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Study Analysis of Acoustic Quality Assessment of Salman-ITB Mosque Using Ecotect Simulation

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Abstract:

The mosque is a place of worship for Muslims that has a significant impact on society. In performing worship, there needs to be tranquility and clarity of speech so that the conveyed message can be clearly and effectively transmitted. In this study, the space used for simulation is the prayer room of Salman Mosque. The aim of the research is to determine the condition, causes, and improve the acoustic quality of the prayer room of Salman Mosque. This research utilizes Ecotect software, focusing on measurements of Rays and Particles, reverberation time, and acoustic response. The data collection method used in the research is simulation method. The simulation results show that measurements using Rays and Particles display sound lines falling on the back wall surface, with sound travel times ranging from 35 milliseconds to 48 milliseconds. These values are close to the desired sound travel time limit. Measurements using reverberation time indicate that in empty building conditions (0% occupancy), the Reverberation time is relatively high at 1.65 seconds. With the mosque filled to 50% occupancy, the Reverberation time decreases to 1.27 seconds, and when fully occupied, it decreases further to 1.03 seconds. Measurements using acoustic response show a reverberation time measurement in the prayer space of Salman Mosque using Ecotect Analysis v5.50 to be 4.05 seconds. This result is below the SNI 1726-2012 standard, which states that the reverberation time in a prayer space should range between 6-10 seconds. Thus, the calculation results for Salman Mosque are below the SNI 1726-2012 standard and are considered good.

Keywords: *Reverberation Time, Acoustic Response, Rays and Particle*

INTRODUCTION

The function of a mosque is as a place of worship for Muslims, with its primary purpose being the transmission of the imam's voice to the congregation during congregational prayers or the voice of the sermon giver (khotib) to the audience during sermons. The delivery of this voice must reach the congregation effectively to maintain solemnity during worship, as the clarity of the voice also affects the solemnity.

Generally, architectural and interior designers of mosques tend to choose materials with hard surfaces and a clean impression, such as marble, granite, GRC, ceramics, etc. If acoustic aspects are not considered, these materials have the potential to cause acoustic defects such as echoes, flutter echoes, and sound focusing, which ultimately can disrupt intelligibility (clarity of hearing speech) within the mosque.

The important aspects of mosque acoustics, according to Joko Sarwono (2018), can be seen in three things: the direction of the sound source, rooms for conversation, and rooms for worship. The direction of the sound source is crucial because it enhances the solemnity of worship. When facing the qibla, the sound should also come from the direction of the imam. Therefore, the arrangement of sound in the mosque is also very important. The adequacy of mosque acoustics is marked by four things: it should be able to orient the hearing towards the qibla, it should provide enough energy to hear with the addition of speakers, it should be sufficient for hearing, it should be sufficient for comprehending information, and it should create a unique auditory experience for the mosque space.

The common issue is the excessively high reverberation time due to hard building materials such as ceramic floors, ceramic walls, and ceramic domes. Additionally, there is an excess of low-frequency sounds, attributed to the lack of proper sound system arrangement. Since most activities in the mosque involve human voices, sound clarity is therefore crucial in a mosque. How can we arrange the sound system properly? According to Joko, the sound system in a mosque depends on the spatial geometry, such as whether the mosque has a domed, flat, or pitched-roofed structure. Different spaces require different sound system settings and cannot be standardized.

The main acoustic problem in mosques is the sound system. An acoustic audit is needed to identify existing acoustic issues, such as reflection, absorption, concentration, and frequency energy imbalance. Once the problems are identified, action must be taken to address them, such as adding absorption materials, modifying architectural designs, or installing sound equipment in the room. The installation of a sound system should only be done when the natural acoustic conditions of the space have been achieved (in accordance with its function). The sound system is a tool to create better listening conditions, but it is not a system to fix room acoustics. If the room has acoustic defects such as echoes, flutter echoes, sound focusing, and excessive reverberation, then no matter how good the sound system is, it cannot fix these issues. Therefore, before installing a sound system, an acoustic analysis should be conducted to assess the acoustic condition of the room and determine the needed sound system requirements. This acoustic analysis can be done by measuring sound levels, measuring sound absorption, and checking sound quality. After understanding the acoustic conditions of the room, the selection and installation of the sound system can then be carried out.

