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THE ROLE OF ACOUSTIC DESIGN IN ENHANCING SUSTAINABILITY IN IRAQI SECONDARY SCHOOLS: MADIHA AL-BIRMANI SCHOOL IS A CASE STUDY

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Abstract

The design of buildings in general and schools in particular requires a careful consideration of the impact of the design on sound clarity in a way that helps in avoiding acoustic problems such as noise, echo, etc. Therefore, emphasis must be placed on achieving auditory comfort and providing a good study environment in the classrooms. To achieve this, the architect must be innovative and thoughtful, planning and designing to achieve a sustainable environment that maintains environmental balance without compromising the divine balance created by the Lord of the Worlds.

For that, and taking into consideration the importance of sound in the success of the teaching and educational process in our schools in Iraq, it is important to shed light on schools designing and find sustainable solutions without using energy sources. Based on the importance of the topic of sound, the researcher explains in the current study the effect of using sustainable materials in reaching acoustic comfort. To achieve this, the researcher chose a classroom in one of the distinguished schools in Iraq as a sample for research and studied it to identify audio problems and find appropriate solutions for them. The researcher resorted to audio analysis using the Odeon program to calculate sound intensity. She introduced different changes to the endings in the Odeon program and measured the sound intensity for each change separately. At the end of the study it was found that changing the ceiling finishes had the greatest impact in reducing acoustic problems. Based on these conclusions, some recommendations and specific suggestions were put forward.

Keywords: Sustainable acoustic design, classrooms, sound, sound intensity, sound frequency, acoustic problems.



Introduction

Given the importance of applying the concept of sustainability by exploiting natural solutions without using energy sources to meet human needs, this research will shed light on the issue of acoustic comfort in particular to make classrooms better through the use of natural acoustic technologies. Acoustic design is one of the necessities for the successful functioning of classrooms and achieving the goals of these classrooms. The influencing factors of sound intensity and its reflections, the use of different reflective surfaces and insulating materials will be analyzed and studied in details to solve acoustic problems in order to achieve the principles of sustainability.

Research Problem

The research problem stems from the importance of sound and its efficiency in school buildings, as acoustic comfort is one of the most important aspects of the educational environment. Accordingly, acoustic design is one of the most important design requirements in classrooms to achieve comfort in its comprehensive sense. The problem of the current study was identified in how to avoid acoustic echoes and noise inside the classrooms through the use of different materials such as (Acoustic Panel, double glassing, carpet, and rubber frames) in finishing the classrooms. To determine the causes of vocal problems and provide appropriate solutions to them, the researcher attempts to answer the following questions:

- 1- To what extent can we reduce the echo level in classrooms using Acoustic Panel?
- 2- Does covering the hall floor with an insulating material (such as carpet) help in reducing acoustic problems?
- 3- Does using rubber windows frames help in reducing noise?
- 4- To what extent does covering walls with insulating materials such as wood reduce acoustic problems?
- 5- Does using double glassing in windows help solve acoustic problems?
- 6- Which of the previously mentioned solutions has the greatest impact on reducing audio problems?

Research Hypotheses

The following hypotheses are proposed in the current study:

- 1- The echo problem can be greatly reduced by using an Acoustic Panel.
- 2- Covering the hall floor with insulating materials (carpet) helps reduce the echo problem.
- 3- The use of rubber frames in windows contributes to reducing acoustic problems.
- 4- Covering the walls with insulating materials such as wood helps reduce acoustic problems.
- 5- The use of double class glass in windows contributes to reducing acoustic problems.
- 6- The effect of changing the ceiling finishes in solving the sound problem is greater than the effect of environmental treatments for the rest of the space's elements.

Variables of the Study

1. **The Independent Variables:** The independent variables can be represented by the use of specific materials to solve the acoustic problems in the classroom. These materials include using the following:
 - a. Acoustic Panel in ceiling finishes.



- b. Using double glazing in the windows of the school hall.
 - c. Using rubber frames in windows.
 - d. Using rubber or carpet flooring.
2. **The Dependent Variable:** One dependent variable in the current study which is sound intensity.

Significance of the Study

The importance of the current study lies in identifying acoustic problems in classrooms and providing suggestions to address them by finding sustainable solutions without using energy sources. The current study is significant through the importance of the issue of sound, its distribution, its spread and its effect on the teaching process specifically in Iraq.

Limits of the Study

There is no study that is free of limitations, whether temporal or spatial. All researchers face some kinds of obstacles that they cannot overcome for one reason or another. The current study is subject to a number of limitations, which are:

- Spatial limitations: The study covers the middle hall in Madiha Al-Birmani School in the center of Babylon Governorate in Iraq, which is a secondary school that includes three academic levels and includes 550 female students.
- Time limits: The study was prepared during the period between 2023 and 2024. The researcher visited the school several times during this period in order to collect the required information and photos after obtaining the necessary approvals from Babylon Education Directorate.

In terms of the quality of research samples, the study included materials available in the market and focused on the least expensive and most efficient materials.

Theoretical Framework

In this part of the study, the most important concepts related to the topic of sustainability in general and sustainable acoustic design in specific will be presented. Also, the acoustic requirements for classrooms with a detailed presentation of acoustic problems and the acceptable degree of sound intensity will be presented.

The Concept of Sustainability

Sustainability, in its various concepts, is of great importance in economic, political and social solutions. It alerts the world to the possibility of potential environmental and human disasters resulting from problems of economic development and human well-being. The term sustainability gained great attention after the famous Brundtland report, "Our Common Future," issued in 1987 by the World Commission on Development and Environment (WCED). In this report, the first definition of sustainable development was formulated as the development that meets the needs of present society and fulfills its requirements without affecting the ability of different generations in meeting their needs (Brundtland, 1997).

As for the educational environment in general and schools in particular, sustainable school design is considered to help achieving a better physical environment for both students and employees alike at the lowest possible costs (The Brendle Group, 2005).



Sustainable Acoustic Design Concept

Sustainable design represents the philosophy of physically and environmentally appropriate design of services to comply with sustainable economic, social and environmental principles. It is sometimes called environmental (eco) or environmentally friendly design as stated by McLennan (2004). Sustainable design seeks to create spaces that are efficient in using energy as well as taking into account health values, which include natural landmarks that help people feel comfortable, increase learning efficiency, deal with stress, and achieve human health and well-being (Alwan & Bege, 2017)

The goal of sustainable design is to mitigate and reduce the negative effects of the modern built settings on the environment. High noise can cause physiological effects represented by mental and physical stress when exposed to (65 decibels), and high noise from the surrounding environment causes psychological and mental health problems such as headaches and high blood pressure, memory loss and lack of comprehension (Albeag, 2014).

