Identification of Acoustic Comfort in Classroom of Gedung Kuliah Bersama V of Bengkulu University

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Abstract. Classroom is a place for a group of people to study and improve their knowledge. To make learning activities becomes more effective, a classroom is expected to have comfort in terms of thermal, lighting, ventilation, and acoustic. This study focused only on the acoustic comfort of the classrooms at Gedung Kuliah Bersama V (GB V), University of Bengkulu (UNIB). Acoustic condition in the classroom has a crucial role for student concentration that affect to student's achievement. Reverberation time (RT), initial time delay gap (ITDG), and the possibility of echo phenomenon in the classroom will be identified in this study as the acoustic parameters. Ecotect v5.5 software is being used to simulate three types of a classroom that represent classroom types at GB V. This simulation is used to identify RT, ITDG, and echo occurs in the classroom. Results of this study showed that ITDG values of these three classrooms had met the standard the classroom that used for conversation, which is under 20 m/s. Echo phenomenon is also relatively not seen in the simulation. It means that these three classrooms were also comfortable enough in terms of acoustic. However, the RT values in the three rooms still have not reached the optimum condition, 1.40 m/s for RK 2.02, which is higher than standard and lower than standard for the first room and 0.23 m/s and 0.10 m/s for the second and third room. So thus, some design recommendations are needed to get an optimum RT value.

Keywords: Acoustic; Reverberation time; Time delay; Echo; Classroom

1. Introduction
A good room is a space that pays attention to comfort, security, and safety for the user. Comfort in the room can be comfort in terms of thermal, ventilation, lighting, and acoustic. Especially in learning activities, this consideration must take place in designing a room or a classroom. All of these comforts also have a high influence on students. When one of these comfort aspects is not fulfilled, the uncomfortable feel by students makes concentration loss and more, decreasing students learning achievement [7]. Moreover, a good acoustics condition in a classroom can create a lively atmosphere inside the room as well as enhance student's moods for receiving knowledge.

Some acoustic comfort study had been conducted before by many researchers, so thus with classroom acoustic comfort quality [7]. Indicators of acoustic comfort quality in a room can be identified by reverberation time (RT), initial time delay gap (ITDG), sounds distribution and reflections that causing the possibility of echo phenomenon [2][3][4][7]. Echo or other unwanted sound can be happened by the quality of room condition. Echo is the repeated of sound heard in the room. This sound repetition can
interfere with direct sound. So thus, Echo can be an unwanted sound, especially in a room where high concentration in listening. Echo can be identified by the reverberation time (RT) and initial time delay gap (ITDG). Reverberation time (RT) is the time needed by the sound to reduce 60 dB according to the room condition [8]. Initial time delay gap (ITDG) is the time needed by the direct sound and the initial reflected sound to reach the audience position. All of these acoustic comfort indicators can be calculated and simulated in a computer software program named Ecotect [2][4].

Reverberation time has wide range standard depends on the different functions of the room. Too short RT will give an empty feeling inside the room [4]. However, if the reverberation time in a room is too long or too buzzing, the clarity of the sound will decrease. RT range for classrooms is 0.6 - 0.8 seconds [7]. Other than 60 dB decay, the development of reverberation time can also be affects by direct sound and initial reflection (EDT) or the decay that occurs less than 60 dB, such as 15 dB (RT15), 20 dB (RT20), and 30 dB (RT30) [5]. ITDG value, it can determine room intimacy level. The shorter the ITDG value, the more intimate the characteristics of the space will be. It makes smaller spaces are more welcome. But in a larger space, the ITDG value may vary depending on the listener’s location. It shows that the shorter the ITDG score, the more intimate the characteristics of the space will be. Room that used for conversation are likely to have less than 30 ms time delay gap [8]. RT and ITDG in a room are affected by several aspects of room design such as room volume, room height, room layout for sound source position and audience arrangements, room capacity, finishing material used for furniture, walls, floor, and ceiling, as well as their shape (Satwiko, 2004)[2][3][4][5][6].

This study will evaluate the acoustic comfort of classrooms in Gedung Kuliah Bersama V (GB V), University of Bengkulu (UNIB). Classroom quality is determined by the value of reverberation time (RT), initial time delay gap (ITDG), and echo phenomenon to their acoustic comfort standard. Ecotect software simulation will be used as the measurement tools. Three types of rooms which represent the rooms in the building will be tested. They are RK 2.02, RK 2.05, and RK 2.07. Room shape and volume, layout, and rooms’ enclosure material are the main variables that will be examined and decides classroom acoustic comfort quality. The result obtained by each classroom then will be used to compare which room is better in terms of acoustic comfort and which room is should be modified for better acoustic comfort quality.

If the simulation results do not match the standard of acoustic comfort, an alternative design will be given to optimizing the acoustic conditions of the lecture hall in Gedung Kuliah Bersama V of Bengkulu University.