In this case, the researcher will investigate the acoustic performance of the space within Salman-ITB Mosque by creating simulations and models using computer software (Ecotect), in order to understand the conditions, identify the causes, and provide solutions to achieve good and optimal acoustic values in the spaces within Salman-ITB Mosque.

METHODOLOGY

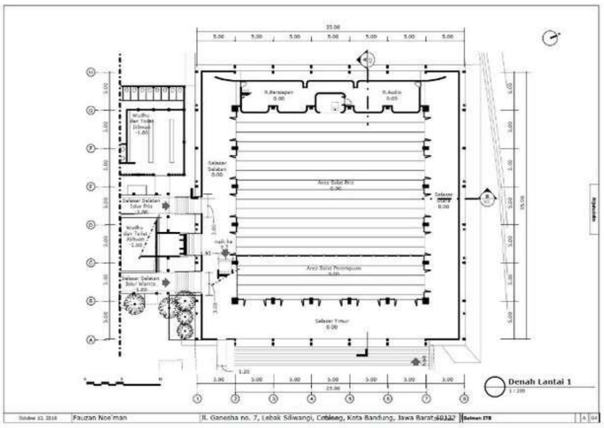
This research will focus on measuring Rays and Particles, reverberation time, and acoustic response. The data collection method used in the research is simulation method. Simulation is defined as a dynamic system that uses computer models to evaluate and improve system performance (Harrel et al., 2004). In this research, simulation will be tested using Autodesk Ecotect software, which is a software used for acoustic simulation involving geometry and acoustic parameters in architectural elements inside the space. The method of analyzing data in this research is conducted by using descriptive analysis. It involves describing or explaining the analysis results generated from measurement data and simulation results (Hasan, 2001). Descriptive analysis is only related to describing or providing explanations about data or situations that function to explain conditions, phenomena, or issues. In this research, the researcher will use quantitative methods to describe the results of measurements in graphs and tables based on existing theories.

RESULTS AND DISCUSSION

General Overview of Masjid Salman

Salman Mosque is located in Ganesha - Bandung. The object of study in this research is focused on the prayer room located on the first floor of the building. The description of the object of study is as follows:

1. Building floor, with a total area of 1,250 m2 covered with parquet material.
2. Capacity of 1000-1500 worshippers.
3. Walls are 9.5 meters high, made of brick material, coated with plywood material.
4. Ventilation/openings, with an area of 180 m2.
5. Main door made of glass material.
6. Imam's door made of 1" thick wood material.
7. Windows, made of glass material.
8. Ceiling, made of plywood material.



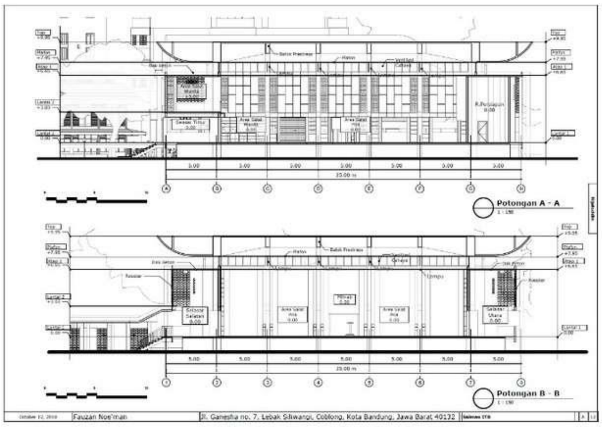


Figure 1. Plan and Section of Masjid Salman
(Courtesy: Salman Foundation)

