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ACOUSTICAL ANALYSIS FOR THE LECTURE ROOMS IN UNIMAP

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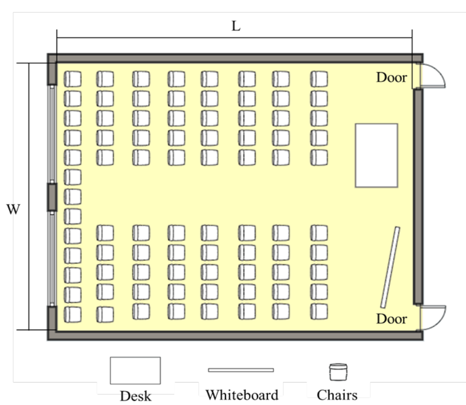
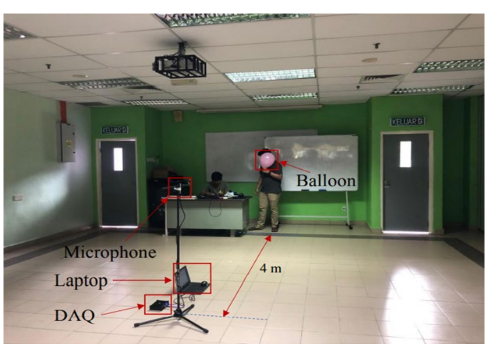
Graphical abstract





Abstract

Acoustic analysis is a measurement used to analyse the behaviour of sound waves in enclosed spaces, which influences speech intelligibility. Another parameter that influences speech intelligibility is reverberation time. Reverberation time is the time for the sound source to decay by 60 dB. A high reverberation time causes sound to dissipate more slowly, resulting in continual reflection of sound waves, which disrupts student concentration in class. Furthermore, a poor acoustic environment could have an impact on health and lecture delivery. The objective of this study is to determine and analyse the acoustic performance for five selected lecture rooms in UniMAP. The reverberation time is the parameter of this study that was obtained from the Root Mean Square (RMS) of the sound pressure by using the impulsive sound source method from a burst balloon. In this study, the "balloon pop" sound pressure was consistently recorded at approximately 105dB across all cases. This measurement indicates the peak sound intensity of the stimulus. The influence of the location of receiver, design, and space volume for the lecture room on the reverberation time was investigated. At a location of 6 m from the sound source, at the back wall of a room with chairs, BKN 5 and BPU 5 measured longer reverberation times of 1.3 s and 1.2 s, respectively. The higher value of reverberation time is caused by where the sound receiver is. If it is close to a wall, the sound receiver will be exposed to numerous reflections of sound waves, causing the room to become reverberant. Compared to other lecture rooms, the length of BKN 5 and BPU 5 is shorter. Their lengths are 11.639 m and 11.689 m, so the sound receiver is closer to the wall and makes the reverberation time higher. BKN 5 room, which has a volume of 258.3 m^3, had the highest reverberation time (1.2 s on average in a room with chairs). This is because it is larger than the other rooms. So, the reverberation times get longer as the room's volume increases. BPU 5 room had the longest reverberation time for a condition room without chairs (an average of 2.4 s), but it also had the smallest space volume (242.4 m^3) compared to the other rooms. Thus, it takes longer for the sound waves in the room to fade away when there are no chairs there. If the smaller room didn't have enough sound-absorbing materials, the reverberation times would be longer.

Keywords: Acoustics, speech intelligibility, reverberation time, sound-absorbing material, lecture room

1.0 INTRODUCTION

The importance of room acoustics has become more prevalent in today's world. These features must be utilized appropriately to create a pleasant learning environment for the students. A good verbal communication can be defined as speech intelligibility as the reverberation time is an important factor that influences the speech intelligibility in the lecture room [1, 2, 3, 4]. Reverberation is referred to the collection of sound in an enclosed space after the sound source has been stop emitting. In contrast, reverberation time is the time it takes for a sound to dissipate after the sound source has stopped. A room should have the optimum reverberation time for its intended use, as 0.5 to 1 second is desired for a small room less than 300 m^3. More than 2 seconds is suitable for a large room like a hall or auditorium [5].