Acoustic Requirements for Halls

The main goal of hall design in general is for the listener in the hall to understand what the lecturer is saying, that is, to ensure that the listener can respond to the speaker's voice tones without distorting them. Acoustic comfort in classrooms can be improved by reducing noise input by insulating building elements and using more compact and insulated window and door frames. Acoustic comfort can also be achieved by using of sound-absorbing materials or acoustic plasterboard to reduce noise, and the use of materials that scatter or absorb sound on the walls to eliminate annoying acoustic echoes between walls. Using absorbent materials in interior surfaces, especially ceilings help reduce acoustic echoes and improve speech clarity. Therefore, long reflections must be avoided by maintaining the shortest distance between the speaker and the listener. This distance must not exceed 17 meters so that no echo occurs. That is, the time period between the direct sound and the reflected sound should not exceed 35-50 milliseconds according to the following equation sited from Korsavi (2020):

$$\text{Distance} = \text{time} * 343 = 17 \text{ metres}$$

Sound

It is a natural phenomenon whose effect we realize before we realize its nature. The generation, transference and perception of sound are very much related to vibration in air. Sound is "a disturbance in the air represented by a rapid strength or weakness of pressure moving from the source towards the outside, then a gradual weakening that ends at the point of final disappearance" (Kuttruff, 2007, 2). It results from the vibrational movement of various bodies, from what we hear in terms of friction or knocking of bodies, or what we hear from various musical instruments, as well as the human voice. The energy emanating from the source through a specific material medium is transferred to the future in the form of a longitudinal wave and in the form of a series of compressions and rarefactions of the molecules of the transmitting medium (Kuttruff, 2007).

Sound Intensity

It is the property by which the ear distinguishes sounds from each other in terms of strength and weakness. The intensity of sound at a point is measured by the amount of sound energy per second



perpendicular to the unit area surrounding that point. It is considered a logarithmic unit and its unit of measurement is the decibel (db) “watts/m²” (Kuttruff, 2007).

Sound intensity is defined as the strength or weakness of the sound, and this depends on the amplitude of the sound oscillation, which is a measure of the flow of sound energy at a rate of time through a unit of area. The intensity of sound is measured in decibels, in other words, it is the sound energy that passes through the unit of area. Intensity has an effect on the ear called loudness, where scientists have agreed that the lowest sound intensity that a person can hear is 20 decibels, and the ear can tolerate sound up to 65 decibels (Mansal, 2021). If the difference between the sound produced directly from the source and the reflected sound that reaches the person’s ears is more than 50 milliseconds, that is, it arrives late, then the listener hears the direct sound first, then the indirect sound, and this phenomenon is called echo. Therefore, the time interval between the sound being emitted and its reflection must exceed a tenth of a second (Al-Khafaji, 1996).

Sound Echoing

The time required for the direct sound to fade is zero, but at the same time there is an indirect sound that is still reverberating on the surfaces, and it takes a period of time for this sound to fade, and this period of time is called the reverberation time. According to Stephens-Pate equation, the chanting time for any hall is a fixed number, regardless of the location of the sound source or the location of the listener within the hall or internal spaces. What affect the repetition time is the amount of absorbent materials and the size of the room. The most famous equation for calculating the repetition time is the Stephens-Pate equation, which is:

$$t = r (0.0118 \sqrt{V} + 0.107)$$

Where t = optimal bounce time in seconds

V = volume of the hall in cubic meters

r = 4 for halls used in conversation (Hassan, 2005).

Sound Problem

The sound emitted from any sound source is in the form of a point in the open air and spreads in the form of spherical waves. As it moves away from the source, its intensity decreases. However, the presence of the source inside a closed space (for example, a hall) results in significant changes in the quality and intensity of the sound that reaches the recipient. These changes occur in three cases:

- Changes for the better, such as strengthening and merging the sound.
- Changes for the worst, such as the occurrence of an echo accompanying the sound.
- Lack of clarity in some syllables in speech.

When sound waves strike with surfaces surrounding space, part of them is reflected, part of them is absorbed by the materials that make up the surfaces, and the remaining part passes through them (Ali, 2018). Sound is transmitted within spaces either through the air or through the surfaces that make up this space, as shown in figure (1) below:

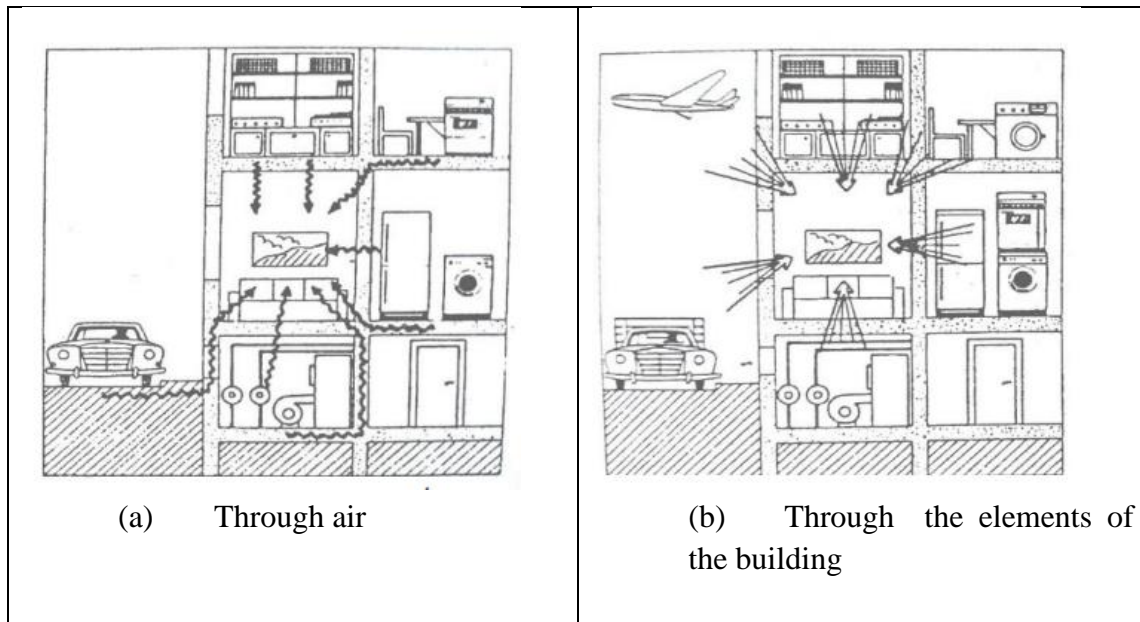


Figure (1) Methods of sound transmission (Al-Khatib, 2002)

