EVALUATION ON ACOUSTICAL PERFORMANCE OF CLASSROOM SPATIAL AND LAYOUT ARRANGEMENT BY USING COMPUTER SIMULATION

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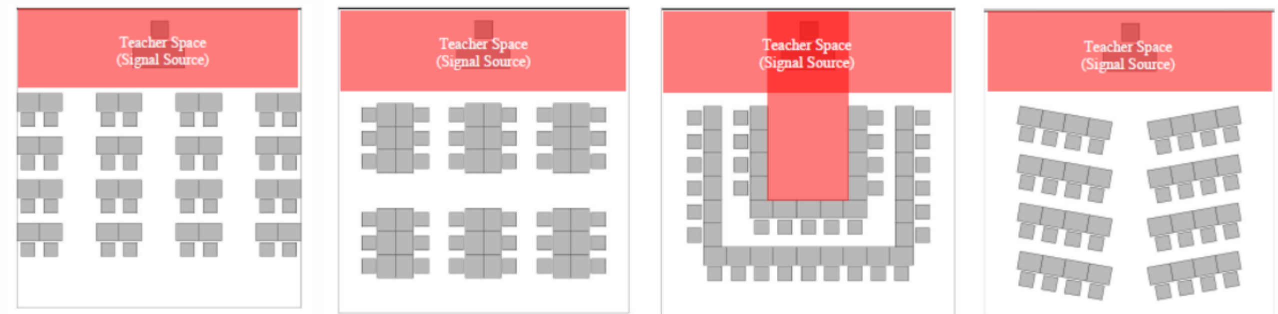
ABSTRACT
A classroom should be created to accomplish good acoustical conditions in order to support an effective learning process. Study shows that one of the ultimate significant solutions around acoustic issues in classroom is by changing the seating arrangement to establish the best and functional proximity for students and improve their performance. The objective of this research is to identify various seating arrangements of classroom, namely traditional arrangement – rows and columns, modular arrangement, horseshoe arrangement and stadium arrangement and evaluate their acoustical performance in the classroom by using computer simulation, ODEON Room Acoustic Software. The base model of the classroom is derived according to study done in 2018, School A which fulfills least of the acoustical criteria with poor speech transmission index. The results were analyzed and compared based on two basic evaluation criteria: i) Reverberation Time (RT), ii) Speech Transmission Index (STI). From the results, it was found that modular arrangement has the best reverberation time among all the seating arrangements while horseshoe arrangement achieved the best speech intelligibility among all. It has also been found that reverberation time of a classroom can be decreased by decreasing the room volume and adding higher absorption material to the classroom.

Keywords: Classroom, Seating Arrangement, Acoustics, Reverberation Time, Speech Intelligibility.

INTRODUCTION
The most proper education occurs in the classroom, where comprehensive verbal communication between students and educator as well as between students and their co-learners during the learning process. A classroom should be created to accomplish good acoustical conditions in order to support an effective learning process (ANSI, 2010; Hodgson, M. 1999). Studies have suggested that appropriate seating arrangement in a classroom is one of the major element to solve the acoustical problems and improve students' academic performance in the teaching and learning environment (Yang, Z. et al. 2013). One of the elements that impact speech awareness is the distance between instructor and pupil in the classroom. Holliman and Anderson (1986) named the real distance between the pupil and the educator as proximity and ascertained in centimeters. Yang et al. (2013) concluded that based on the student's requirement, the ultimate significant solution around acoustic issues is changing the seat arrangement to establish the best and functional proximity for students and improve their performance. Students sitting in the front rows have better achievement when compared with pupils sitting near the back of the class. The distance between pupils and educator can effectively affect the instructing and correspondence process. While a substantial body of research exists regarding the acoustical performance for classroom, little attention has been given to effect of spatial and seating arrangement within a classroom on acoustical performance of the classroom. Most schools in Malaysia especially government schools adopt a similar spatial and layout arrangement for the classrooms due to standardized guidelines and templates set to design a school. This study is a continuation of previous comparative study conducted in 2017-18 (Chang, 2018). The data collected from the comparative study will be utilized and used as a reference to conduct this study. It is divided into two objectives: i) to analyze the different spatial and layout arrangement of classroom, ii) to evaluate the acoustical performance of different classroom seating arrangement. A series of simulation will be carried out by using computer simulation, ODEON Room Acoustic Software to evaluate the acoustical performance of different classroom layout arrangement. The result generated through the simulation will be compared.