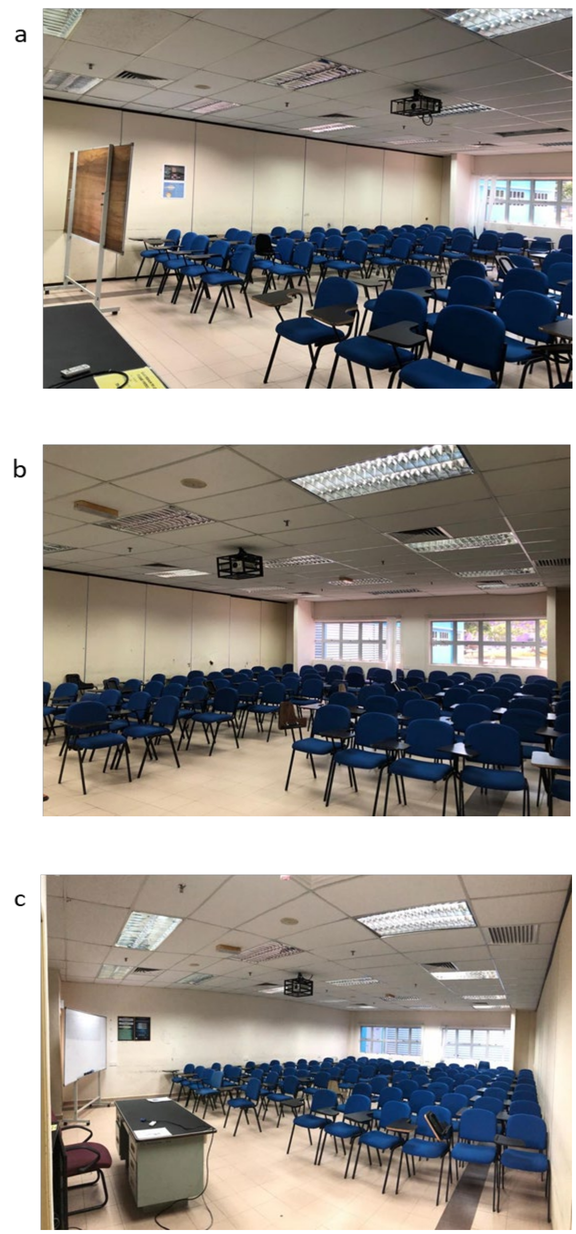
The optimum reverberation time depends on the purpose use of the space which is the ideal reverberation might differ from room to room, depending on characteristics such as the arrival of reflections at the receiver [6]. Higher reverberation time with persistent reflection of sound waves affects speech intelligibility, making it difficult for our ears to hear and understand, which could lead to a poor acoustic environment for lecture delivery and cause the lecturer to raise their voice, which causes vocal strain and affects their health.

The time taken for the sound to travel, which is the reverberation time, is inversely proportional to the speech intelligibility. The shorter the reverberation time, the higher the speech intelligibility [7]. In contrast, reverberation time for a small room size should not less than 0.3 second, that could lead to difficulty to hear the sound or speech. The size and design of the space, as well as the ambient sound-absorbing material, all have an impact on how effectively such a room serves its objective. A study on estimating reverberation time in classrooms limited the application approach to rooms that were too small to avoid measurement data distortion [8].

The reverberation time increases with the volume of room and decreases with the addition of sound-absorbing material in the room [9, 10]. The room with furniture material offer better acoustics on reverberation time compared to an empty room [11]. However, higher absorbency of material will lead to early decay of sound that will affect the speech intelligibility [12]. A small rectangular with the hard wall can cause drawback to the reverberation time which will make the reverberation time longer due to small room sizes and causes modal behaviour to dominate the room response. The acoustics of small spaces are frequently characterised by uneven sound distributions at low frequencies [5]. The different size of the room and the influence of sound absorption material have an effect on the reverberation time [13]. Hence, a smaller space with high absorption has the shortest reverberation time, while a larger room with moderate absorption has the longest reverberation time [14].

2.0 METHODOLOGY

This study includes five different lecture rooms to perform acoustical analysis, which are four BKN's lecture rooms (BKN 1, 2, 3, and 5) and one from BPU's lecture room (BPU 5). Figure 1 shows the selected lecture rooms at UniMAP premise as the location to perform the acoustical analysis of reverberation time. The equipment required to perform the experiment includes a laptop, multi-channel data acquisition, and measurement microphone, as shown in Figure 5. Laptop and acoustics analysis software used to visualize the data and graph from the microphone signal. All five (5) selected lecture rooms with the condition set for the location of receiver to the sound source are conducted with the constant design of lecture room, which is in rectangular shape, and at the various space volume of each selected room, in condition with and without chairs. Figure 2 illustrates the floor plan for the lecture rooms in the UniMAP. All the dimensions of the rooms and the number of chairs in the room is depicts in Table 1.



