An Investigation on Factors That Cause Error in Reverberation Time Measurement (ISO 3382) in UTHM Lecturer Room

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ABSTRACT

This study was conducted to determine the cause of error that occurred on the reverberation time measurement. Measurements were performed in a UTHM lecturer room in accordance with ISO 3382 standards. Room was designed with different conditions; empty room, room with curtain and room that used egg containers as sound absorber. The results of measurements were compared with the results based on calculation using Sabine, Millington-Sette and Eyring formula. Comparisons were made using the Mean Absolute Error (MAE) statistical method. The analysis showed that the error occurs due to the factors of absorption materials selection, sound frequency, room shapes, material position and background noise.

Keywords: Reverberation time; theoretical method; sound measurement; frequency; absorption coefficient; ISO 3382

1. INTRODUCTION

An effective discussion should be conducted in an area with good acoustic quality. In a closed space, the discussion can be disrupted by the presence of reverberation sound. Reverberation sound can be measured by measuring the duration of its presence. This period is calculated starting when the sound source is stopped. Theoretically, reverberation time is calculated in units of seconds in the 60 dB reduction of noise level after the sound source is stopped (1).

Various ways can be used to predict reverberation time such as Finites Element Method (2), Boundary Element Method (3) and Ray-Tracing (4). However, these methods require complex processes. By using theoretical method, measurement can be made easier. The theoretical method is the method that predicts reverberation time by using formulas such as Sabine (5), Eyring (6) and Millington-Sette (7).

Measurement method can detect the reverberation time more accurately. Among the measurement methods are interrupted noise and impulse response method. These two methods are based on ISO 3382 standards (8). However there are problems such as error and inaccurate data may arise in the measurement.

The objective of this study was to find the factors of error in the measurement conducted in a lecture room. Results of this study can produce improvement in reverberation time measurement so that more accurate data can be obtained.

2. ERROR OCCURRENCE FACTORS

There are many factors that contribute for error in measurement. The factors course the reading of the measurement to be inaccurate. Thus, the factors need to be identified.

Frequency is an important factor in measuring the sound character in a room and it has a great potential to create change in the calculation or measurement. There are various parameters which can be influenced by the frequency, and sound absorption is one of them. Material properties such as hard, soft, porous or have open cell space can change the reading of a sound of measurement depending on the frequency of the sound. Hard material can absorb sound in the high rate at low frequencies while porous materials absorb sound efficiently at high frequencies (9). Materials with open cells absorb more effectively at high frequencies. Besides reacting to material properties, frequency also influences the stability rate of noise reduction graph. In the low-frequency, graph of reduction noise level decreass at unstable rate (10). It causes error in reading. But when frequency is increased, the stability of graph of reduction sound level graph improves. When the frequency is increasing, noise levels reduce at a more stable condition.

Material selection is so important in determining the characteristic of room acoustic. These materials are able to determine the use of a room whether as a place for voice recording, the speech room or reading area. Porous materials have high sound absorption rate. When the sound energy violates porous surface it causes sound energy to be converted to heat energy due to the vibration caused by the breach of tiny particles of porous material (10). This can reduce noise energy. Hard materials have properties that reflect sound. In addition, the thickness of the material also plays an important role in influencing the sound absorption efficiency. When thickness of material increases, it increases the sound absorption ability. Material that have open cell reduces sound energy by reflecting and trapping it into the other corner of the same cell. Thickness also increases the efficiency of open-celled materials to reduce sound energy. By using curtains, room acoustic properties can be changed. Curtains can be categorised as porous materials. The way for hanging the curtains can also affect the character of a room. The percentage of folded curtain also affect the sound absorption efficiency. Therefore the selection of material may result in a change in the calculation or measurement.

Material location can change the characteristics of the room acoustic (10). The characteristics change is due to noise response on hard surfaces. Especially porous material, it can change the sound absorption rate. When sound waves approach the wall, the pressure rises, but the speed of the air particles will be zero. When wavelength distance from the wall is 1/4, the pressure becomes zero and the air particles become higher in speed. If the porous material is placed at a distance of 1/4 wavelength from the wall, the sound absorption will be at maximum at a frequency as the speed of the particle is at the maximum rate on the material and lead to a loss due to friction.

Background noise can disrupt a measurement of character noise in a room. Based on the theoretical spectrum of the background noise, each noise spectrum has a relationship with frequency (11). White noise is one of the sound spectrums that when frequency increases the noise level also increases. For masking noise spectrum, its noise rate fall by 3 db to 6 db per octave at medium and high frequencies. Low background noise will be reduced when the frequency increases. Based on the above statement, if the background noise is too high, the measurement will be interrupted and cause change in the noise level due to interference of external noise frequency.