LITERATURES REVIEW

Classroom size and shape serves a crucial part in making space for fundamental classroom interactions and exercises (Veltri, S. et al., 2006; Roskos, K., and Neuman, S. B., 2011). The size and shape of a classroom also determines the loudness of the teacher's voice (signal) based on the distance between the teacher (signal source) and each student. At the distance of 3ft, the loudness of a voice usually measures approximately 60dB. However, each doubling of distance reduces the signal strength by roughly 6dB. For a student sitting 6ft away, the signal is 54dB. At 12ft, the signal is only 48dB



(a) (b) (c) (d)

Fig. 1 Types of Classroom Arrangement; (a) Traditional rows and columns arrangement, (b) Modular arrangement, (c) Horseshoe arrangement and (d) Stadium arrangement

The spatial attributes in this paper focus on the layout arrangement of the classroom. Traditional rows and columns arrangement shown in Figure 1(a) is the most prominent in most learning environment, especially in college and secondary school settings. Before, the rows and columns arrangement created to make full utilization of the main adequate lighting then accessible—regular light from side windows (Sommer, 1969). Despite the fact that lighting has been developed in the 21st century, traditional arrangement still dominates the classroom seating arrangement. Research by Delefes and Jackson (1972) shows that students who were left out for communicated are those who seated further from the teacher as compared to those who seated at the front row of the class, while students seated in the middle and the back of the class were more probable to commence communication with the teacher than to receive it.

The modular arrangement shown in Figure 1(b) is suitable for classes conducted in small groups which require teacher to supervise closely rather than the whole class. Such arrangement allows for maximum interaction among the student groups while minimizing the obstruction from other groups. A recent research of secondary school classrooms conducted by Ramli et al. (2013), suggests that teachers who choose this arrangement as it can foster students' participant in the teaching and learning process and promote interactions between students.

The horseshoe arrangement shown in Figure 1(c) is often found in smaller classes, such as seminars. Due to the 'dead space' in the center, a few rooms, particularly for bigger class are not physically helpful for this arrangement. Research done by Ramli et al. (2013) perceived that the horseshoe arrangement is improper in the classroom as it will distract the student attention and concentration during the teaching and learning process but may encourage cooperative learning activities (Lofty, 2012). Stadium arrangement shown in Figure 1(d) is best applied to larger classes (Norazman, N. et al. 2019). Stadium arrangement is best suited for teacher centric classes which put the emphasis on the educator. This arrangement enables educators to observe students and give a clear view of classroom front to all the students. It could take up less floor space as compared to other arrangement and make it easy for students to work in pairs. Most of the classroom setting in Malaysia is generally limited to the traditional rows and columns arrangement and modular arrangement due to space limitation and the lesson conducted in primary and secondary school is mainly teacher centric.

METHODOLOGY

Firstly, the 3D model of typical classroom of School A is obtained from research done by Chang (2018) to serve as the base study model of this study. School A is an all-boys secondary school located along Jalan Tun Ismail, Kuala Lumpur. It is established in 1917 and considered to be one of the oldest schools in Malaysia. The typical classroom of this school is selected to be the base model of this study as it has the poorest RT and STI value. The information of the classroom is shown in Table 1.

Four types of selected seating arrangements are modelled using Google Sketchup® and applied to the base study model. In the base study model, architectural details including ornament, cornice and framing were omitted during the 3D modelling as these details do not produce any strong early reflections to the receivers. When modelling the chairs and tables, only sit, back rest and table top are modelled out. Legs and other small details are omitted. Then the models are exported into ODEON Room Acoustic Software 13.0. The validity of a model must be check before the room model is assigned. Simulation accuracy is ensured with complete enclosure of the room model by doing the water tightness test. Four types of seating arrangement which are most commonly seen in Malaysia school classroom were chosen in this study. They are i) Traditional Arrangement; ii) Modular Arrangement; Iii) Horseshoe Arrangement; and Iv) Stadium Arrangement.