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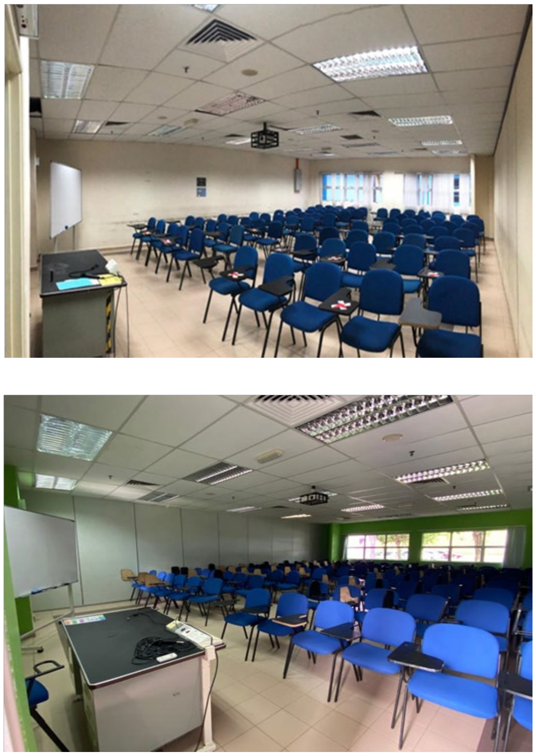

Figure 1 Selected five (5) different lecture rooms (a) BKN 1, (b) BKN 2, (c) BKN 3, (d) BKN 5, and (e) BPU 5

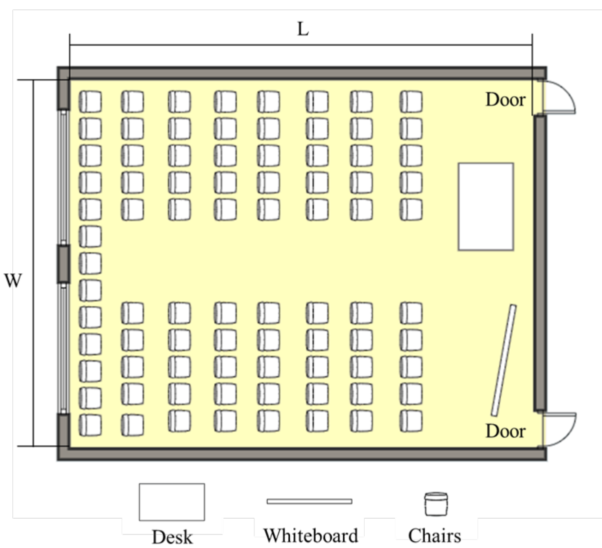

Figure 2 Floor plan for lecture room in UniMAP

Table 1 Dimensions of the rooms and the number of chairs in the room

Selected lecture room	Dimensions of the rooms (m³)			Number of chairs in the rooms	Space volume (m³)
	Length	Width	Height		
BKN 1	11.759	7.561	2.816	88	250.4
BKN 2	11.720	7.670	2.800	85	251.7
BKN 3	11.732	7.621	2.806	95	250.9
BKN 5	11.639	7.930	2.798	80	258.3
BPU 5	11.689	7.529	2.754	96	242.4

The distance of the receiver from the sound source is set from 2 m to 4 m, and 6 m with the sound source (balloon) is placed at 1.3 m height and conducted with the same person constantly in all cases, as shown in Figure 4. Figure 3 illustrates the floor plan for the lecture room in the UniMAP, showing the sound source spot placed at the front of the lecture room and the receiver spot with a different distance. The reverberation time data collection is obtained by using VA-Lab acoustics software with impulse method using sound level meter application in the software. Throughout the study, background noise levels were consistently recorded at approximately 35dB, while the "balloon pop" sound pressure was consistently measured at around 105dB. This significant difference ensures that the decay rate estimation for RT60 is not adversely affected. Root Mean Square (RMS) is equal to the average of the sound pressure. Thus, for this study, the reverberation time is obtained based on the decay curve from the RMS of the sound pressure against the time graph.