Rays and Particles

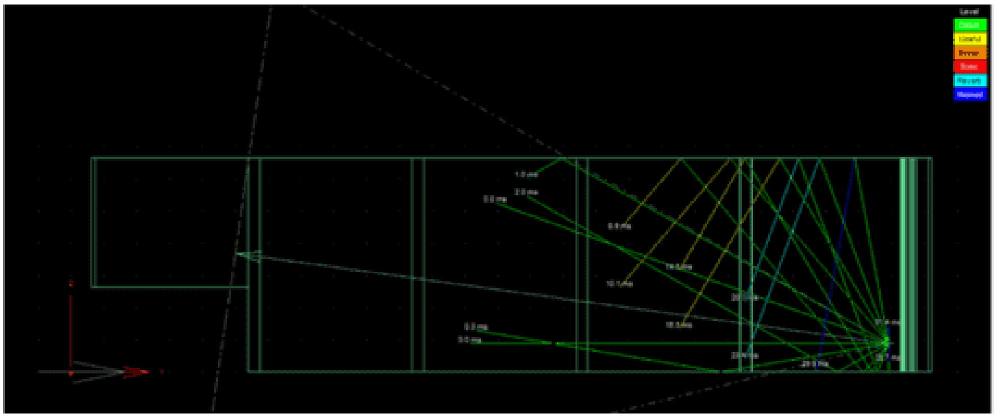


Figure 2. Rays and Particles
(Courtesy: analytic 2022)

Ecotect provides a more complex sound line analysis with the Particle and Rays Analysis (PRA) feature. PRA analysis is animated and is a variation of the more interactive and informative linked acoustic rays facility. Sound ray distribution is visualized in both two and three dimensions, and changes in sound energy during travel are detected. Sound energy distribution is not visualized with line objects but with point objects (particles), making the spread of sound in three dimensions easy to detect.

To accommodate the need for analyzing the influence of the absorption panel positions on reverberation time, it is necessary to use the Linked Acoustic Rays feature. With this, the sound journey within the space can be traced and used to determine the surfaces in the room as either reflective or absorptive surfaces. This process can be performed using Ecotect to analyze and identify the absorption panels. The software will calculate and display the absorption panels by measuring sound intensity and reverberation time for each reflected point. This data can then be used to determine how the position of the absorption panels will affect the reverberation time. Thus, it can evaluate the impact of the absorption panel positions on the reverberation time and take necessary actions to improve sound quality.

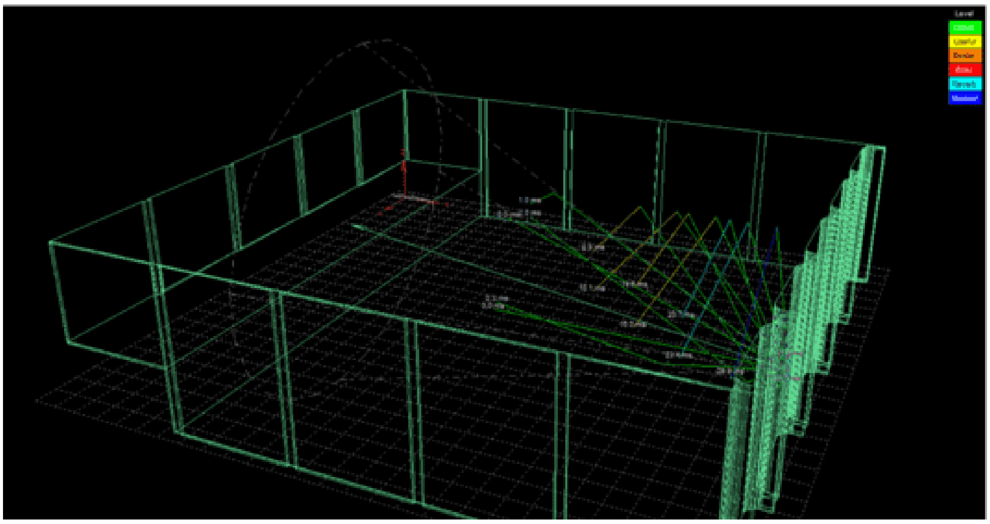


Figure 3. Rays and Particles

(Courtesy: analytic 2022)

PRA also provides facilities to calculate acoustic values such as audibility, sound index, and contour sound index. This feature allows users to visualize how sound moves within the room and how sound characteristics change over time. These facilities also enable users to evaluate acoustic impacts and identify critical points in the room, thus assisting in the acoustic design process. PRA also provides tools to analyze the interaction between sound and frequency, which can aid in assessing the acoustic impact of a room on sound quality. The results of PRA analysis, besides being used to observe sound drop points on a surface after a desired number of reflections, are also used to analyze the characteristics of sound energy propagation, both in absolute values (expressed in sound dB value decreases) and relative to direct sound, expressed in color codes (direct sound, useful, border, echo, reverberations, and mask).

