Potential acoustic treatment analysis using sabine formula in unoccupied classroom

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Abstract. Effective teaching and learning, not only taking into account the good teaching methodology and facilities but the acoustic level in the classroom should also be addressed. RT-60 is the time required for sound decay in a classroom. The time taken for the sound to decay depends on the absorption coefficients (α) of surface material and the volume of the room. This paper aims to identify potential treatment materials for improving the value of RT-60 of the selected unoccupied teaching hall/classroom at one of the higher learning institution in Malaysia. The value of RT-60 is calculated using Sabine formula and used the same parameter like the surface material, surface area, and room's volume identified in previous research. The best RT-60 value is 0.6s for the classroom with 10k-20k cubit feet in volume and it coincides with the volume of the selected classroom which is about 14320 cubic feet. To ensure that room has the optimum RT-60 values, the materials used on the ceiling, walls, floors, windows, and doors are assessed for sound absorption rate and then materials with appropriate absorption coefficient are proposed for improvement purposes. As a result, it found that gypsum board is suitable to use for wall and plywood 12mm thick is proposed for ceiling material. By applying this proposed material will then enhance the acoustical performance of the unoccupied teaching hall especially in RT-60 value.

1. Introduction
Nowadays, learning process especially formal education in Malaysia where mostly takes place in a classroom becomes more challenging since the ability of learning is influenced by the ability of students while listening to the lecturer's speech. In classroom, the learning process usually involves verbal communication between lecturers and students. The acoustical factors such as reverberation time and speech transmission index are the key factors that contribute to the effectiveness of learning process. Thus, these terms especially reverberation time for each classroom must be in the acceptable range So that a good acoustical quality of the classroom will contribute to better communication between lecturers and students. Thus, it will give more benefits to students because of the best teaching quality from the lecturers [1].

2. Literature Study
One of the important acoustical measurements called Reverberation Time (RT or RT-60) is used to determine how quickly the sound in a room decays. Reverberation time depends on the physical
volume and surface materials of a room. Large spaces such as cathedrals and gymnasiums usually have longer reverberation times and sound dynamic. While, small rooms, such as bedrooms and recording studios are usually less reverberant and sound “dry” or “dead” [2]. The length of time the sound takes to die away is called the reverberation time. It is measured in seconds. If the reverberation time is too long, the reflected sounds will not clear and hence will make it hard to understand to what someone is saying. Sometimes, the reflected sound is good because it may strengthen the voice of someone’s speech thus making it more understandable and clearer. But, it must be balanced or in other words the room must have a good reverberation time; if not the reflected sound is not beneficial at all [3].

RT-60 is more than enough to describe characteristics of attenuation in the room. The RT-60 value is not accurate if the room has unusual shape. The optimum reverberation time for different rooms depend on the volume of the space, finishes of the room and the frequency of the sound concerned. In general, the optimum RT-60 for rooms for speech is less than the optimum RT-60 for rooms used for music [4]. The first step in architectural acoustic design is to identify the appropriate values of the reverberation time depending on the purpose of the room when the room is built. Once the values of RT-60 are determined, the materials that will be used to construct the room can be selected in order to realize the desired value of the RT-60. For example, a classroom should have the reverberation time in the range of 0.4 to 0.6 seconds. In reality, many did not manage to get the suitable reverberation time but having reverberation time of 1 second and more. So, lecturers have to compete against the continuous reflection of his or her own voice to get the student’s attention [5]. The recommended value of RT-60 in a classroom is to limit the value to a maximum of 1.0 second [6].

There are two well-known models used to determine the value of RT-60. They are Sabine and Eyring models. Sabine and Eyring models based on the diffuse sound field assumption are wildly used as prediction methods for reverberation time. Sabine concluded that the reverberation time is according to the average absorption coefficient of the walls [7]. Sabine formula is more necessary for small spaces and low frequency ranges rather than classrooms. Therefore, the Sabine equation can be an acceptable method to predict reverberation time in standard size classrooms with low absorption surfaces [8]. The determination of absorption coefficient by using Sabine Formula is a very useful method and the Sabine absorption coefficient values may exceed a value of 1.0, especially for highly absorptive materials [9].