The sound source and receivers will be applied into the room after the materials is applied to all the surfaces in the model in ODEON. The study only limited for sound sources frequencies ranging from 125Hz to 8000Hz only due to the availability of material databases of sound absorption characteristics. Speech usually falls between 100Hz and 8000Hz range and may start having difficulty perceiving speech once it exceeds over 3000Hz. Therefore, the concentration on this study will be given on mid-frequency that are between the 250Hz and 2000Hz range, which is where human can intelligently determine human speech or typical human hearing.

A single point of natural raised sound (BB93_RAISED_NATURAL.SO8) will be used as sound source in this study as shown details in Table 2. Raised natural sound source will be applied instead of normal natural sound source to represents a more formal speaking to the class because the normal natural sound source is for normal conversation between the students. This sound source will represent the lecturer standing and teaching in the classroom. The source will be located in the front center of the class, 1 meter in front of the blackboard and 1.5 meter (standing position) above the ground, while the receiver is placed 1.2 meter (sitting position) above ground and at least one meter away from the wall to provide a more accurate simulation. There are 6 simulated points in each classroom according to the seating position of the students and the table arrangement in the classroom. The sound source (red dot) and receiver points' (blue dot) distribution for each room models are shown in Table 4.

The simulation verification using 3D billiard test was performed to ensure whether the room model is completely enclosed as shown in Figure 2. For this research, materials used are adopted from the materials chosen for the base study model done by Chang (2018) as shown in Table 3. However, there are limitation in the investigation where the simulations processes were done without considering the opening of doors and windows as it would be difficult to make a fair comparison between the classrooms because of its background noise discrepancies. Simulation would be limited to the selective acoustical parameters.

Table 1 Information of Typical Classroom in School A

Dimension X (mm)	7650
Dimension Y (mm)	7560
Height (mm)	5450
Area (m^2)	58.5
Volume (m^3)	318.8

Table 2 ODEON point source used for this study

Frequency, Hz	125	250	500	1000	2000	4000	8000
Sound power, dB	59.0	69.5	74.9	71.9	63.8	57.3	48.4

Table 3 Absorption Coefficients of Materials applied for Experiment

	Frequency (Hz)			
Materials	**250**	**500**	**1000**	**2000**
Floor: Material 102, Smooth concrete, painted or glazed (Bobran, 1973)	0.01	0.01	0.02	0.02
Wall: Material 1000, Smooth brickwork with flush pointing, painted (Knudsen & Harris, 1950, 1978)	0.01	0.02	0.02	0.02
Ceiling: Material 4035, Plaster, gypsum, or line, rough finish on lath (Harris, 1991)	0.14	0.60	0.05	0.04
Window: Material 10006, Glass, ordinary window glass (Harris, 1991)	0.25	0.18	0.11	0.07
Door: Material 10007, Solid wooden door (Bobran, 1973)	0.10	0.06	0.08	0.10
Chair (Wooden): Material 11003, Audience on wooden chairs, 1 per sq. m (Meyer, Kunstmann, & Kuttruff 1964)	0.24	0.56	0.69	0.81
Desk: Empty desk (Hassan, 2009)	0.13	0.14	0.17	0.18

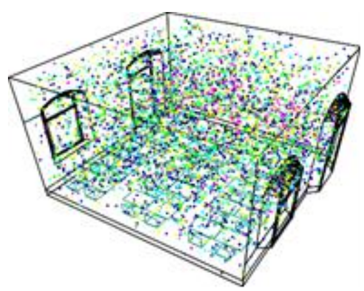
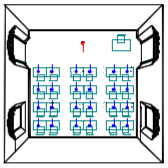
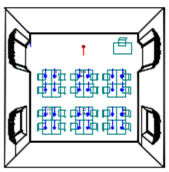
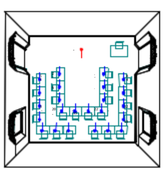
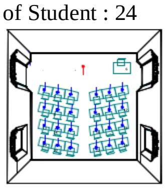