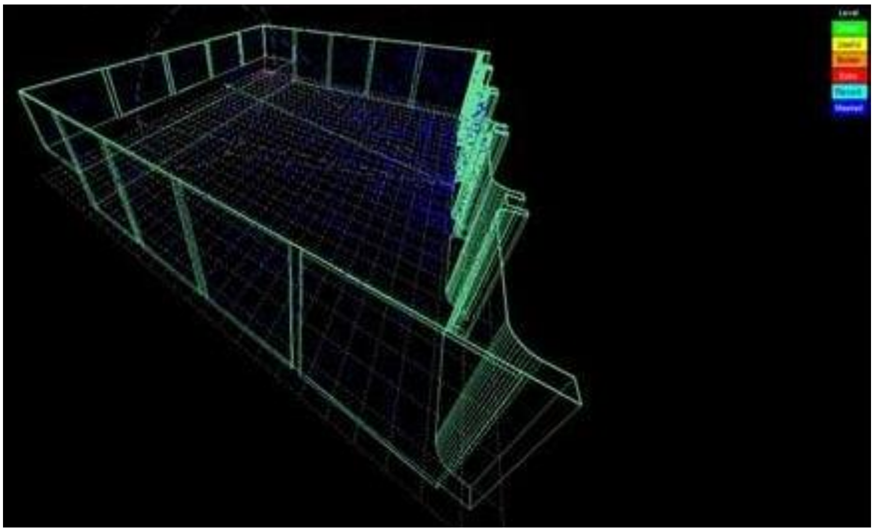


Figure 4. Rays and Particles

(Courtesy: analytic 2022)

In Figures 5, 6, and 7, sound lines moving horizontally towards the front side will reflect at sharp angles and have the potential for multiple reflections on the facing wall plane. Sound lines moving vertically upwards or downwards will reflect at flat angles and have the potential for multiple reflections on the ceiling or floor of the room. Furthermore, observing the sound lines falling on the back wall plane, the travel time of the reflected sound ranges from 35 ms to 48 ms. This value approaches the desired travel time limit. To weaken the reflected sound energy (thus reducing travel time), absorptive material is constructed on the back wall. To address this issue, additional absorptive material is needed to optimize reverberation time and background noise inside the mosque. Sound falling on the floor or ceiling planes near the podium may potentially reflect repeatedly on both planes.

Similarly, sound lines falling on the floor and ceiling near the back wall will reflect repeatedly to the ceiling or floor, then to the back wall, and back to the center of the room. This creates a multiple bounce effect, making the sound appear louder. This is known as the "rebound effect" or "reflection effect". This effect can increase the volume of sound and make it clearer. However, if there are too many reflections, the sound can become too loud and harsh. Therefore, it is important to control the number of reflections that occur by using sound-absorbing materials such as carpets, rugs, acoustic panels, and others. Sound reflection can help increase the volume of sound produced, but it can also increase the amount of excessive noise. Therefore, it is important to reduce the rebound effect so that the sound produced is not too loud. One way to do this is by using materials that can absorb sound such as carpets, foam, and wooden panels. By placing sound-absorbing materials in areas that would otherwise reflect sound, the rebound effect can be reduced, making the sound smoother.

Reverberation Time

Reverberation time is an analysis of the length of reverberation time based on the volume of the room and data on the material of the room surface. The calculation method in Ecotect software adopts the Sabine, Norris Eyring, and Millington Sette formulas, or known as the statistical reverberation method. All formulas for reverberation time analysis are then applied to each octave band of sound and supplemented with facilities to observe the effects of seating arrangements and the number of users. Since the calculation is based only on the total absorption coefficient (the product of the absorption area multiplied by the coefficient of each material used), three-dimensional modeling functions more as visualization only and the calculation proceeds quickly.