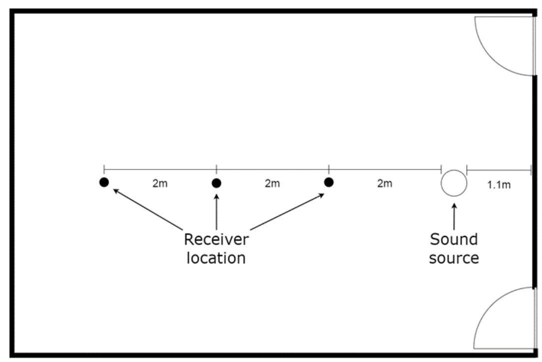

Figure 3 Sound source (white circle) spot placed at front of the lecture room and the receiver (black dot) spot distance varies from 2 m to 4 m, and 6 m from the sound source

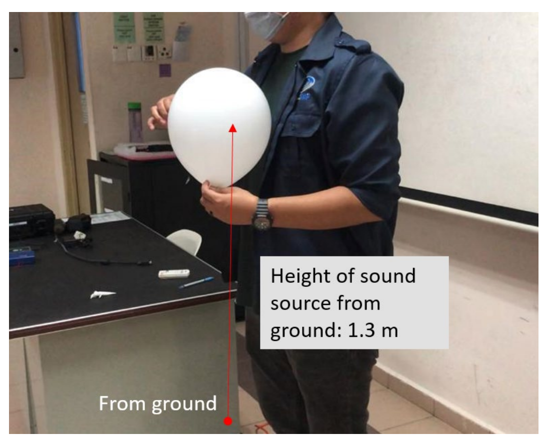

Figure 4 Height of sound source (balloon) constantly at 1.3 m

2.1 Sabine equation

The Sabine equation (Eqn. 1) is an equation that calculated the reverberation time by multiplying the space volume of the room in cubic meters and divided with the surface area of the room in square meters times the average sound absorption coefficient of the room [15]. For the equation, it shows that there is relationship between the space volume of the room to the reverberation time. Reverberation time is depending on the volume of the room, as the higher the volume of the room, the higher the reverberation time and the higher the average sound absorption coefficient of the room, the lower the reverberation time will be.

$$RT_{60} = 0.161\frac{V}{S\bar{\alpha}} \qquad \text{(Eqn. 1)}$$

V = The volume of the room (m^3)

S = The surface area of the room (m^2)

$\bar{\alpha}$ *= The average sound absorption coefficient*

2.2 Experimental Measurement Setup

The impulse response method, which generates the sound source from an impulsive sound like a burst balloon, is the most practical approach to utilise [16]. The sound source is placed at a constant distance of 1.1 m from the wall. The height of the microphone is set at a constant height, which is 1.3 m using a stand. Experimental data is measured by using the impulse sound from a burst balloon that repeats the process at different distances from the microphone from the sound source. The result of reverberation time is obtained based on the RMS of the sound pressure graph by using the general reverberation time measurement from Figure 6. The 60 dB decay of sound from the sound source has stopped emitting is the reverberation time of the room. The experimental setup is shown in Figure 5 for measurement in room conditions without chairs at a location 4 m from the sound source (balloon).

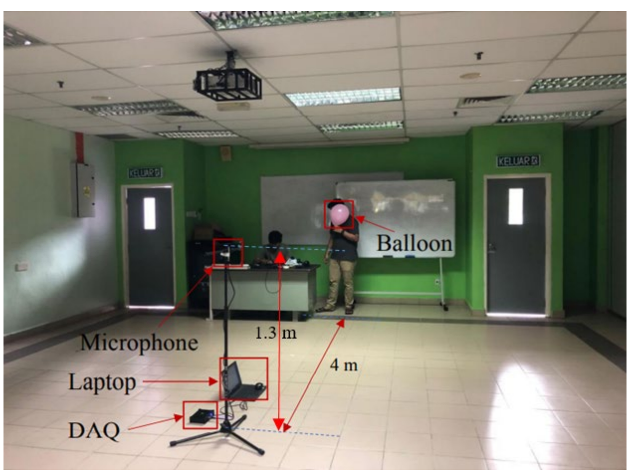

Figure 5 Experimental measurement in room conditions without chairs at a location 4 m from the sound source (balloon)

