on the other side. Some of the sounds in classroom 1 can be absorbed by the gypsum ceiling and cloth seats, though the absorption areas are very small (%). For classroom 2, the absorption surface comes from the carpet and also the stacked wood front wall. This arrangement also causes sound waves to be broken up and dispersed. A large space allows the sound to be reflected several times before it reaches the students; however, the results showed that the stacked wood front wall had a reverberation time which is equal to the classroom 1.

RT60 for classrooms 1 and 2 were compared with the Royal Albert hall in London (Figure 6).[30] Reverberation time is the most important factor to the acoustics quality in the classroom environment, which affects emotional status.[31-32] Based on these results, both classrooms did not create this environment (some loss of articulation) as it can be seen with a frequency of 1000 Hz and a reverberation time above RT60, which is slightly higher than that of Royal Albert Hall. This means that both classrooms are suitable only for the general use of both speech and music. This led to over 34% of students feeling anxiety at a severe level, at a minimum, because they could not understand the speech clearly. Besides that, a small space has a short reverberation time, while a large space has a long reverberation time.[33] However, the results from this study indicate otherwise for frequencies above 1000 Hz.

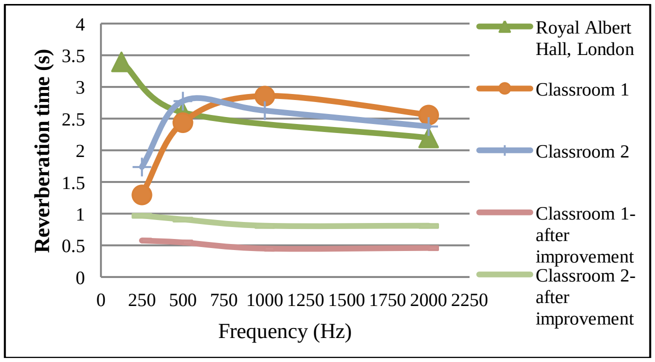


Figure 6 Comparison with the existing auditorium

The improvements of sound absorption characteristics on both sidewalls are the main priority for lowering reverberation time that is suitable for a learning environment. The improvements applied on both classrooms were based on the French standard, which emphasizes more on volume and reverberation time. Thus, for classroom 1, whose volume is less than 250 m^3, the RT was between 0.4 and 0.8 seconds for frequencies 500 Hz, 1000 Hz, and 2000 Hz. For classroom, whose volume was more than 250 m^3, the RT was between 0.7 and 1.2 seconds. The results showed improvements in the RT60 of classroom 1 and classroom 2, with around 0.5–1 second and 0.7–1 second, respectively. This new RT enables students to speak and hear clearly, and lecturers can talk comfortably. So both teachers and students will not have any stress or anxiety in understanding the speech.

4.0 CONCLUSION

In conclusion, acoustical quality in term of reverberation time in of both classrooms represented new and old class deviates from optimum conditions of 1.0 second established by international standards. This raises the level of severe anxiety among the students. Thus, the classroom environment can be remedied by covering the interior part of painted block concrete with kenaf fiber, whose sound absorption coefficient is higher. The reduction in reverberation time after the application of kenaf fiber improved the acoustics quality in the classroom.

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