2. Method
The room to be used is a room with learning activities, it's RK 2.02, RK 2.05, and RK 2.07. These three rooms have different dimensions, layouts and positions. As for materials, these three rooms use materials use wall brick, concrete floor and ceiling, and clear glass with allumn frame for windows and doors.
Measurements use center frequency. The frequency of room acoustic sound generally ranges from 125Hz-4000Hz which is divided into 6-octave parts, i.e. 125, 250, 500, 1000, 2000, and 4000Hz. 125-250Hz low frequency, 500-1000Hz middle frequency, and 2000-4000Hz high frequency. Low-frequency reverberation time is better for rooms with large volumes and middle frequency is better for small volumes [6].

The results of the acoustic analysis in the Ecotect application to analyze the RT calculation are not only based on the statistical reverberation formulas of Sabine, Norris-Eyring and Millington, but also equipped with acoustic geometric analysis (acoustic particles) which can be visualized in 2 dimensions or 3 dimensions. This is an advantage and an opportunity for designing an acoustic space that takes advantage of speed and accuracy in calculations and can simultaneously visualize the results of the analysis carried out, so this is an important point to support and make room acoustic design decisions [12]. Thus, acoustic simulation can be carried out in several stages. Its spatial geometry modeling, room material determination and sound source determination.

The lecture hall is simulated with Ecotect software according to its existing conditions. The sound of a source is placed at the front in a position assumed to be at the level of the human ear when viewed from a comparison with the window.
3. Findings and Discussion

3.1. Initial Time Delay Gap (ITDG)
To see the delay time value in the three rooms, the Rays & Particle section is treated as follows:

**Table 1. Setting in Rays & Particle section**

| Settings                  | Circular pattern |
|---------------------------|------------------|
| Generate rays             | Circular pattern |
| Azimuth angle             | 90°              |
| Axial rotation angle angle| 90°              |
| Angular increment         | 5.0°             |
| Bounces                   | 2                |
| Display                   | Animated rays    |

From the above treatment, the ITDG results were 9-13 ms at RK 2.02 and ITDG values <20 ms at RK 2.05 and RK 2.07. According to the reflection quality table, the three rooms meet the standards for a room with a conversation activity function.

**Figure 2.** (a) RK 2.02 Existing; (b) RK 2.05 Existing; (c) RK 2.07 Existing.

3.2. The Echo phenomenon
To see the echo phenomenon at RK 2.02, RK 2.05, and RK 2.07 Rays & Particle in the Ecotect software section were treated:

**Table 2. Setting in Rays & Particle section for echo**

| Settings |                      |
|----------|-----------------------|

**Figure 3.** (a) ITDG RK 2.02; (b) ITDG RK 2.05; (c) ITDG RK 2.07.
Generate rays  Spherically-Random
Azimuth angle  180°
Altitude range  90°
Number of Rays  10000
Bounces  20
Display  Animated Particle

After being given the treatment, the results of the three tested rooms were free of the Echo phenomenon. This can be seen from the absence of red-colored particles from the three images below.

![Figure 4](image)

**Figure 4.** (a) Echo phenomenon at RK 2.02; (b) Echo phenomenon at RK 2.05; (c) Echo phenomenon at RK 2.07.

3.3. **Reverberation Time (RT)**
Before the model is simulated, the following treatments are given.

| Setting for RT |
|----------------|
| **Table 3.** Setting for RT |
| **Settings** |
| Auditorium  | 41 (Upholstered) |
| Seating     | with 90% Percentage Occupied |
| Display type | All Algorithm |
| Reverberation time algorithm | Millington-Sette (RK 2.02) and Norris-Eyring (RK 2.05 & 2.07) |

3.3.1. **RK 2.02**
After calculating, Ecotect shows that the optimum RT for speech space function in RK 2.02 with a frequency of 500 Hz is 0.60 s (see figure 5). However, the RT generated from the model with this frequency has a higher value of 1.40 s (RT Algorithm Millington-Sette).
The non-optimum RT value is also shown in the graph above, where the graph is above the blue area at a frequency of 500 Hz.

Furthermore, in the acoustic response section, it shows that the RT value at a frequency of 500Hz for a decrease of 30db takes about 2.6s (pink graph).

For a more precise calculation, see the derived curve below. The chart appears to be far above the blue range. This shows that the value in RT RK 2.02 still does not meet the standard.
3.3.2. RK 2.05

Results RT value of RK 2.05 at a frequency of 500 Hz with the recommended formula Ecotect (Norris-Eyring) is 0.23 s. However, the optimum RT value for this room with speech function is 0.67 s. When viewed from the image below, the Norris-Eyring chart (red graph) is under the blue shaded area. This indicates that the RT value is still not by the optimum RT for this room.

