Optimization of Sound Absorbers Number and Placement in an Enclosed Room by Finite Element Simulation

S F Lau¹, *M H Zainulabidin*¹,², M N Yahya¹, I Zaman¹, N A Azmir¹, M A Madlan¹, M Ismon¹, M Z Kasron¹ and A E Ismail²

¹ Noise and Vibration Analysis Research Group (NOVIA), Faculty of Mechanical & Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia
² Mechanical Failure Prevention and Reliability Research Center (MPROVE), Faculty of Mechanical & Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia

Corresponding author: *hafeez@uthm.edu.my

Abstract. Giving a room proper acoustic treatment is both art and science. Acoustic design brings comfort in the built environment and reduces noise level by using sound absorbers. There is a need to give a room acoustic treatment by installing absorbers in order to decrease the reverberant sound. However, they are usually high in price which cost much for installation and there is no system to locate the optimum number and placement of sound absorbers. It would be a waste if the room is overly treated with absorbers or cause improper treatment if the room is treated with insufficient absorbers. This study aims to determine the amount of sound absorbers needed and optimum location of sound absorbers placement in order to reduce the overall sound pressure level in specified room by using ANSYS APDL software. The size of sound absorbers needed is found to be $11 \text{ m}^2$ by using Sabine equation and different unit sets of absorbers are applied on walls, each with the same total areas to investigate the best configurations. All three sets (single absorber, 11 absorbers and 44 absorbers) has successfully treating the room by reducing the overall sound pressure level. The greatest reduction in overall sound pressure level is that of 44 absorbers evenly distributed around the walls, which has reduced as much as 24.2 dB and the least effective configuration is single absorber whereby it has reduced the overall sound pressure level by 18.4 dB.

1. Introduction

Sound is influential to human being; we use sound to communicate to each other, to learn effectively, to receive information precisely, experiencing through hearing makes life significant. Unfortunately, excessive or unwanted sound may become a noise which creates unpleasant environment. Noise is defined as disagreeable or undesired sound where the differentiation of sound and noise is highly subjective as perceived by one [1]. Excessive unwanted sound contributes to noise pollution where it may become a serious matter which tends to disrupt the natural rhythm of life. Noise is believed to cause annoyance and disturb activities and communication which contributing to stress and illness [2].

Noise pollution can be controlled through systematic approach by the application of engineering principles. The methods of control include control at the source, control at the transmission paths and the control at the receiver [3]. Noise control meant to reduce sound emissions which aim to bring human comfort, as for environmental considerations or legal compliance. Sound absorbers are used to control
the noise within a particular space where they reduce the sound level by converting it into heat when sound waves are impinged on them. Most of the commercially available sound absorbing materials are made from synthetic fibers such as minerals and polymers [4]. Even though synthetic sound absorbing materials have excellent acoustical performance, but they are quite expensive to manufacture and to install.

The sound in a room is a combination of direct sound and indirect sound, so what we hear are the direct sound from the speaker and also the indirect reflected sound that bounce off the medium it encountered. Reflected sound may results in standing waves as it interferes with incident waves. Sound reflection will also causes reverberation where the sound is prolonged and the details of the listened contents will be masked. These phenomena cause sound distortion and greatly affects the acoustic quality.

Excessive sound reflection contributes to poor room acoustic and causes intolerable reverberation. Peters et al. [5] recommended that for small lecture room which consists of less than 50 people, the reverberation time should be kept less than 0.8 second for a good learning environment.

Giving a room proper acoustic treatment is both art and science. Different rooms may require different treatment as over-treated or wrong types of material can have adverse effects. Acoustic design brings comfort in the built environment and also reduces noise level by using the sound absorbers. The pressure distribution in a room is closely related to the placement of absorbents. Mounting sound absorbing materials flat and evenly distributed on the walls as shown in Figure 1 can help to reduce the effect of standing waves effectively [6]. Besides, there is a little more absorption and more diffuse sound environment by placing the absorbers not only on ceiling, but also on the walls [7]. Finite element method (FEM) had been used to investigate the proper locations of absorbers in different polygonal small rooms at low frequencies and the results showed that the absorptive materials are best located at the pressure antinodes around the sidewalls for low frequency modes below 100 Hz [8].

This study is aimed to determine the effect of installing sound absorbers in a small room on the overall sound pressure level. Consequently, this study is aim to determine the amount of sound absorbers needed and its optimum placement by using ANSYS APDL.

![Figure 1](image_url)

Figure 1. Placement of sound absorbers in staggered position for maximum effectiveness

2. Methodology

The model of rectangular room with dimensions of 3m high × 4m wide × 5m long was built in ANSYS as illustrated in Figure 2 with a total volume of 60m³. All the surfaces were made from unpainted concrete which have absorption coefficients of 0.01.
Since the recommended maximum reverberation times for small room consists of less than 50 person would requires $RT_{60}$ less than 0.8, where it is suitable for speech, so the room was modified by introducing the correct amount absorptive materials, through utilization of Eqn. (1).

$$RT_{60} = 0.161 \times \frac{V}{A}$$  \hspace{1cm} (1)

where $RT_{60}$ is the time required for reflections of a direct sound to decay by 60 dB, $V$ is the room volume in m$^3$ and $A$ is the total absorption in Sabins [9].