Fig 3 Example of water tightness test via 3D Billiard in a room model

Table 4 Classroom Seating Arrangements Source and Receiver Coordinates

Abb.	Arrangements	Receiver Coordinates							
A1	**Traditional Rows and**	**Receiver**	**X**	**Y**	**Z**	**Receiver**	**X**	**Y**	**Z**
	Columns	R1	3.05	0.88	1.20	R13	5.45	0.88	1.20
	Number of Student : 24	R2	3.05	1.77	1.20	R14	5.45	1.77	1.20
		R3	3.05	3.38	1.20	R15	5.45	3.38	1.20
		R4	3.05	4.28	1.20	R16	5.45	4.28	1.20
		R5	3.05	5.88	1.20	R17	5.45	5.88	1.20
		R6	3.05	6.77	1.20	R18	5.45	6.77	1.20
		R7	4.25	0.88	1.20	R19	6.65	0.88	1.20
		R8	4.25	1.77	1.20	R20	6.65	1.77	1.20
	Source Coordinate	R9	4.25	3.38	1.20	R21	6.65	3.38	1.20
	X = 1.20	R10	4.25	4.28	1.20	R22	6.65	4.28	1.20
	Y = 3.83	R11	4.25	5.88	1.20	R23	6.65	5.88	1.20
	Z = 1.50	R12	4.25	6.77	1.20	R24	6.65	6.77	1.20
A2	**Modular**	**Receiver**	**X**	**Y**	**Z**	**Receiver**	**X**	**Y**	**Z**
	Number of Student : 24	R1	3.05	0.88	1.20	R13	5.45	0.88	1.20
		R2	3.05	1.77	1.20	R14	5.45	1.77	1.20
		R3	3.05	3.38	1.20	R15	5.45	3.38	1.20
		R4	3.05	4.28	1.20	R16	5.45	4.28	1.20
		R5	3.05	5.88	1.20	R17	5.45	5.88	1.20
		R6	3.05	6.77	1.20	R18	5.45	6.77	1.20
		R7	4.25	0.88	1.20	R19	6.65	0.88	1.20
		R8	4.25	1.77	1.20	R20	6.65	1.77	1.20
	Source Coordinate	R9	4.25	3.38	1.20	R21	6.65	3.38	1.20
	X = 1.20	R10	4.25	4.28	1.20	R22	6.65	4.28	1.20
	Y = 3.83	R11	4.25	5.88	1.20	R23	6.65	5.88	1.20
	Z = 1.50	R12	4.25	6.77	1.20	R24	6.65	6.77	1.20
A3	**Horseshoe**	**Receiver**	**X**	**Y**	**Z**	**Receiver**	**X**	**Y**	**Z**
	Number of Student : 24	R1	3.05	0.88	1.20	R13	5.45	0.88	1.20
		R2	3.05	1.77	1.20	R14	5.45	1.77	1.20
		R3	3.05	3.38	1.20	R15	5.45	3.38	1.20
		R4	3.05	4.28	1.20	R16	5.45	4.28	1.20
		R5	3.05	5.88	1.20	R17	5.45	5.88	1.20
		R6	3.05	6.77	1.20	R18	5.45	6.77	1.20
		R7	4.25	0.88	1.20	R19	6.65	0.88	1.20
		R8	4.25	1.77	1.20	R20	6.65	1.77	1.20
	Source Coordinate	R9	4.25	3.38	1.20	R21	6.65	3.38	1.20
	X = 1.20	R10	4.25	4.28	1.20	R22	6.65	4.28	1.20
	Y = 3.83	R11	4.25	5.88	1.20	R23	6.65	5.88	1.20
	Z = 1.50	R12	4.25	6.77	1.20	R24	6.65	6.77	1.20
A4	**Stadium**	**Receiver**	**X**	**Y**	**Z**	**Receiver**	**X**	**Y**	**Z**
	Number of Student : 24	R1	3.05	0.88	1.20	R13	5.45	0.88	1.20
		R2	3.05	1.77	1.20	R14	5.45	1.77	1.20
		R3	3.05	3.38	1.20	R15	5.45	3.38	1.20
		R4	3.05	4.28	1.20	R16	5.45	4.28	1.20
		R5	3.05	5.88	1.20	R17	5.45	5.88	1.20
		R6	3.05	6.77	1.20	R18	5.45	6.77	1.20
		R7	4.25	0.88	1.20	R19	6.65	0.88	1.20
		R8	4.25	1.77	1.20	R20	6.65	1.77	1.20
	Source Coordinate	R9	4.25	3.38	1.20	R21	6.65	3.38	1.20
	X = 1.20	R10	4.25	4.28	1.20	R22	6.65	4.28	1.20
	Y = 3.83	R11	4.25	5.88	1.20	R23	6.65	5.88	1.20
	Z = 1.50	R12	4.25	6.77	1.20	R24	6.65	6.77	1.20

RESULT AND DISCUSSION

The results of the acoustical parameter simulation of all the room models are analyzed and tabulated in the form of grid responses and figures to compare.