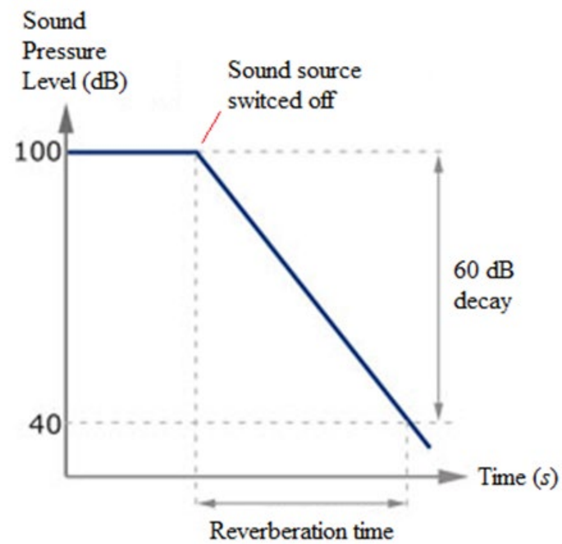

Figure 6 Basic principle of the reverberation time measurement [17]

3.0 RESULTS AND DISCUSSION

The method used to obtain the RT60 values is the impulse method using sound level meter application in the VA-Lab acoustics software. The RT60 is obtained based on the decay curve from the sound pressure against the time graph. The "balloon pop" sound pressure was consistently recorded at approximately 105dB for all cases investigated in this study, which significantly exceeded the background noise level of 35dB.

Tables 2 and 3 show the reverberation times obtained from the rooms with and without chairs. Figure 7 shows the reverberation time data for both environments with and without chairs. Based on Figure 7 (a), (b), and (c), the green colour bar represents the rooms with chairs occupied. The measured reverberation time indicates that a lecture room occupied with chairs or sound-absorbing material in the room will result in a lower reverberation time compared to a lecture room without the chairs. Rooms without chairs (shown by the blue bar) had higher measured reverberation times.

Table 2 Reverberation time (s) for rooms with chairs

Selected lecture room	Reverberation time (s) at location of receiver from the sound source (m)			Space volume (m³)
	2 m	4 m	6 m	
BKN 1	1.0	1.0	1.0	250.4
BKN 2	1.2	1.2	0.9	251.7
BKN 3	1.2	1.2	1.0	250.9
BKN 5	1.2	1.0	1.3	258.3
BPU 5	1.0	1.1	1.2	242.4

Table 3 Reverberation time (s) for rooms without chairs

Selected lecture room	Reverberation time (s) at location of receiver from the sound source (m)			Space volume (m^3)
	2 m	4 m	6 m	
BKN 1	2.2	2.4	2.1	250.4
BKN 2	2.2	2.2	2.2	251.7
BKN 3	2.2	2.2	2.2	250.9
BKN 5	2.2	2.4	2.4	258.3
BPU 5	2.2	2.4	2.5	242.4

Figure 7 Graph of reverberation time against lecture rooms with and without chairs at location (a) 2 m, (b) 4 m, and (c) 6 m

There is a significant relationship between the sound-absorbing material and the reverberation time. If there are more sound-absorbing materials in the space, it will achieve the ideal reverberation time, which is less than one second for a small-sized room of less than 300 m^3. The desired reverberation time for speaking should be less than 1 second but not less than 0.3 seconds because the room will be acoustically "dead," making it impossible to hear in the back room [18, 19]. Therefore, a small lecture room will have good acoustic quality for presenting the lecture efficiently and will have improved speech intelligibility if the reverberation time is not less than 0.3 s and not more than 2 s.

3.1 Effect Of Receiver Location From The Sound Source To The Reverberation Time

Based on the obtained reverberation time showed in Figures 7(a)-7(c), the parameter set for this experiment to investigate the relationship of reverberation time to the location point of the receiver, which is microphone from the sound source shows not much strong relation to each other. In contrast, there are relationship between the location of receiver to the back wall of the room. From the result, it shows that the value of reverberation time is slightly decreasing at location 2 m to 6 m for the lecture room's BKN 1, 2, and 3. The space volume of these three rooms are not much different, which are 250.4 m^3 (BKN 1), 251.7 m^3 (BKN 2), and 250.9 m^3 (BKN 3). Results for the lecture room BKN 5 and BPU 5 shows that the reverberation time is higher at the back location of 6 m distance from the source. They were recorded as 1.3 s, and 1.2 s that is near to the back wall of the room. Thus, there are increasing value occur for the reverberation time when the location of the receiver from the sound source is near to the back wall compared to other three lecture rooms that are showing the decreasing value.