The most important audio problems can be identified by noise and echo, as follows:

Noise:

It is a mixture of unwanted sounds that affects workers' activity and production, in addition to its effect on hearing, the nervous system, and other human systems. Studies, including the study conducted by Hassan (2005), indicate that uncomfortable classrooms cause mood swings and feelings of discomfort, which contributes to increased stress and fatigue among students in addition to a decrease in cognitive skills. According to the World Health Organization, the safe level of noise in the classroom cannot exceed 65 decibels, after which the ability to learn is weakened. Hassan adds that there are several studies that found that with every increase of 10 decibels in the classroom, students' grades decrease by 5 to 6 grades.

There are several factors that make a sound be a noise, the most important of which are:

- 1- Sound level: The most annoying sounds are the loudest.
- 2- Frequency: High-frequency and sharper sounds are more annoying.
- 3- The randomness and interruption of sounds causes disturbance.
- 4- Sounds whose origin is unknown are considered more annoying.
- 5- The sounds accompanying activities (for example, the sound of walking, eating, etc.) are annoying.
- 6- The psychological state, for example, the person who performs mental work is more sensitive than the one who performs manual labor (Hassan, 2005).

Echo

It is the phenomenon of repeatedly hearing sound resulting from reflection, as the sound is reflected on solid surfaces and when it is heard again, the phenomenon of sound reflection is called echo. It is one of the first natural phenomena that attracted human attention. It is the clear repetition of the original sound after the sound source has stopped, and its occurrence depends on the time gap between the arrival of the direct sound and the reflected sound. Most audio studies indicate



that this period reaches 50 milliseconds, with a path difference of up to 17 meters between direct and reflected sound (Hammad, 1996).

The phenomenon of echo also becomes clearer as the time period increases between the arrival of the direct sound and the reflected one, which causes problems in clearly understanding speech. It also occurs if the difference in the length of the distance traveled by the direct sound from the source to the listener and the length of the distance it travels from the source to the reflecting surface and then to the listener exceeds 7 feet, and is often the result of reflections from the back wall. (Kuttruff, 2007)

The Practical Part of the Study

In order to test the hypotheses and achieve the research objectives, the researcher chose Madiha Al-Birmani School to be the research sample, which represents a model for schools in Iraq. This particular school was chosen after visiting a number of schools to detect sound problems and conducting interviews with teachers and students in those schools. She found that Madiha Al-Birmani School was the school that suffers most from acoustic problems.

Regarding the reliability of the research, the researcher tried to make the research at a high degree of reliability and accuracy by taking the required data, whether it was the hall measurements or the materials used in construction, and she obtained this data accurately from the School Buildings Department/Engineering Division in the Babylon Governorate Education Directorate.

As for the accuracy of the analysis and results, the Autodesk Revit program was used to draw the study sample (Madiha Al-Birmani School Space) and the Odeon program, which is a program, specialized in evaluating acoustic performance, as it provides tools for performing acoustic analysis, which stimulates sound and echo in architectural designs.

Description of Madiha Al-Birmani School

Madiha Al-Birmani Preparatory School is located in the Babel neighborhood, opposite Al-Noor Children's Hospital and adjacent to Al-Waeli Girls School. It includes only three academic stages (fourth, fifth, and sixth). It has two entrances; the first is the main entrance on the northern side and on the main street. The second entrance is on the northeastern side. The school includes 14 classrooms and accommodates more than 550 female students. The school is located at the corner of two streets with constant traffic and operation during the day (during official hours), so it is exposed to noise resulting from the sounds of cars and the constant movement of people.

The school suffers from acoustic problems in the central hall, which is an indoor hall with an area of 279 square meters and a ceiling height of 9 meters in the middle of the school. A number of important activities take place in this hall such as the flag raising event that takes place every Thursday, meetings and seminars, and meetings with the students' parents. In addition, it is used as an examination hall. Because of the acoustic problems, these activities are annoying for students and teaching staff as well.

Bricks are used in the walls and finish them with cement mortar and sand. As for the ceiling, only the iron structure and sandwich panels (which are reflective materials) are used, so they cause echoes. Granite stone material was used to finish the floors, and it also causes sound reflections, which increases acoustic problems. See the following figures (the researcher's photographs of the hall).



Figure (2) Photographs of the School under Study

Below are plans of the school's plans, which were obtained from the School Buildings Department of the Babylon Education Directorate.



Figure (3) The plans of the School

Then the following diagrams were drawn in the Rivet program to represent the current design of the school:

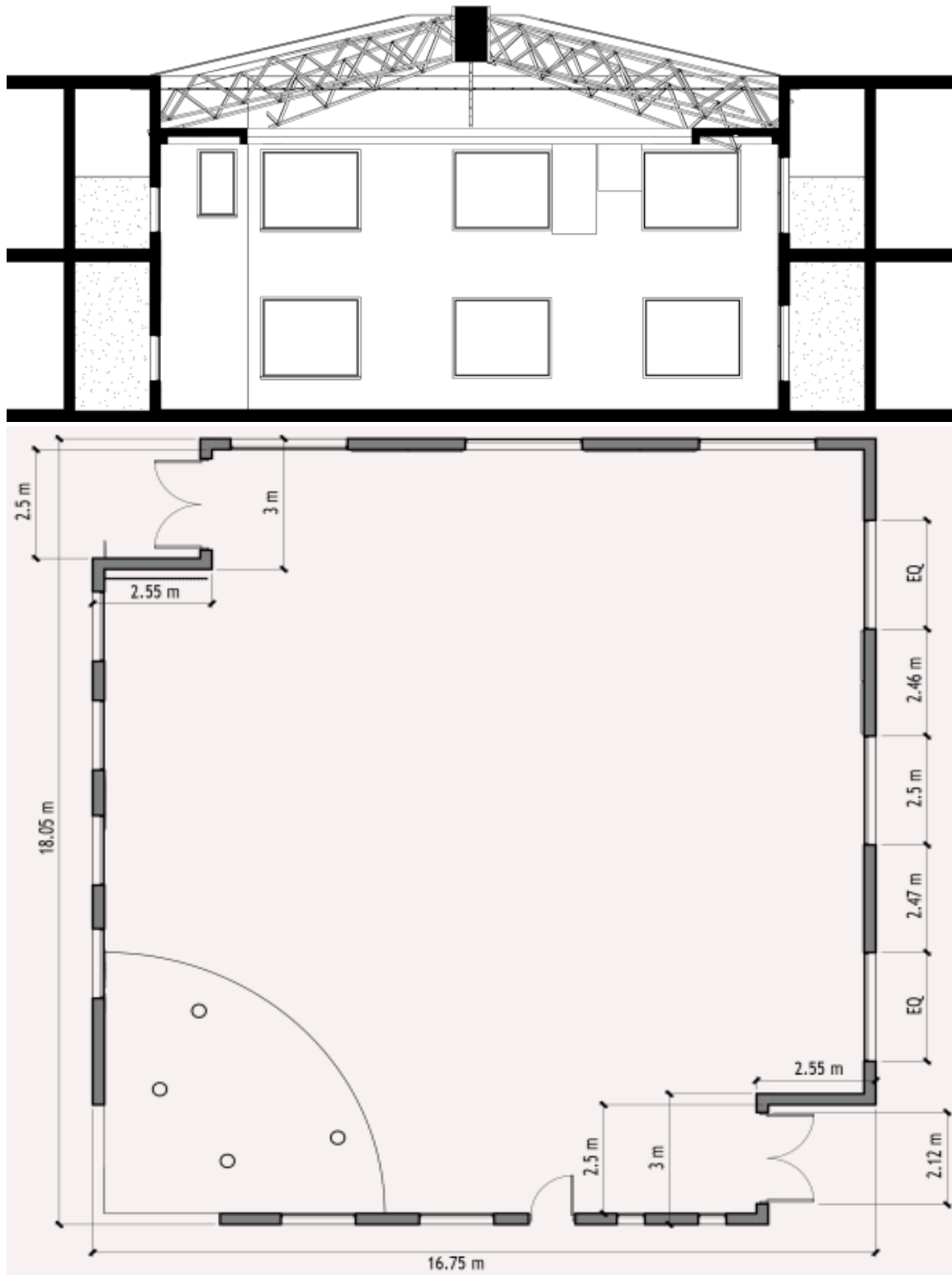


Figure (4): Revit Diagrams of the School under Study

Calculation of Sound Intensity in Space

Sound intensity was measured in two ways:

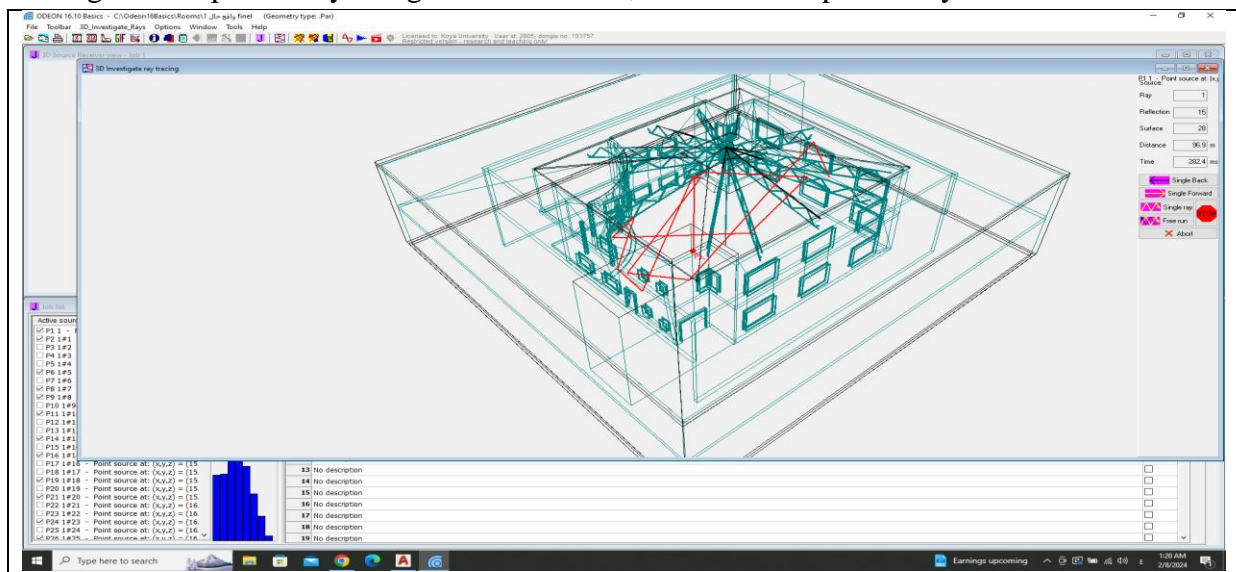
The first method: The sound intensity was measured with the PCE acoustic calibration device, which is a device used to calibrate the sound meter. The sound intensity at the normal level ranged

between 65 to 70 decibels in the presence of small numbers of occupants, and ranged between 85 to 100 decibels in the presence of large numbers of occupants.



Figure (5) PCE acoustic calibration device

The second method: The school's diagrams that are drawn using Revit program were entered into the analytical program Odeon, determining points for the sound source and points for the recipient, and calculating the sound frequency for the current status in the hall under study. The result was 69.2 decibels (as shown figure: 6), which is considered very loud and represents a real problem with sound. This is consistent with what the researcher's measure of the sound frequency when visiting the site practically using the PCE device, as mentioned previously.