1. Reverberation Time

Based on Figure 3, the reverberation time for classroom decreases as the frequency increases from 250Hz to 2000Hz. This is because most materials do not absorb low frequency well, thus resulting in shorter reverberation at higher frequency and longer reverberation in lower frequency (Zannin & Zwirtes, 2009). Under ANSI Standard S12.60 for Classroom Acoustics, the maximum reverberation time in an unoccupied, furnished classroom with volume under 10,000 cubic feet is 0.6 seconds, and 0.7 seconds for a classroom between 10,000 and 20,000 cubic feet at 500Hz. The volume of the classroom selected is 318.8 cubic meters which is around 11,258.3 cubic feet. At 500Hz, A1 shows the highest RT value compared to other seating arrangements which is at 2.16s followed by A2 at 2.09s, A3 at 2.02s and A2 at 1.98s which is the lowest among all the seating arrangements. Based on the results, all the seating arrangements fall out of the range to be considered acoustically good. RT is affected by two factors, the room volume and absorption area. According to Sabine’s formula, reverberation time, $T = 0.161\ (V/A)$, where V is the volume for the room and A is the total sound absorption area. Thus, the poor RT may be due to the lack of non-absorptive materials used in the classroom and the ceiling height.

2. Speech Transmission Index

According to Steeneken and Houtgast (1980), in order to achieve “Good” speech intelligibility, the classrooms need to have STI value of 0.60 and above. Based on the results shown in Figure 4, all the seating arrangements had an average STI value of 0.47, which fall under “Fair” STI rating. The results are plotted in STI versus distance graph. From the graph, all the seating arrangements fall under “Fair” STI rating which is above 0.45. From the simulation, it can be seen that the STI values of all the seating arrangements decrease as the receivers (students) are further away from the source (teacher) except for horseshoe arrangement.

This double U-shaped arrangement allows the sound wave from the source to transmit better to the student sitting furthest away as there is less obstruction in between the teacher and students sitting furthest from the teacher compared to other arrangements. This arrangement also provides an advantage for the teacher to navigate easily from the front to the center of the classroom in order to improve the speech intelligibility. However, we expected the STI value will decrease as the number of student increases.