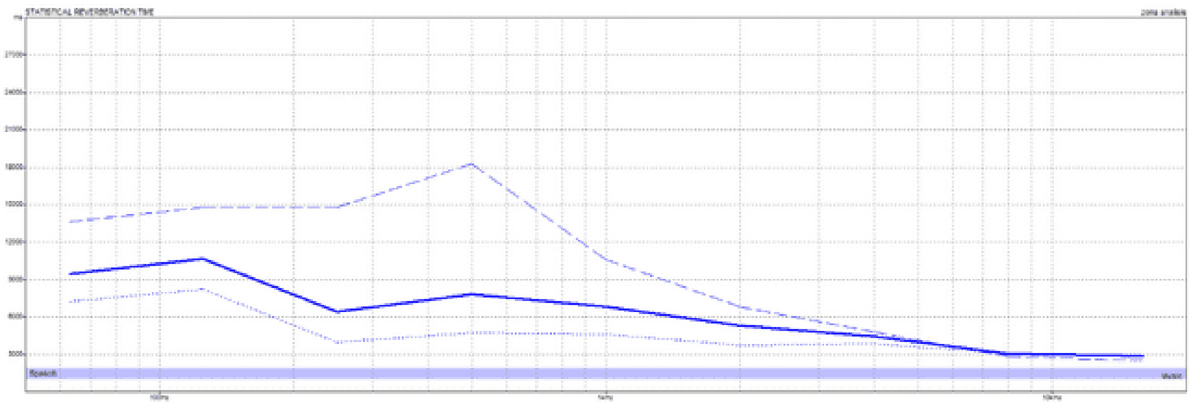


Figure 5. Reverberation Time

(Courtesy: analytic 2022)

In Figure 8, if the building is empty (0% occupancy), the Reverberation time is quite high at 1.65 seconds. If the mosque is 50% occupied, the Reverberation time decreases to 1.27 seconds, and when fully occupied, the RT becomes 1.03 seconds. The condition of the mosque being fully occupied results in a lower Reverberation time due to sound absorption by objects in the room. The more objects in the room, the more sound is absorbed by these objects, resulting in a decrease in Reverberation time.

As the number of worshippers in the mosque increases, the Reverberation time in the prayer room approaches the optimum Reverberation time of 0.98 seconds. This is due to the increased absorption coefficient factor from the worshippers, resulting in a decrease in Reverberation time. Additionally, worshippers standing in the mosque can also increase the intensity of the sound produced by the sound system used during prayers. By increasing the sound intensity, the sound will more easily absorb into the prayer room, thus further reducing the Reverberation time. Therefore, the more worshippers standing in the mosque, the closer the Reverberation time in the prayer room will approach the optimum Reverberation time of 0.98

seconds. Because Reverberation time is the time required for sound to dissipate from the room, approaching the optimum Reverberation time means that the sound will not be heard repeatedly or echo. Thus, the sound will be clear and perfect.

The optimal Reverberation time will help the sound become clearer, allowing worshippers to hear the recitation of the Quran or the sermon clearly and without being disturbed by repeated sounds. Based on the results of Table 1, the frequency of 500 Hz (the mid-frequency used for conversation spaces) with room occupancy at 0% achieves a Reverberation time value of 18.29 s, room occupancy at 50%: 7.80 s, room occupancy at 100%: 2.94 s.

Table 1. Table Format

	TOTAL	EMPTY	50%	FULL
FREQ.	ABSPT.	RT(60)	RT(60)	RT(60)
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63Hz:	110.242	13.65	9.46	7.22
125Hz:	94.656	14.81	10.66	8.25
250Hz:	87.857	14.78	6.42	4.01
500Hz:	57.917	18.29	7.80	4.72
1kHz:	83.584	10.60	6.83	4.62
2kHz:	100.843	6.85	5.30	3.75
4kHz:	155.895	4.77	4.47	3.88
8kHz:	166.961	2.83	3.07	3.06
16kHz:	140.972	2.54	2.86	3.00

From the simulation results, reflections to the back wall are not necessary and not beneficial because they will only be reflected back into the room, resulting in excessive reverberation on sound. The more reverberation on sound, the more it will affect the Reverberation time. It is advisable that the ceiling does not need to use reflective materials but only needs to use absorbing materials. Only the first reflection towards the audience is needed. The goal is to ensure that the direct sound, the first reflection, goes directly to the audience with a delay time not exceeding 40 m/s. This way, the sound will be clearer and more comfortable to hear.