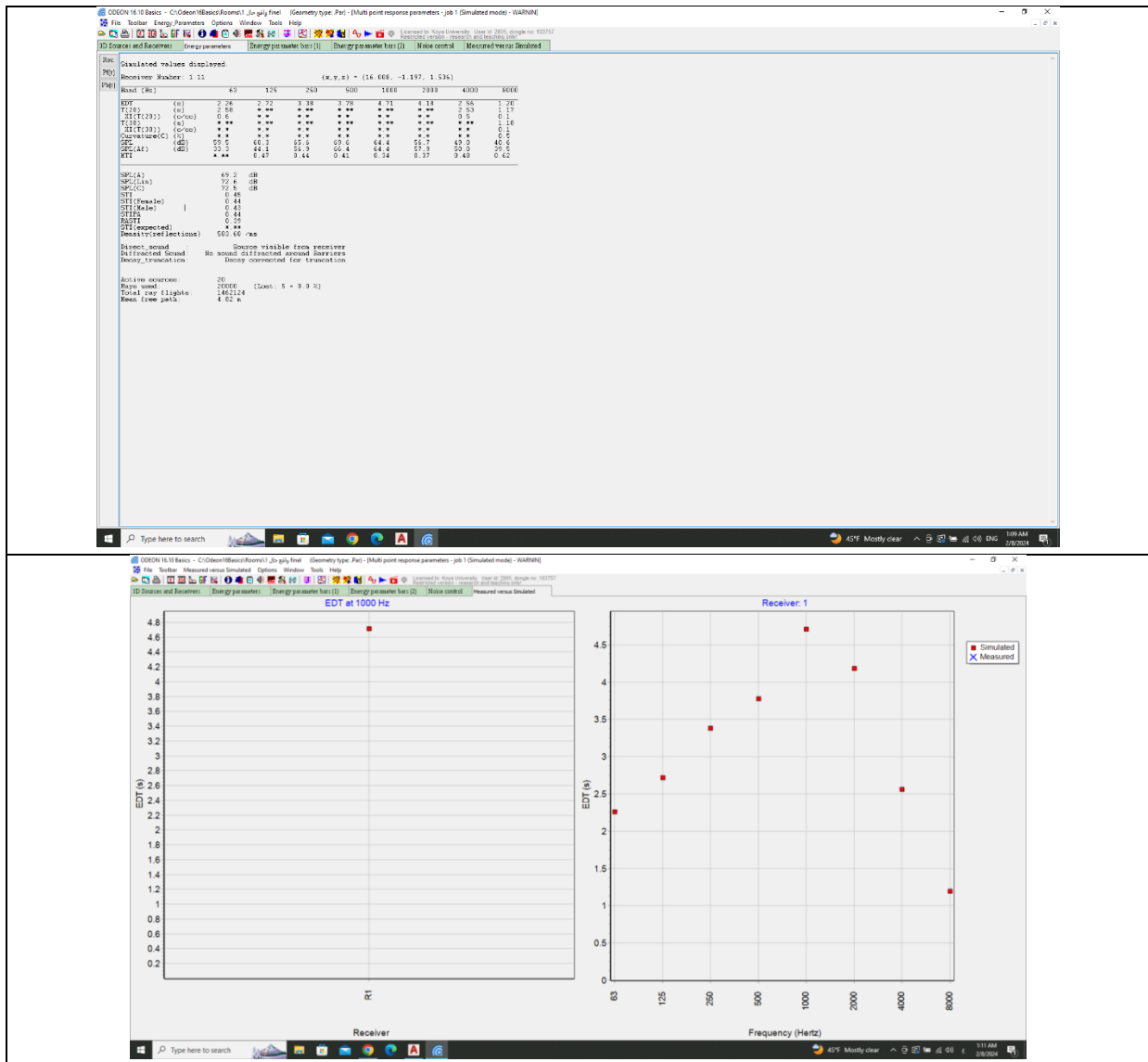


Figure (6) Odeon's Calculating the Sound Frequency

By calculating the Stephens equation, it was found that the rebound time is 2.793:

$$t = r(0.0118 \sqrt{v}) + 0.107$$

v The size of the hall is 2511 cubic meters, r = 4, as it is a speech hall

$$t = 4(0.0118 \sqrt{2511}) + 0.107$$

$$t = 2.793$$

Since the optimal frequency time in acoustic halls ranges between 1.4 and 1.5 seconds, -as stated by Hassan (2005), this time (2.793) is considered high and needs to be treated to reduce or prevent the occurrence of interference or noise.

The Analysis

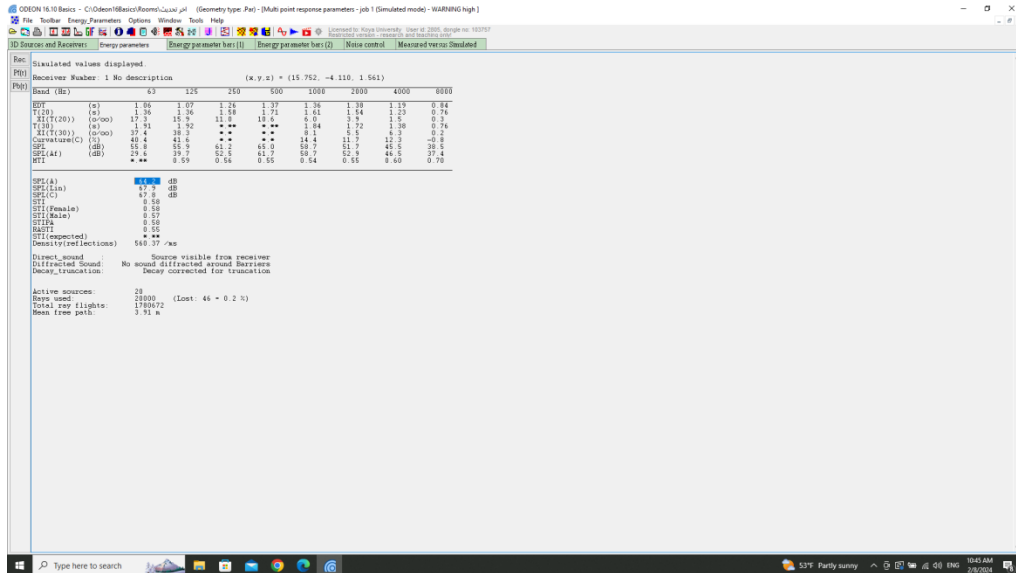
The required analyses were done using the Odeon Program to test the research hypotheses, as shown below:



Testing the First Hypothesis

The first hypothesis states: The echo level can be reduced to a large extent by using an acoustic panel.