At the same time, there are relationship between the location of receiver to the back wall of the room. The BKN 5 room has a bigger space volume than other rooms, but the length of the room is shorter than other rooms, which causes the late decay of sound and reflection of sound. Late decay of sound will make the sound that propagates to bounce back at the surface of wall in the room that cause reverberation and echoes phenomenon is happened. Same goes to the smaller room like BPU 5, the smaller room also leads the sound wave to be reflected or bounce back to the surroundings if the room does not have proper sound-absorbing material applied in it.

The farther the sound receiver from the source, the lower the sound intensity. Small rooms (less than 300 m^3) show a minimal relationship between location and reverberation duration, whereas large rooms show a difference when the receiver is farther from the sound source. In conclusion, the location of the receiver in a small room and the reverberation time in terms of the distance between the receiver and the back wall of the room are related.

3.2 Effect Of Space Volume To The Reverberation Time

According to the data shown in Table 2, the reverberation time for the room with chairs, the average value of the reverberation time to each three-location point for five lecture rooms is 1.1 s, except for BKN 5, which is 1.2 s. From Table 3, the average reverberation time for the condition room (BKN 1, BKN 2, BKN 3) without chairs is 2.2 s. Besides, the average reverberation time for BKN 5 and BPU 5 without chairs was recorded as 2.3 s and 2.4 s. The obtained result shows the reverberation time for BKN 5 room recorded the highest value compared to other rooms, with a space volume of 258.3 m^3, which is larger than other rooms. The BPU 5 room recorded the second highest reverberation time for the condition room without chairs, while the space volume for this room was measured as the smallest among the other rooms. This is because the sound-absorbing material, which are the chairs, have been removed from the room, causing the sound wave propagation in the enclosure space to take longer to dissipate than in the room with chairs.

Thus, the larger the space volume of the room, the higher the reverberation time. However, for the smaller room without proper sound-absorbing material, the room would become reverberant too. The removal of the sound-absorbing material, which are chairs, causes the sound wave propagation in the enclosure space to take longer to dissipate than in the room with chairs. The result shows that the space volume of the room is not the only factor that would affect the reverberation time. Still, another thing that affects the reverberation time is how it relates to the average sound absorption coefficient.

3.3 Effect Of Sound-Absorbing Material In The Room To The Reverberation Time

Sound-absorbing material is referred to the chairs in the rooms for this study. A comparison has been made between the rooms with and without chairs. Based on the results from the conducted experiment, there are prominent differences in reverberation time between the room with and without chairs. The difference shows that the sound-absorbing material has a great influence on the reverberation time.

Based on the results, the lecture room of BPU 5 has the second highest reverberation time of 2.4 s in the condition of the room without chairs. Even though the reverberation time for BPU 5 is relatively high in the absence of chairs, it can achieve the same average reverberation time as other rooms in the presence of chairs. It is because the number of chairs in the BPU 5 room is higher, which is 96 chairs, compared to other rooms with 88, 85, 95, and 80 chairs. Thus, with a higher number of chairs in the room, the sound waves that travel in the space will be absorbed partly by the surfaces of the chairs or objects in the room, which will reduce the numerous sound reflections.

The number of chairs in the room could be a factor influencing the reverberation time results. Based on the Sabine equation, it also shows that the average sound absorption coefficient has a significant relationship to the reverberation time. Therefore, with an adequate amount of sound-absorbing material in the room, the reverberation sound will be reduced. As a result, the reverberation time for a room would vary with the sound-absorbing material used.

4.0 CONCLUSION

In this study, the reverberation time for the lecture rooms in UniMAP for the condition of the room with chairs of BKN 1 is recorded as 1.0 s in average. For the lecture room of BKN 2, BKN 3, and BPU 5 is recorded as 1.1 s in average except BKN 5 with 1.2 s. Hence, the reverberation time of the lecture room in UniMAP have been determined as nearly at the optimum reverberation time which is the optimum reverberation time is less than a second for a small category size of the room and with the space volume that less than 300 m^3 [5, 9, 20]. However, the reverberation time for all this rooms still able to be reduced to the desired reverberation time if proper improvement is implemented such as putting the adequate amount of sound-absorbing material in the room.

The comparison of the condition of the room with and without chairs is concluded, as the reverberation time is reduced by having the sound-absorbing material in the room. If a sound receiver is placed close to a wall, it will be subject to multiple reflections of the sound wave that travels from the sound source, which makes it highly reverberant. The larger the space volume of a room, the higher the reverberation time. Even so, other factors like the average sound absorption coefficient would be the alternative to reduce the reverberating time.

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