The appearance of the room such as building edges can increase the error in the measurement of sound character in a room (12). When the sound is produced, the sound waves will travel at the same intensity in each direction. The sound does not only come to the receiver directly from the sound source, but partly derived from the results of the sound waves from hard surfaces of the room. Sound reflections from different directions have different rates of energy and its presence is delayed due to the increasing travel distance of sound waves. Reflections characteristic have three quantities, that are relative error, relative strength and relative of time that have to be taken for sound to arrive to receiver.

3. Experiment methodology

A lecturer room in UTHM was used as a study object and assigned to three different conditions as variables; empty room, room with curtains and room with egg containers as sound insulation. The weight of curtains was 238.89 g/m^2, while the egg cottons area was 9.61m^2 and 0.05m thick. The room parameter was measured and all materials of the room were identified.

Reverberation times of the room were predicted by theoretical method calculation using Sabine, Eyring and Millington-Sette formulas. The three formulas were used to see whether the formula factors contributed to the occurrence of errors. These were the formulas that been used:-

Sabine

$$T_{60} = \frac{0.161 \times V}{S\bar{\alpha}} \quad (1)$$

Eyring

$$T_{60} = \frac{0.161 \times V}{-S\, ln(1-\bar{\alpha})} \quad (2)$$

Milingtton-Sette

$$T_{60} = \frac{0.161 \times V}{-\sum S ln(1-\bar{\alpha})} \quad (3)$$

where

V is the volume of the room
S is the area of each material
$\bar{\alpha}$ is the absorption coefficient of each material
ln is the neperian logarithm

The measurement in real room was accordance with ISO 3382 standards, which use noise Interruption method. Equipment such as Omni directional speakers, amplifiers and microphones were used in this measurement. Computer software, namely DB Bati was used to receive and collect data of reverberation time.

The first measurement was done in an empty room. The second measurement was performed when the room was installed with curtains on the main window and the condition was 50% pleated. The last measurement was performed in a room that used egg container as sound insulation. Eggs containers were glued on the whole wall of the room except for windows and doors.

After the measurement data from the three variables were obtained, comparisons were made on calculation with the measured data. MAE statistical methods were used to analyze the differences on the data obtained. Below is the MAE formula used;-

$$MAE = \frac{\sum(a-e)}{n} \quad (4)$$

where

a is the actual value.

e is the predicted value.

n is the total value of the research data.

Comparison of the analytical results MAE was used to find the factors that caused errors during the measurements.

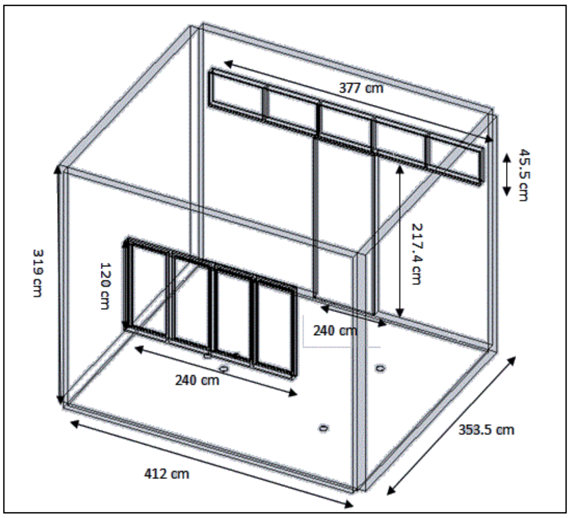

Figure 1. Scale of the room that had been used for the measurement

Table 1. Value of absorbtion coefficient for construction material and variable (curtain and egg containers) (13)(14).

Material	**Frequency (Hz)**					
	125	250	500	1000	2000	4000
Window	0.35	0.25	0.18	0.12	0.07	0.04
Wooden door	0.14	0.1	0.06	0.08	0.1	0.1
Plaster brick	0.013	0.015	0.02	0.03	0.04	0.05
Cork Tile	0.02	0.03	0.03	0.03	0.03	0.02
Concrete	0.01	0.01	0.01	0.02	0.02	0.02
Egg container	0.04	0.3	0.42	0.48	0.69	0.69
Curtain	0.07	0.31	0.49	0.75	0.7	0.6

4. REVERBERATION TIME RESULTS AND COMPARISON BETWEEN MEASUREMENT AND CALCULATION

Reverberation time calculation results obtained using the formula were classified according to the type of formula (Sabine, Eyring and Millington-Sette). It was then compared with the measured reverberation time in a real room. Comparison was made using the MAE.