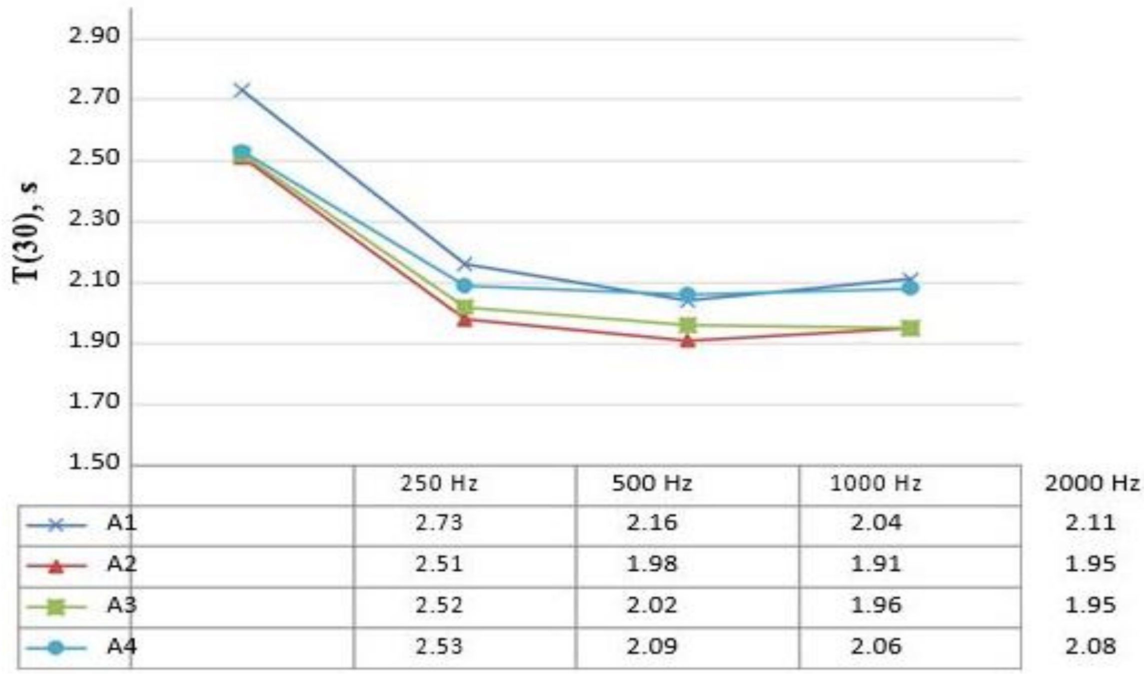


Fig 3 Comparison of Reverberation Time, T30 for each Room Model

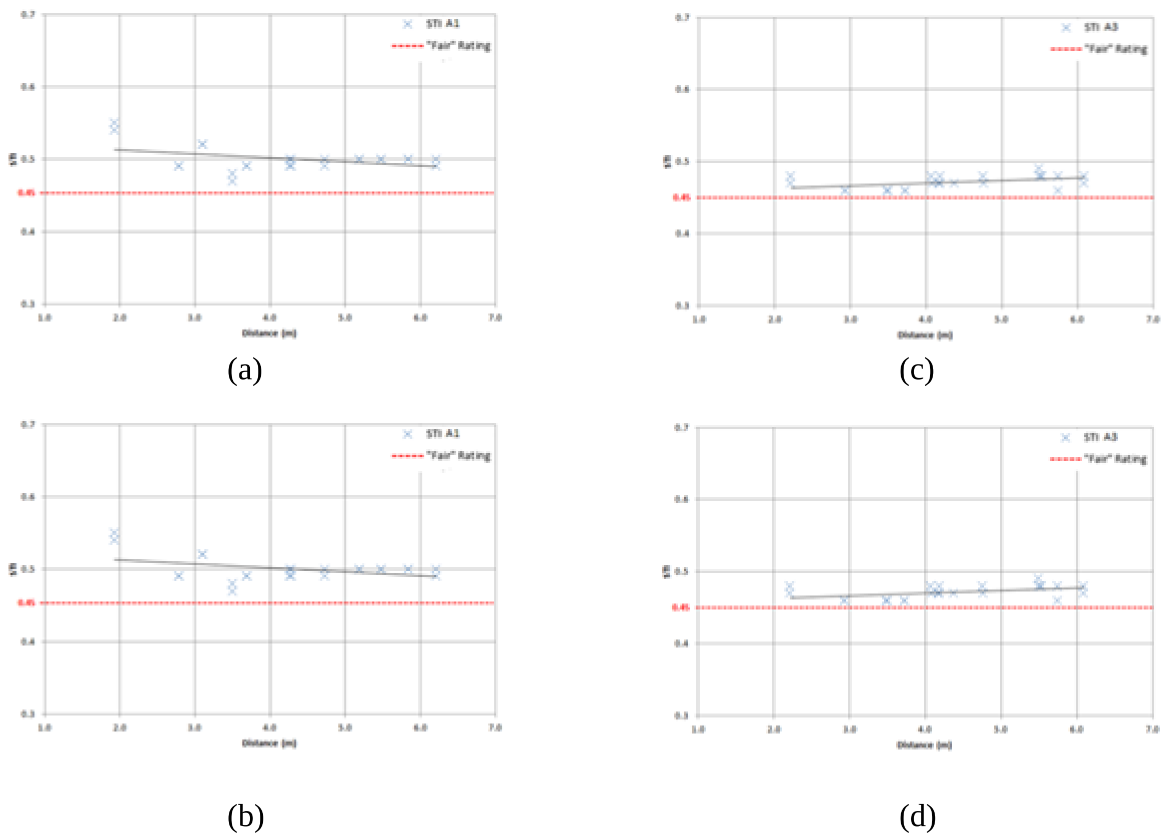


Fig 4 Result of STI versus Distance for (a)A1, (b)A2, (c)A3 and (d)A4

From the analysis, all the room models do not fulfill most of the acoustical criteria which is considered not suitable for speech and lecture, which is the main activity in a classroom. Therefore, two experiments had been carried out:

i. To examine the effect of height of classroom on the reverberation time and speech transmission index.
ii. To study additional material with better absorption coefficient in the classroom.