3. Methodology
Preliminary research has been done to identify the acoustical performance of unoccupied classroom at one of the higher learning institution in Malaysia. Two acoustical parameters have been selected in the previous project which is the Reverberation Time, (RT-60) and Speech Transmission Index (STI) value. The analysis shown in Table 1 states that that the RT-60 value for unoccupied classroom for 1000Hz frequency value is 0.4s which leads to the poor acoustical performance and it also shows that the value of RT-60 that meets the standard is only at a frequency of 250Hz [1].

There are 3 different surfaces in selected classroom for ceiling, wall, and floor. Table 2 shows the absorbent coefficient for each of the material surfaces used in selected classroom within a standard normal speech frequency of 1000Hz. This study aims to obtain potential material treatment to optimize RT-60 value for 1000Hz frequency value. Therefore, the data obtained in the previous study will be used as reference in the process to achieve the objectives of this study.

| Frequency (Hz) | RT60 (s) |
|---------------|----------|
| 250           | 0.63     |
| 500           | 0.51     |
| 1000          | 0.43     |
Table 2. Absorption coefficient for each material involved in classroom [1].

| Layers | Material            | Absorption Coefficient, for 1kHz |
|--------|---------------------|----------------------------------|
| Ceiling| Micro-fiber         | 0.75                             |
| Walls  | Reinforced concrete | 0.07                             |
| Floor  | Carpet              | 0.26                             |

Figure 1 shows the flow chart of the overall project. After the data is gathered, the trial and error method will be used in obtaining the potential treatment material for RT-60 value. The absorbent coefficient for each material will then be referenced from the acoustical data standard contained in acoustic website. After the material is chosen, then the absorption coefficient for the selected material will then be substituted into Sabine formula as below:

\[
RT_{60} = (0.16 \text{ } s/m) \frac{V}{S_e} \tag{1}
\]

\[
S_e = \alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3 + ....... \tag{2}
\]

where:
- \( RT_{60} \): reverberation time, in s
- \( V \): room Volume, in m\(^3\)
- \( S_e \): effective absorbing area
- \( \alpha \): the average surface absorption coefficient
- \( S \): the room surface area, in m\(^2\)

Sabine formula equation has been created using Microsoft excel to ease the calculation process as shown in Table 3. Every time the absorption coefficient is changed, the RT-60 will also get the new value as well. These steps will be repeated over and over again until the RT-60 fall within the standard.
Get data from Odeon software

Identify potential treatment material

Calculate the effective absorbing area, $S_e$

Input the $S_e$ into Sabine formula

YES

RT-60 within standard

End

NO

Figure 1. Process flowchart.

Table 3. Calculated RT-60 value using Sabine formula.

| Area   | Floor | Real Wall | Front Wall | Sidewall | Ceiling | Door | Window |
|--------|-------|-----------|------------|----------|---------|------|--------|
| Volume |       |           |            |          |         |      |        |
|        | 162   | 114.26    | 162        | 19.44    | 1.3     |      |        |
| $S_e$  |       |           |            |          |         |      |        |
| RT-60  |       |           |            |          |         |      |        |

4. Result and Discussion

RT-60 is often calculated via an unoccupied room. This is due to occupied classroom leads to an increased sound absorption; such as people and their clothes, furniture, curtains and teaching and learning process materials’. Referring to Sabine’s formula, RT-60 is dependent on only two things; (a) the volume of the space and, (b) the amount of absorption in the space. The recommended RT-60 for a typical classroom of 10,000 cubic feet or less stated in the new American National Standards
Institute (ANSI) S12.6 – 2002[10] standards, should not exceed 0.6 seconds for each octave band with frequencies of 500 Hz, 1000 Hz and 2000 Hz. Meanwhile, for classrooms between 10,000 and 20,000 cubic feet in volume, the RT-60 should not exceed 0.7 seconds of all three frequencies. Figure 2 represents interior modeling simulation of unoccupied classroom using Odeon Software. The coordinates of X, Y and Z represent width, length and height respectively in actual classroom with a rough calculation/estimation for each classroom’s angle to be 3-meter tall, 9 meters wide and 15 meters deep as shown in Figure 3.