The highest average value of error recorded during the measurement error was 3.6 s, recorded when room using curtains at 250Hz frequency. While the lowest value was recorded in the room that used egg containers as sound absorbers, totalling 0.47 s at frequency of 2000Hz and 4000Hz.

When using the Sabine formula, the highest comparative value was 0.87s at frequency 250Hz, recorded in the room installed with curtains. The low comparative value was 0.09s, when the room was empty at frequency 2000Hz. When using the Eyring formula, the highest difference value was 0.9s recorded in the room with curtains, at frequency 250Hz. The lowest value was 0.1s recorded when the room was empty at frequency 1000Hz. The highest comparative value when used the Millington-Sette formula was 1 s when the room was empty at a frequency of 125Hz. The lowest comparison value recorded was 0 s when the room used curtains at a frequency of 1000Hz.

Table 2. Result of reverberation time by measurement

Room condition	**Frequency**					
	125	250	500	1000	2000	4000
Empty room	3.29	3.13	3.28	2.8	2.62	2.67
Curtain	3.32	3.6	1.55	1.17	1.17	1.18
Egg Container	2.16	0.8	0.72	0.53	0.47	0.47

Table 3. Result of reverberation time by calculation using Sabine formula

Room condition	**Frequency**					
	125	250	500	1000	2000	4000
Empty room	2.61	2.9	3.13	2.75	2.53	2.42
Curtain	3.64	2.73	2.28	1.65	1.57	1.59
Egg Container	1.86	0.51	0.39	0.34	0.24	0.25

Table 4. Result of reverberation time by calculation using Eyring formula

Room condition	Frequency					
	125	250	500	1000	2000	4000
Empty room	2.92	2.86	3.08	2.7	2.49	2.39
Curtain	3.6	2.7	2.23	1.59	1.52	1.54
Egg Container	1.82	0.46	0.34	0.29	0.19	0.2

Table 5. Result of reverberation time by calculation using Millington-Sette formula

Room condition	Frequency					
	125	250	500	1000	2000	4000
Empty room	2.92	2.7	3	2.68	2.48	2.37
Curtain	3.36	2.49	1.94	1.17	1.19	1.32
Egg Container	1.68	0.43	0.3	0.26	0.15	0.15

5. ANALYSIS CAUSE OF ERROR BASED ON MAE GRAPH

An analysis was performed by producing graphs based on the data comparison of MAE value between measurement and calculation of reverberation time. The graphs were based on three variables stated earlier.

Based on Figure 2, it can be seen the error value was reduced when the frequency increased. During the measurement, the room was empty and there was no sound absorbing materials. This indicates that the error that occurred can be attributed to the factor of sound frequencies. As seen, high error rates occur at low frequency. This is due to the current graph measurements of noise reduction was less stable and give inaccurate readings. At the frequency of 4000 Hz, the error increased most likely, this happened because of the background noise that came from construction at nearby buildings. It can be concluded that the error occurred on the Figure 2 was influenced by the factor of frequency of the sound and background noise.

In figure 3, at frequency of 250 Hz, the highest error value was recorded. The main factor that likely contributed to this error was due to the used of curtains as sound absorbing materials. When using curtains, classified as porous material, the distance factor from the hard surfaces of wall should be emphasized. The error occured might due to the distance of curtains from the wall that was not in the position of 1/4 wave length. Position of 1/4 wave length caused the sound to be absorbed at the maximum rate. At frequency of 125 Hz, the error rate was small. It can be stated that position of the curtains in the suitable point for the absorption for frequency 125 Hz.

Based on figure 4, it was found that the error value decreased from low frequency to high frequency. The errors occurred due to the selection of sound absorption material. The sound absorption materials used were egg containers and the whole wall of the room was affixed with egg containers. Probably the egg containers used did not resemble the egg containers from the absorption coefficient experiment from the literature review. The difference in thickness could cause change in sound absorption rate. Besides that, opening cell cavity and the air space behind the egg container could make different in sound absorption rate. As a result, it was caused error to increase.

Background noise and the appearance of the rooms also contributed in producing errors. Background noise factor caused the error because when measurement was done there were disruptions by vehicle noise and at that time there were renovations carried out in a nearby building that generated construction sound. Appearance of the rooms also contributed to the error. When viewed from the formula structural, it did not take into account the angle and sound reflection generated because of the appearance of the room. Due to this matter, reflection may produce different reverberation time from the calculations method. By using calculation, differences were found between the three formulas. This is because these three formulas were used for different conditions. Sabine was a formula that could be used in rooms that lack sound absorption material, while Eyring and Millington-Sette were otherwise.