The simulation results indicate a decrease in the reverberation time values in both full and half occupancy room conditions. The reverberation time values in full occupancy conditions range from 2.57 to 3.69 seconds (frequency 125Hz-2000 Hz), while in half occupancy conditions, the reverberation time values range from 3.04 to 4.50 seconds. Despite experiencing a decrease in reverberation time values compared to the empty room condition, both of these conditions still do not meet the standard reverberation time values allowed in mosque prayer rooms, which are 2.20-2.75 seconds on average.

Acoustic Response

The acoustic response in a mosque refers to the acoustic reaction caused by sound or noise heard within the mosque. This may include the sound of people talking, music, traffic noise, or other instrument sounds. The acoustic response occurring in the mosque will affect the sound quality in the mosque, including clarity, intensity, and level of sound produced. Excessive noise can degrade the sound quality in the mosque and reduce the comfort of worshippers. Therefore, acoustic control is needed to improve the acoustic quality in the mosque. This may involve the use of insulation materials, such as carpets, ceilings, and layered materials, as well as the use of acoustic monitoring techniques to measure the noise level.

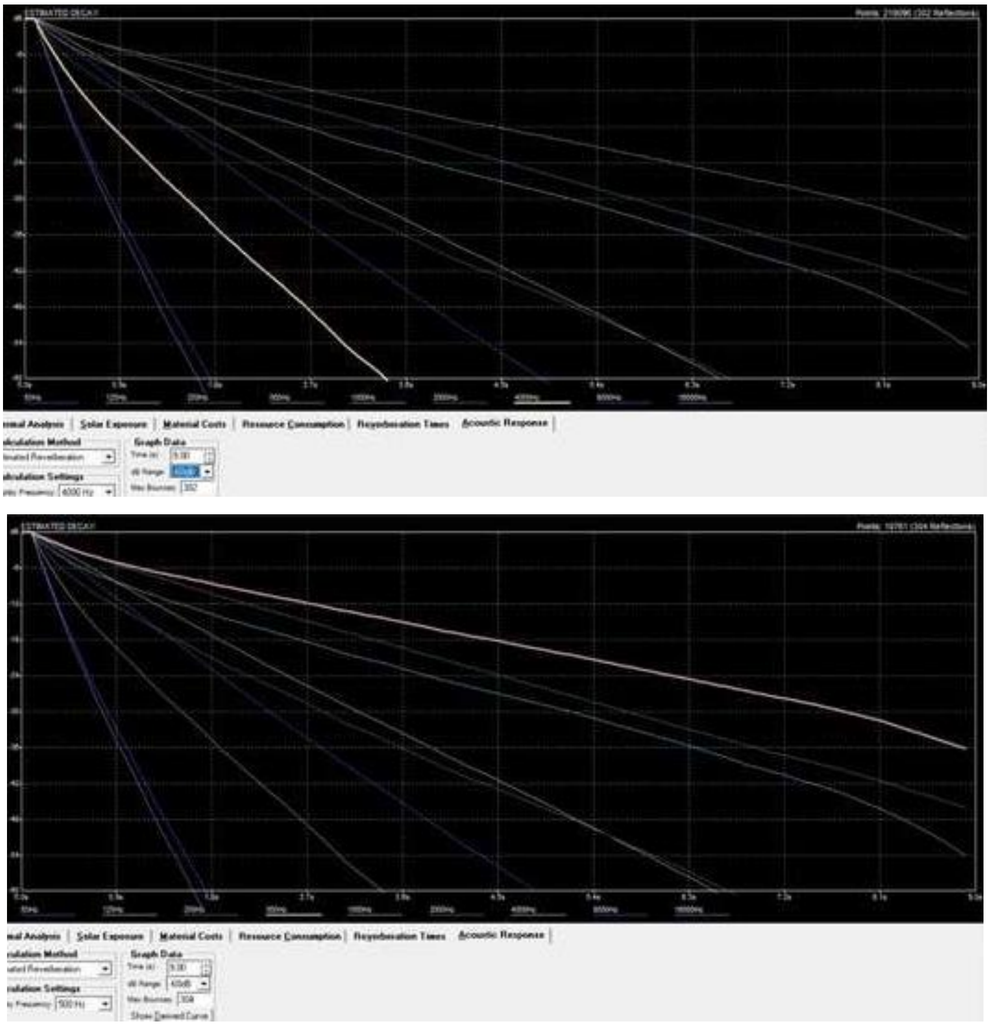

Figure 6. Acoustic Response

(Courtesy: analytic 2022)

From the reverberation time calculation results in the prayer space of Masjid Salman using Ecotect Analysis v5.50, it is 4.05 seconds. This result is below the standard of SNI 1726-2012 which states that the reverberation time in prayer spaces should range between 6-10 seconds. Thus, the calculation result in Masjid Salman is below the standard of SNI 1726-2012 and is considered good. The magnitude of speech intelligibility in the simulation results is a comparison between the sound energy reaching the listener within the first 50-80 ms and the total energy perceived by the listener in the room, thus the reverberation time of the room has a significant influence. The recommended reverberation time ranges from 0.7 - 1 second, depending on the size of the room. To achieve the recommended reverberation time, the use of sound energy absorbing materials is necessary. The surface area absorbing sound and the volume of the room will determine the extent of reverberation in the room. The magnitude of speech intelligibility is also influenced by other factors such as room shape, type of acoustic material, and the level of noise present in the room. Therefore, it is important to choose the right sound-absorbing material according to the room conditions and needs. To achieve good speech intelligibility, it is important to choose sound-absorbing materials and surface areas that are suitable for the room conditions. They should have good quality to reduce reverberation and absorb sound energy. Additionally, it is important to ensure that the room has sufficient surface area absorbing sound to achieve optimal speech intelligibility.