Throughout this study, the absorptive materials were assumed to have an absorption coefficient of $\alpha = 1$. Hence, the additional absorption $A$ needed for the room is 11.135 Sabins. This is corresponding to an area of 11.135 m$^2$ of absorptive materials. For simplification, the total area of absorptive materials used was 11 m$^2$.

Absorptive materials of total area 11 m$^2$ were applied to the walls, either on single wall, two opposing walls, at the corners or evenly distributed on every walls. The absorber patches of 11 m$^2$, 1 m$^2$ and 0.25 m$^2$ were used to treat the room to see the effect of number of absorbers to the pressure distribution of the room. Different absorbers patches used were of the same total area. Table 1 shows the number of absorptive patches used during the room treatment.

| Unit area (m$^2$) | Number of absorptive materials | Total area (m$^2$) |
|------------------|-------------------------------|-------------------|
| 11               | 1                             | 11                |
| 1                | 11                            | 11                |
| 0.25             | 44                            | 11                |

Type of element used to model the fluid medium was FLUID30 and the element size used 0.1 m and hence this made a total of 60000 finite elements. ANSYS recommends that at least 12 elements per wavelength should be used for FLUID30 in order to obtain the acceptable accurate results [10].

For uniformity purpose, the materials properties were evaluated at atmospheric pressure of 1 atm and 20$^\circ$C where the density of air was equal to 1.2041 kg/m$^3$ and speed of sound in the air was 343.24 m/s. The finite element model was analyzed by harmonic analysis at octave band middle frequency of 16, 32, 63, 125, 250, 500, 1000 and 2000 Hz.

A 0.2 Pa pressure loading source was located at the front of the room. Six receivers were used to measure the pressure response inside the room, with each of them located at equidistant from both side walls as shown in Figure 3.
The absorbers installation of different configurations caused a reduction of sound pressure level (SPL) in the room. The total SPL for each of the frequency for each configurations was obtained by combining the individual SPL values from the six receivers, using Eqn. (2).

\[
Total\ SPL = 10 \log \left( 10^{\frac{SPL_1}{10}} + 10^{\frac{SPL_2}{10}} + 10^{\frac{SPL_3}{10}} + \cdots + 10^{\frac{SPL_6}{10}} \right)
\]

The overall SPL over the frequency range for each configurations was obtained by combining the individual total SPL values of the eight frequencies obtained by Eqn. (2), by using Eqn. (3).

\[
Overall\ SPL = 10 \log \left( 10^{\frac{Total\ SPL_{10}}{10}} + 10^{\frac{Total\ SPL_{200}}{10}} + 10^{\frac{Total\ SPL_{63}}{10}} + \cdots + 10^{\frac{Total\ SPL_{2000}}{10}} \right)
\]

The configurations of the absorbers are as follows:

a) Single absorber on one side wall
b) 11 absorbers installed identically on two side walls
c) 11 absorbers installed oppositely on two side walls
d) 11 absorbers evenly distributed on walls
e) 11 absorbers evenly distributed around corner walls
f) 44 absorbers installed identically on two side walls
g) 44 absorbers installed oppositely on two side walls
h) 44 absorbers evenly distributed on walls
i) 44 absorbers evenly distributed around corner walls

Figures 4(a)-(i) show the absorbers arrangement for each configuration.
3. Results and Discussion
The results in the form of continuous contour plot within the room for bare room and every absorber configurations as shown in Figures 5(a) to 5(j) are viewed in the general postprocessor (POST1) using command PLNSOL. From these plots, the distribution of the sound pressure level in the room can be clearly pictured based on the color indicators shown.
Figure 5. Continuous contour plots of room SPL: (a) Bare room; (b) Single absorber on one side wall; (c) 11 absorbers installed identically on two side walls; (d) 11 absorbers installed oppositely on two side walls; (e) 11 absorbers evenly distributed on walls; (f) 11 absorbers evenly distributed around corner walls; (g) 44 absorbers installed identically on two side walls; (h) 44 absorbers installed oppositely on two side walls; (i) 44 absorbers evenly distributed on walls; (j) 44 absorbers evenly distributed around corner walls.
Table 2 illustrates data relating to overall sound pressure level (SPL) in the room. There are a total of 9 different configurations for the absorber placement: 1 for the 11 m² unit area, 4 for the 1 m² and another 4 for the absorber of 0.25 m² unit area. SPL for bare room is included for comparison.