Experiment 1

In Experiment 1, the height of the base model is changed to 3000mm to examine the impact of classroom height on the RT and STI value in the classroom as shown in Table 5. A1 is chosen as the base model for this experiment as it is the most common seating arrangement found in Malaysia. Based on Table 7, MO1 shows that when the ceiling of the classroom is lowered from 5450mm to 3000mm, the RT value drops significantly from 2.16s to 1.25s at frequency of 500Hz. This shows that ceiling height has a significant impact on the acoustical performance in classroom. In term of speech transmission index as shown in Table 8, MO1 shows improvement from an average value of 0.47 to 0.56. However, the STI rating still falls under “Fair” rating.

Experiment 2

In Experiment 2, absorptive material such as bulletin board are added the classroom with lowered ceiling height to examine the impact on RT and STI value in classroom. Materials chosen are as close as possible to the real material available as shown in Table 6. Based on Table 9, MO2 shows that applying absorptive panel in the classroom improved the RT value from 2.16s to 1.14s at frequency of 500Hz.

Based on the experiments, the ceiling height has a significant impact on the RT and STI value of the classroom. Adjusting the ceiling to a lower height and applying higher absorptive furniture or material can further improve the RT and STI value in the classrooms. In terms of speech transmission index as shown in Table 10, MO2 shows a slight improvement in STI value from an average value of 0.47 to 0.57. However, the STI rating still falls in the “Fair” rating. Better absorptive material can be applied to other element in classroom such as blackboard in order to further improve the STI value in classroom to achieve a conducive space for learning.

Table 5 Information of Base Model for Experiment 1

Dimension X (mm)	7650
Dimension Y (mm)	7560
Height (mm)	3000
Area (m^2)	58.5
Volume (m^3)	175.5

Table 6 Absorption Coefficients of Materials applied for Bulletin Board in Experiment 2

	Frequency (Hz)			
Materials	**250**	**500**	**1000**	**2000**
Panel: 13mm thick, without slots, on 30mm studs with mineral wool	0.32	0.12	0.06	0.03

Table 7 Comparison of T30 Results for the Modified Classroom across Four Octave Bands (250Hz-2000Hz) – Experiment 1

Room Models	**Frequency, Hz**			
	250 Hz	500 Hz	1000 Hz	2000 Hz
O	2.73	2.16	2.04	2.11
MO1	1.56	1.25	1.17	1.28

Table 8 Comparison of STI Results for the Modified Classroom – Experiment 1

	Min	**Max**	**Average**
O	0.45	0.48	0.47
MO1	0.54	0.58	0.56

Table 9 Comparison of T30 Results for the Modified Classroom across Four Octave Bands (250Hz-2000Hz) – Experiment 2

Room Models	**Frequency, Hz**			
	250 Hz	500 Hz	1000 Hz	2000 Hz
O	2.73	2.16	2.04	2.11
MO2	1.26	1.14	1.16	1.39

Table 10 Comparison of STI Results for the Modified Classroom – Experiment 2

	Min	**Max**	**Average**
O	0.45	0.48	0.47
MO2	0.54	0.59	0.57

CONCLUSION

In this study, four types of different classroom seating arrangement are derived and applied to the study model to evaluate their impact on acoustical performance in classroom. From the results, it was found that modular arrangement has the best reverberation time among all the seating arrangements. In terms of speech transmission index, horseshoe arrangement achieved the best speech intelligibility among all. Two experiments were carried out by changing the height of classroom and applying additional absorptive material to analyze the effect on acoustical performance of the classroom. It can be concluded that reverberation time of a classroom can be decreased by decreasing the room volume and adding higher absorption material to the classroom. Further investigations and comparative simulation

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