In the Odeon program, the ceiling finish was changed using acoustic panel units, and the following results were shown:



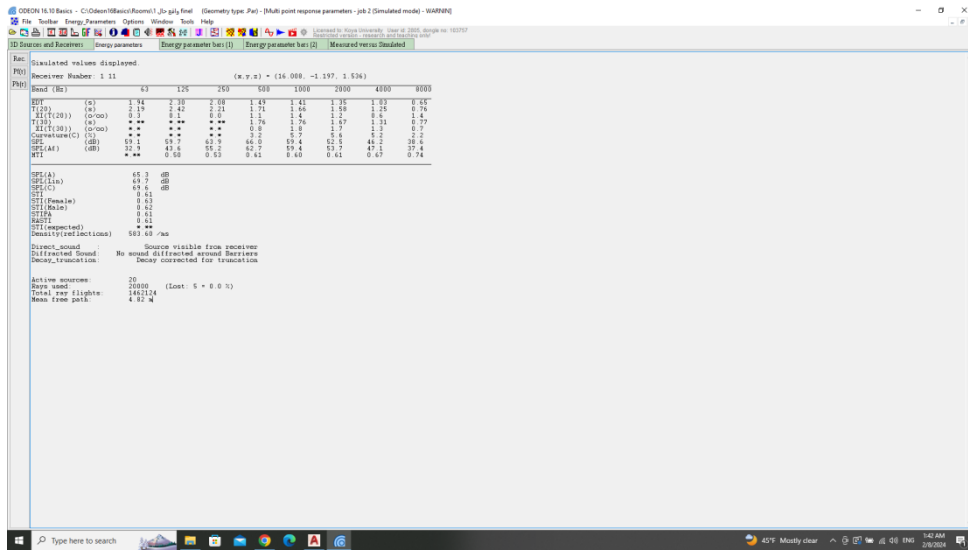


Figure (9) Odeon Calculation of Sound Intensity after Using Carpet
 As shown in figure 9 above, the sound intensity was changed from 69.2 to 65.3 after adding the carpet to the window which validate the second hypothesis

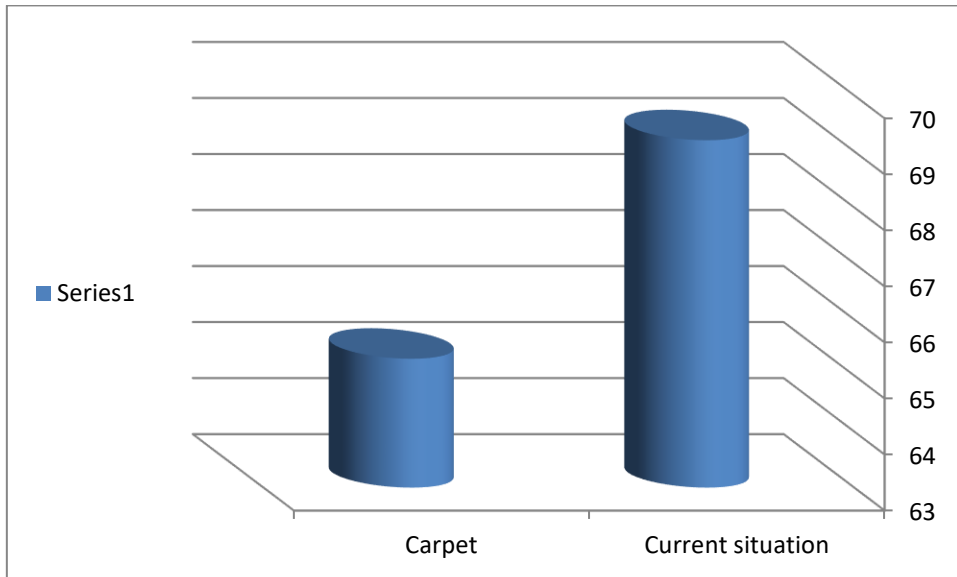


Figure (10) The Difference in Sound Intensity After Using Acoustic Panel
 The Third Hypothesis
 The third hypothesis states that the use of rubber frames in windows contributes to reducing acoustic problems. In the Odeon program, rubber frames were added to the windows and the following results were achieved:

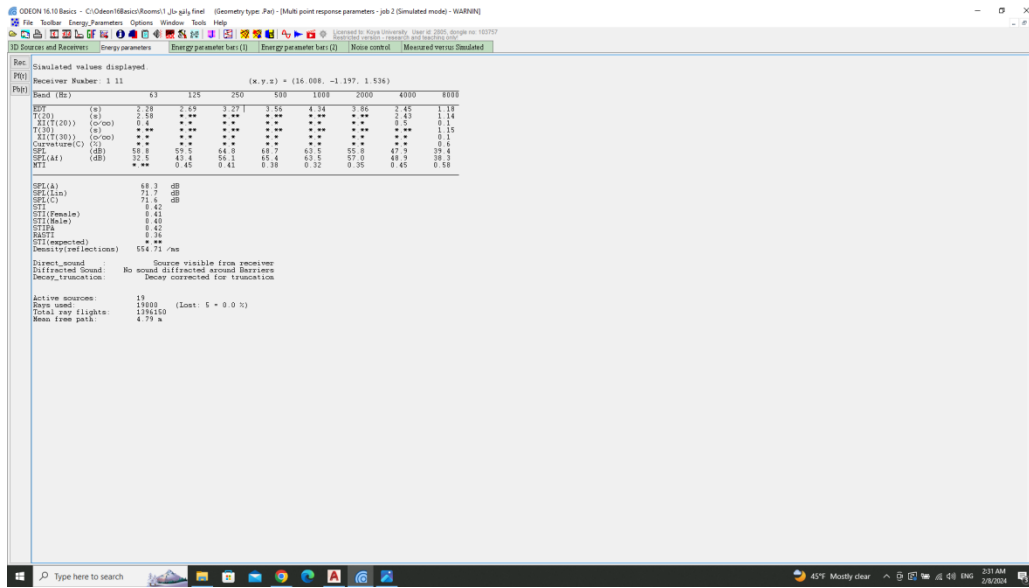


Figure (11) Odeon calculation of Sound Intensity after Using Rubber Frames
 The third hypothesis was accepted because the sound intensity was lower from 69.2 to 68.3 after using the rubber frames in the windows.