Furthermore, the acoustic response from RK 2.05. The results of the analysis on the acoustic response show that the ability of this room to decay 30dB with a frequency of 500Hz takes about 3.9 s.
Then in the derived curve below, it is shown that the graph is above the blue area.

(Agustinus D, 2007)

3.3.3. *RK 2.07*

RT value at the frequency 500 Hz, is 0.10 s (Norris - Eyring). Meanwhile, the optimum RT for this room is 0.6 s and the graph of RT value is below the blue areas.
Then the results in the acoustic response that the time it takes to decay 30 dB with a frequency of 500 Hz is 30 s.

Furthermore, to make the graph more precise, it is shown in the derived curve below.

Just like the two previous rooms, the graph is above the blue area. This shows that the RT value in this room is still not optimal.

4. Design Recommendations
Of the three simulated rooms, the ITDG is suitable, and there is no echo phenomenon in the three rooms. However, the RT values in the three rooms were not at optimum condition. Therefore, the design
recommendations given do not reach the stage of changing the shape of the ceiling but only changing the material.

4.1. RK 2.02
Previous material:
- Ceiling: Suspended concrete ceiling
- Wall: Brick Plaster
- Floor: Concrete Floor Tile Suspended
- Door: Glass Door
- Window: Single Glass Aluminium Framed

Then the ceiling material is changed to acoustic tile suspended, and the results are:

![Figure 17. Graphic of the RT value of RK 2.02](image)

In the figure above, the graph has dropped to the blue area and the RT (Millington-sette) value at a frequency of 500 Hz has met the optimum RT value.

![Figure 18. RT Value of RK 2.02](image)

Furthermore, in the acoustic response section, the results show that the time it takes for 30dB to drop is 1.5 s. This shows that the room is free from echo.
Likewise, the derived curve. The graph has dropped to the blue area. The RT in this room has reached its optimum value by changing the ceiling to suspended acoustic tile material.

After changing, the results obtained at a frequency of 500 Hz are already in the blue graph with a value of 0.64 s (Milington-sette). This shows that the RT value at RK 2.05 is in accordance with the standard.
Furthermore, in the acoustic response, the following data are obtained.

The time it takes to decay the sound by 30dB takes 2.1 s. Then on the derived curve, the graph has also dropped to the blue area.
4.3. **RK 2.07**

Previous material:
- Ceiling: Suspended concrete ceiling
- Wall: Brick plaster
- Floor: Concrete floor tile suspended
- Door: Glass door
- Window: Single glass aluminium framed

So far RK 2.07 has not found a material that can change the RT value to an optimum. Meanwhile, the material is made the same as the design recommendation RK 2.05, namely:
- Ceiling: Acoustic tile suspended
- Wall: Brick plaster
- Floor: Concrete floor timber suspended
- Door: Glass door
- Window: Single glass aluminium framed

It can be seen in the picture, the RT value graph is not yet in the blue area. This shows that the RT value generated by RK 2.07 is still not optimal. From three formulas below, no result is close to the optimum RT conditions.
However, the time it takes to break the sound by 30 dB to a drop is only 1.4 s.

Likewise, in the derived curve, at a frequency of 500 Hz the graph also drops to the blue area.

So, even though the material has been changed, and the RT value is still not optimum, the material change in RK 2.07 is able to make a derived curve in an area that is blue.

5. Conclusions
Gedung Kuliah Bersama V Universitas Bengkulu is a place for Engineering students and Mathematics and Natural Sciences students to study. This room should be able to comply the comfort aspect in terms of acoustics.

The results of the simulation using the Ecotect software obtained the following data:

| Freq. | Absorption | Sabine | NCR-ER | MIL-SE |
|-------|------------|--------|--------|--------|
| 63Hz  | 0.01       | 0.01   | 0.01   | 0.01   |
| 125Hz | 0.01       | 0.01   | 0.01   | 0.01   |
| 250Hz | 0.01       | 0.01   | 0.01   | 0.01   |
| 500Hz | 0.01       | 0.01   | 0.01   | 0.01   |
i) RK 2.02, RK 2.05, and RK 2.07 have ITDG values that comply with acoustic standards with a conversation room function (≤ 30 ms).

ii) The absence of echo phenomena in the three rooms.

iii) The RT values generated by the three rooms have not reached the optimum conditions for conversation rooms. The RT values of the three rooms were 1.40 s at RK 2.02, 0.23 at RK 2.05, and 0.10 s at RK 2.07. This is shown in the Derived curve graph, in the three rooms the derived curve graph is above the blue area.

iv) The RT value after the recommendation for RK 2.02 and RK 2.05 meets the standard for conversation rooms. The RT values in each room were 0.61 s and 0.64 s. Whereas for RK 2.07 the RT value still did not meet the standard, namely 0.9 s. However, the graph of the derived curve in these three rooms has dropped to the blue area.

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