![Figure 2. Classroom model inside the Odeon Software](image1)

**Figure 2. Classroom model inside the Odeon Software**

![Figure 3. X, Y and Z coordinates for classroom in Odeon Software](image2)

**Figure 3. X, Y and Z coordinates for classroom in Odeon Software**

Detailed measurement of this unoccupied classroom was tabulated in Table 4. Calculation of RT-60 for this unoccupied classroom is obtained from the theory of calculations using Sabine formula incorporated various materials as shown in Table 5. This RT-60 was calculated for only one octave band; 1000 Hz. 1000 Hz was chosen for the reason of it being the representative frequency to speech. If this RT-60 is acceptable, then the RT-60 throughout the speech range will likely be acceptable.

Ultimately, more sound absorbed means a shorter reverberation time taken. Referring to Table 5, RT-60 value for existing unoccupied classroom is 0.343 and after proposing better material, RT-60 is increased to 0.632. These are all demonstrated using the Sabine equation. There was a clear increment of 84% when walls and ceilings were changed for a lower absorption coefficients material. This value ultimately achieved ANSI standards for unoccupied classroom which is in the range of 0.6 to 0.7.

| Width (m) | Length (m) | Height (m) | Volume (m$^3$) | Area (m$^2$) |
|-----------|------------|------------|---------------|--------------|
| 8.61      | 14.95      | 3.15       | 405.47        | 128.72       |

Table 4. Measurement of unoccupied classroom.
Table 5. Result of RT-60 for different material.

| Items      | Material Types          | Absorption coefficient, $\alpha$ | Surface Area (m$^2$) | Material Types          | Absorption coefficient, $\alpha$ | Surface Area (m$^2$) |
|------------|-------------------------|----------------------------------|----------------------|-------------------------|----------------------------------|----------------------|
| Floor      | Carpet                  | 0.26                             | 162                  | Carpet                  | 0.26                             | 162                  |
| Real Wall  | Reinforced Concrete      | 0.07                             | 114.26               | Gypsum board            | 0.03                             | 114.26               |
| Front Wall | Reinforced Concrete      | 0.07                             |                      | Gypsum board            | 0.03                             |                      |
| Sidewall   | Reinforced Concrete      | 0.07                             |                      | Gypsum board            | 0.03                             |                      |
| Door       | Solid Timber            | 0.08                             | 19.44                | Solid Timber            | 0.08                             | 19.44                |
| Ceiling    | Microfiber              | 0.75                             | 162                  | Plywood 12mm thick perforated 5mm diameter holes 6200 m$^2$ 11% open area with 60mm deep air space behind | 0.3                       | 162                  |
| Window     | Glass                   | 0.12                             | 1.3                  | Glass                   | 0.12                             | 1.3                  |
| $\text{RT}_{60}$ | Glass                   | 0.343                            |                      |                         | 0.632                            |                      |

Referring to Table 5, gypsum board was proposed as a change to reinforced concrete, with a smaller absorption coefficient compared to reinforced concrete as shown in Figure 4. Gypsum board as shown in Figure 5 is a premier building material for wall, ceiling and partition system in residential, institution and commercial structures. It possesses great beneficial impact on noise reduction and provides an effective sound insulation since it was designed to supply a physical barrier to sounds, incorporating together a sound break thus minimising the reverberation time.

**Figure 4.** Reinforced concrete wall.  
**Figure 5.** Gypsum board.
5. Conclusion and Future Work

As a conclusion, acoustical quality in term of RT-60 is represented by using Sabine formula. From the findings of this study, gypsum board for wall and plywood 12mm thick for ceiling is proposed to provide potential better acoustic material replacing the existing absorption material in unoccupied classroom. Simulation result using Odeon shows that RT-60 value’s is 0.43. This is due to the Odeon simulation using the average value of the absorption coefficient in finding the RT-60. Once again calculations are made using Sabine equation by applying absorption coefficient value at frequency of 1000 Hz only. The value obtained is 0.34s and it is proven that it is still in the weak acoustic category.

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