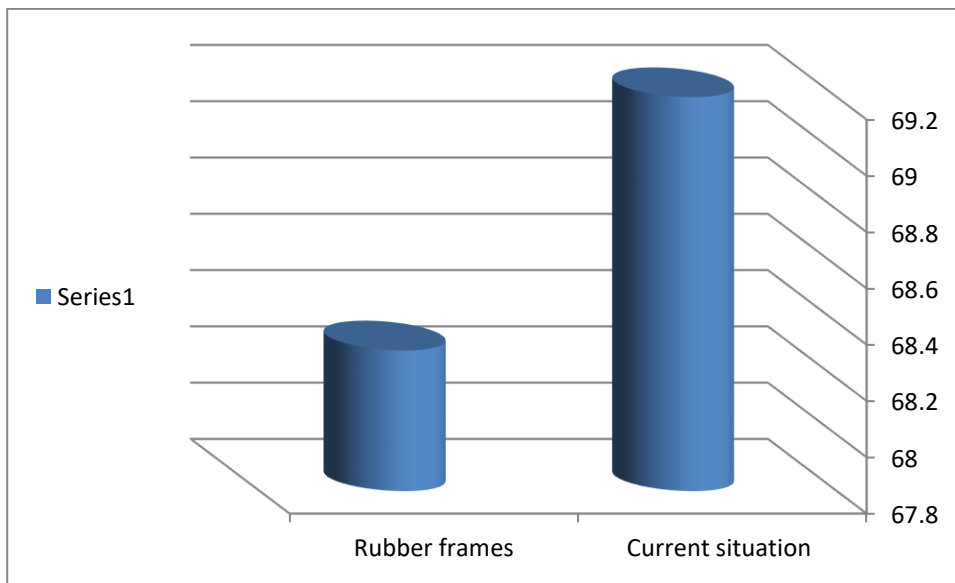


Figure (11) The Difference in Sound Intensity after Using Rubber Frames
 The Fourth Hypothesis

The fourth hypothesis reads that covering the walls with insulating materials such as wood helps reduce acoustic problems. Within the Odeon program, wood was used to cover the walls and the following results were obtained:

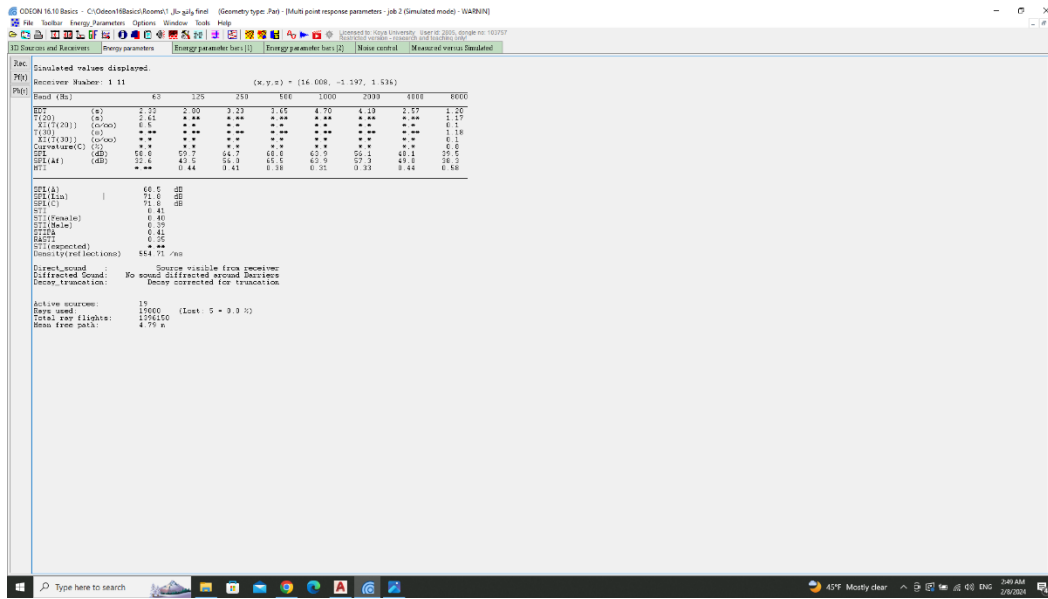


Figure 13: Odeon's Calculation of Sound Intensity After Using Double Glass
 The sound intensity changed from 69.2 to 68.5, and thus the hypothesis was also proven to be correct.

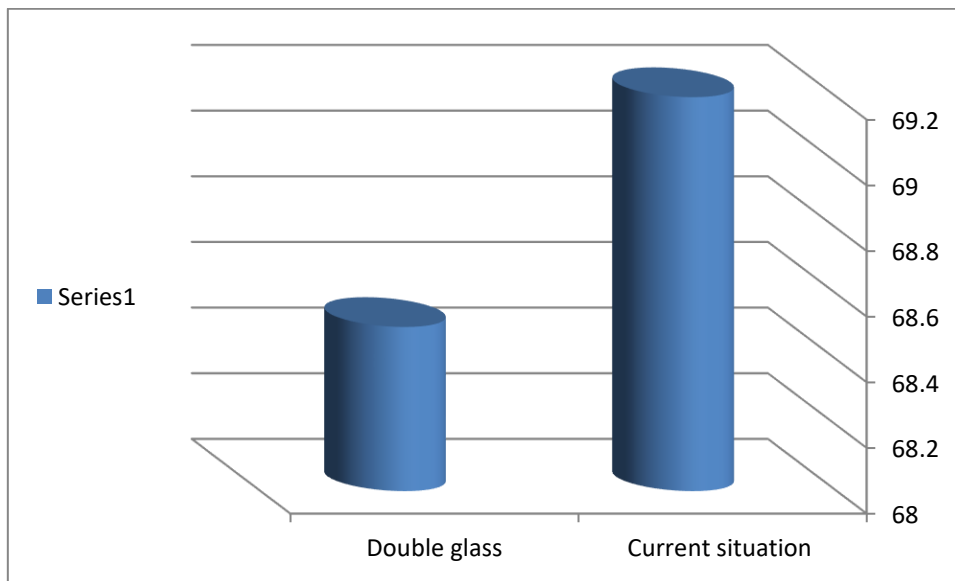


Figure (13) The Difference in Sound Intensity after Using Double Glass

The Sixth Hypothesis

At the end, and in order to test the sixth hypothesis, which states that the use of acoustic panels in ceiling finishes has the greatest impact in solving the sound problem than other solutions in the school in question, the researcher calculated the sound intensity when making all the changes studied above (which are the use of acoustic panels in the ceiling, carpet in the floor, wood in covering the walls, double glassing, and rubber frames in the windows). The Results showed that the lowest amount of sound intensity was obtained with the use of acoustic panel, which is 60.5, as shown below.