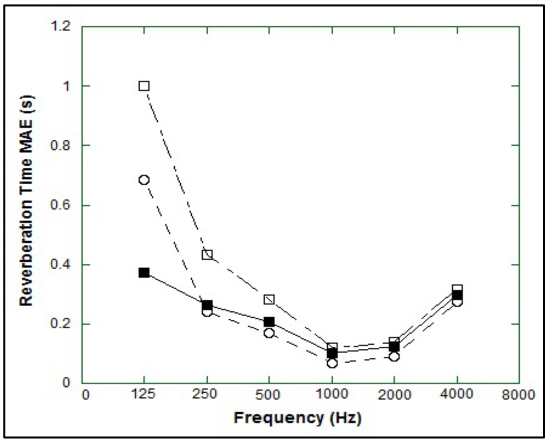

Figure 2. MAE graph for empty room (○ = Sabine’s formula, ■ = Eyring’s formula, □ = Melingtton-Sette’s formula).

Table 6. MAE value for empty room

Formula	Frequency					
	125	250	500	1000	2000	4000
Sabine	0.684	0.24	0.17	0.069	0.092	0.274
Eyring	0.373	0.265	0.208	0.1	0.126	0.299
Millington-Sette	1	0.435	0.281	0.12	0.138	0.361

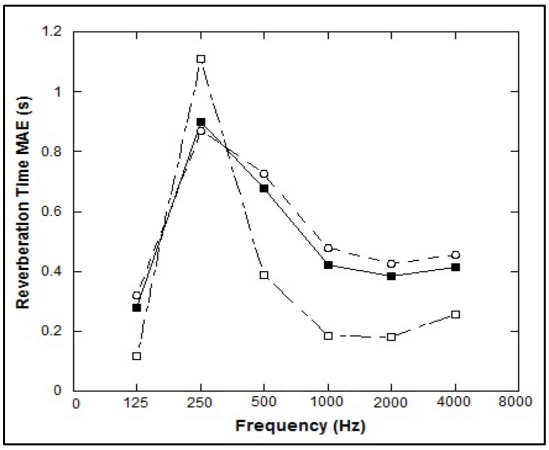

Figure 3. MAE graph for room with curtain (○ = Sabine's formula, ■ = Eyring's formula, □ = Melingtton-Sette's formula).

Table 7. MAE value for room with curtain

Formula	Frequency (Hz)					
	125	250	500	1000	2000	4000
Sabine	0.319	0.87	0.728	0.479	0.425	0.454
Eyring	0.279	0.899	0.678	0.423	0.383	0.414
Millington-Sette	0.116	1.109	0.388	0.183	0.182	0.255

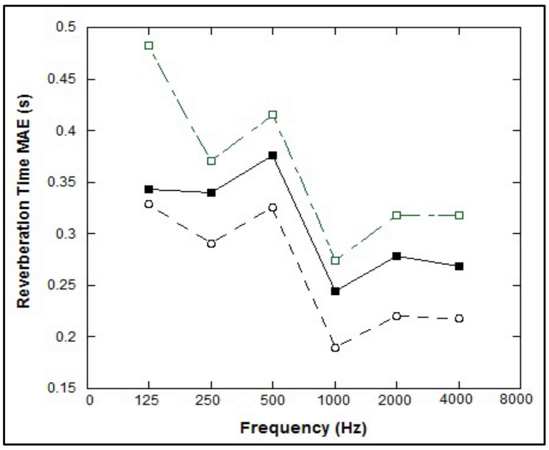

Figure 4. MAE graph for room that used egg container as sound absober (○ = Sabine's formula, ■ = Eyring's formula, □ = Melingtton-Sette's formula).

Table 8. MAE value for room that used egg container as sound absober

Formula	Frequency (Hz)					
	125	250	500	1000	2000	4000
Sabine	0.329	0.291	0.326	0.19	0.22	0.218
Eyring	0.343	0.34	0.376	0.244	0.278	0.268
Millington-Sette	0.483	0.37	0.416	0.274	0.318	0.318

6. CONCLUSION

From the analysis, it can be concluded that the results of this study were affected by errors. Less accurate selection of materials was a major contributor for errors to occur. Besides, frequencies also play a role in giving rise to the difference between measurement and calculation. From this study it can be concluded that several factors must be taken into account to obtain measurement results close to the calculations. The following factors are: -

- Proper selection of materials
- Selection of the appropriate frequency of sound
- Location sound that less of background noise
- Appearance of room
- Location of sound absorption materials

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