Table 2. Overall sound pressure level (SPL) for every absorbers configurations

| Configuration                        | Overall SPL (dB) |
|--------------------------------------|------------------|
| Bare Wall                            | 92.5             |
| One Side Wall                        | -                |
| Both Side Walls - Identical          | -                |
| Both Side Walls - Opposition         | -                |
| Evenly Distributed                   | -                |
| Evenly Distributed Around Corner Walls | -                |
| Bare Room                            | -                |
| 1 Absorber                           | 74.1             |
| 11 Absorbers                         | 70.7             |
| 44 Absorbers                         | 71.0             |
| Evenly Distributed                   | 69.4             |
| Evenly Distributed Around Corner Walls | 71.9             |

Referring to Table 2, it can clearly be noticed that the SPL in room has been reduced significantly after absorber has been installed regardless of any configurations, whereby the initial overall SPL for bare room is as high as 92.5 dB. For the ease of comparison, the SPL data is presented in column chart as depicted in Figure 6.

Figure 6 shows the overall SPL of the room for single unit absorber on a wall compared to those of multiple absorbers installed on multiple walls. Different trends can be seen for various absorber configurations, while 44-absorber configuration showed the greatest reduction in overall SPL especially the one that evenly distributed in the room.
By looking at the trend, single unit absorber is the least effective in reducing the overall SPL. It is only capable to bring down the overall SPL by 18.4 dB, from 92.5 dB to 74.1 dB. This may due to the reflected sound waves that bounce off the two opposing parallel walls because the absorber is only installed on a single wall. There is superposition of sound waves emitted from a source interfering constructively with its reflected waves which is in opposite direction, forming the standing waves which contributes to higher overall SPL than the other configurations.

The overall SPL is further reduced when the 11 m² absorber is divided into smaller pieces: 11 absorbers and 44 absorbers. By using 11 absorbers of 1 m² unit area, the overall SPL has went down to values ranging from 69.4 dB to 71.9 dB for different configurations, as shown in Figure 7 above. The best configuration for 11 absorbers is by distributing them evenly around the walls as this configuration has resulted in a decrement in overall SPL by 23.1 dB, which is from 92.5 dB to 69.4 dB. It is followed by installing absorbers identically in both side walls, oppositely in both side walls and evenly distributed around the corner walls.

For the case of 44 absorbers, the absorbers placement when they are evenly distributed around the walls contributes to the lowest overall SPL, 68.3 dB, where it has decreased as much as 24.2 dB as compared to overall SPL of bare room. It is then followed by placing the absorbers evenly around the corner walls, identically in both side walls and oppositely in both side walls.

To sum up, all three categories (single absorber, 11 absorbers and 44 absorbers) has successfully treating the room by reducing the overall SPL. The greatest reduction in overall SPL would be by using 44 absorbers evenly distributed around the walls and the least effective would be by using one whole absorber. Table 3 summarizes the results comparison for the overall SPL received by the receivers and their percentage of reduction.

| Table 3. Comparison results for overall SPL received by the receivers |
|---------------------------------------------------------------|
| **No. of Absorbers (patches) & Configurations**          | **Overall SPL (dB)** | **Percentage of Reduction (%)** |
|---------------------------------------------------------------|
| **Before** | **After** |                                                                                   |
| 1 One Side Wall | 74.1 | 19.9 |
| Both Side Walls - Identical | 70.7 | 23.5 |
| Both Side Walls - Opposition | 71.0 | 23.2 |
| Evenly Distributed | 69.4 | 25.0 |
| Evenly Distributed Around Corner Walls | 92.5 |                                                                                   |
| 44 Both Side Walls - Identical | 69.9 | 24.5 |
| Both Side Walls - Opposition | 70.3 | 24.0 |
| Evenly Distributed | 68.3 | 26.2 |
| Evenly Distributed Around Corner Walls | 69.6 | 24.8 |

4. Conclusion
The rectangular room model with dimensions of 3m high × 4m wide × 5m long with the predefined conditions as mentioned above has been modified by introducing the correct amount of absorptive materials. By taking the recommended maximum $RT_{60}$ for small room consists of less than 50 person into account, the number of sound absorbers needed to treat the room is found to be 11 m². This number indicates the total coverage areas that must be introduced into the room in order to reduce $RT_{60}$ to less than 0.8 seconds, where it is suitable for speech. After the room simulation was carried out using ANSYS APDL for each and
every absorber configurations, the data shown that the optimum location of sound absorbers placement is by placing them on every wall with even distribution. The absorbers that were evenly distributed in the room contribute to the biggest reduction in overall sound pressure level (SPL) that received by all the receivers. This is true for both of the 11-absorber and 44-absorber cases. For 11 absorbers that is evenly distributed around the walls, the overall SPL in the room has reduced to 69.4 dB, where there is a total reduction of 23.1 dB equivalent to 25 % of decrement in overall SPL as compared to bare room. On the other hand, 44 absorbers evenly distributed around the walls has successfully reduced the overall SPL by 24.2 dB or 26.2 %, from 92.5 dB for bare room to 68.3 dB for this configuration. To conclude on this study, the total amount of sound absorbers needed to treat the room is $11 \times 12$ and the optimum location or best configuration would be placing the absorbers evenly in staggered position on every wall by using 44 absorbers. More absorber division means different area on the walls can be covered and the problem with standing waves can be prevented as well because every walls are now covered by some absorbers to lessen the superposition of reflected sound waves which promotes higher overall sound pressure level (SPL).

5. References

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