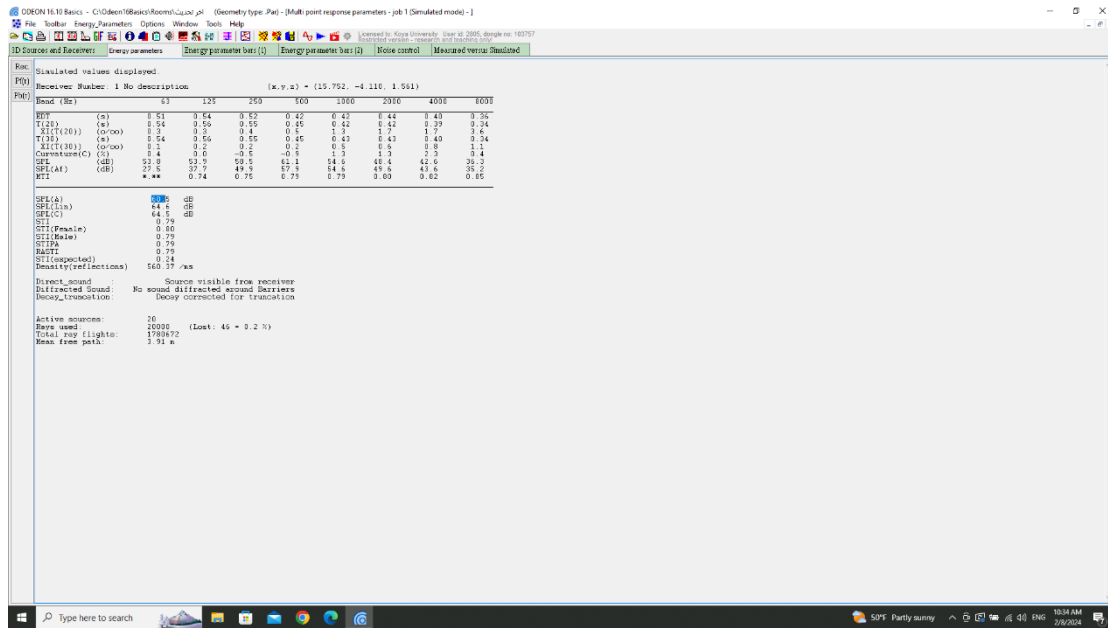


Figure (16) Odeon's Calculation of All the Changes Virtually Made in the hall

The sixth hypothesis was proven that the sound intensity was 60.5, which the lowest value is obtained when making any of the other changes, as shown in the figure (15) below:

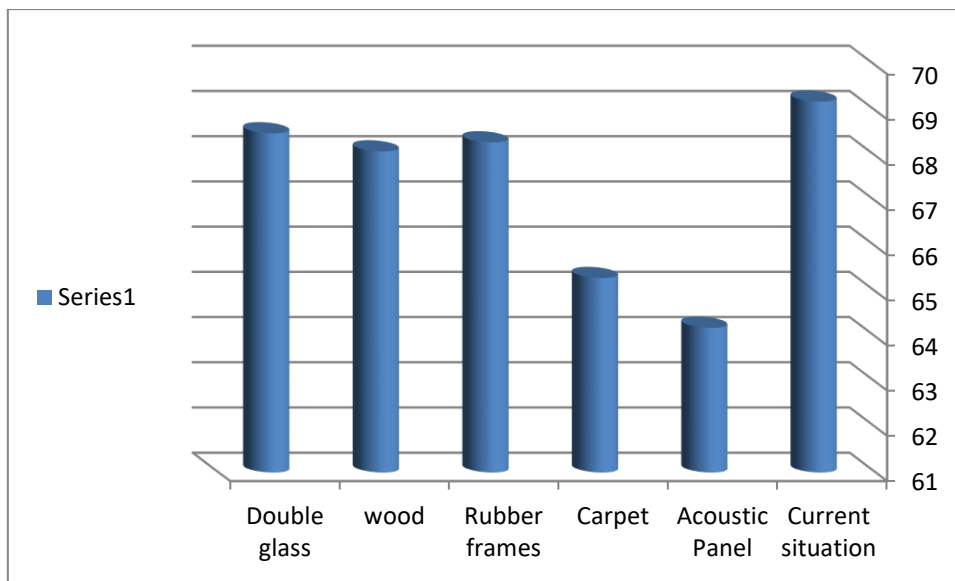


Figure (15): Sound Intensity for all the changes made in the Hall (Calculated in Odeon Program)

Conclusions:

At the end of the study, the researcher reached the following conclusions:

Theoretical Conclusions:

Built upon the literature reviewed the following conclusions can be set forward:

A- The use of sound-reflecting materials in the finishing of the hall causes the problem of echoes.



B- The location of the classroom and its surroundings has a high impact on making the noise problem.

T - The use of indoor plants helps dissipate sound, which helps reduce the occurrence of echo phenomena to achieve a better acoustic environment.

D - The use of porous and sound-scattering materials on the interior surfaces of halls in general and the classroom in particular helps improve speech clarity.

Practical Conclusions

Based upon the results obtained from the analysis and the calculation done through Oden Program, the following conclusions are reached at:

1- The use of an iron structure in the ceilings of classrooms increases the intensity of the sound, which negatively affects the clarity of the sound heard by the recipients.

2- All of the materials proposed to reduce sound problems, such as acoustic panels, carpet, rubber frames, double glassing for windows, and wood, are all useful in reducing sound intensity, which contributes to solving acoustic problems.

3- The use of acoustic panels in ceiling finishes has the greatest impact in solving acoustic problems.

Recommendations

Examining the research findings and the theoretical and practical conclusions reached at, the researcher presents the following recommendations:

1- It is preferable to treat the ceiling with one of the following solutions:

- a. Raising the ceiling a good distance from the wall so that this distance allows sound to penetrate and not bounce back.
- b. Using insulating materials to cover the ceiling, such as acoustic panels.
- c. Planting landscaping around the building and using indoor plants to dissipate sound and soften the atmosphere.
- d. Using materials which scatter sound, including wood and porous materials on internal surfaces, to reduce acoustic echoes and improve speech clarity.
- e. Using double glassing for windows.
- f. Furniture the floor with carpet or thick felt.
- g. Using adhesive rubber strips in door and window frames to achieve sound insulation.

2- Finally, the researcher puts forward the following proposal for solving the acoustic problems in the school under study:

Redesigning the interior space (of the hall included in the study) using acoustic panels in the ceiling, carpet in the floor, wood in covering the walls, double glassing, and rubber bands in the windows.



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