There are several factors to consider to achieve good acoustics in a mosque. First, the quality of materials used for the construction of walls and floors must be carefully chosen. Walls and floors should be made of strong and durable materials, such as bricks, concrete, or wood. Typically, these materials will have higher absorption rates compared to others. Second, the mosque's acoustic design should consider the room's shape. Generally, simple room shapes like square or rectangular are preferable, as they can prevent sound from bouncing. If there are pillars or columns inside the room, they should ensure they are strong enough to bear the acoustic load. Third, the position of the imam's pulpit should be carefully placed to ensure that his voice can be heard by everyone in the mosque. Additionally, if there are electronic equipment, such as speakers or microphones, they should be properly positioned. Fourth, the paint used inside the mosque should be chosen carefully. Paint that is too bright or contains glossy pigments can cause sound to reflect, thus reducing acoustic quality. Fifth, if there are holes or gaps in the mosque, they should be repaired to prevent sound leakage. The use of fabric or sound insulation can also help improve acoustic quality. Additionally, acoustic fixtures such as inserts and acoustic panels can be used to enhance acoustic quality in the mosque. Inserts and acoustic panels can absorb sound spreading in the room, making the sound clearer and easier to hear.

CONCLUSION

The objective acoustic condition of the prayer space at Masjid Salman after conducting an acoustic audit using Ecotect is as follows:

a. Measurements using Rays and Particles show sound lines falling on the rear wall, with sound travel time ranging from 35 ms to 48 ms. This value approaches the desired sound travel time limit, indicating that the rear wall has been well-designed to minimize sound interference.
b. Measurements using reverberation time indicate that in empty building conditions (0% occupancy), the Reverberation time is quite high at 1.65 seconds. When the mosque is 50% occupied, the Reverberation time decreases to 1.27 seconds, and when fully occupied, RT drops to 1.03 seconds. A low RT indicates that the room has good acoustics. In other words, the room produces soft and clear sounds.
c. Measurements using acoustic response show a reverberation time measurement in the prayer space at Masjid Salman using Ecotect Analysis v5.50 is 4.05 seconds. This result is below the SNI 1726-2012 standard, which states that the reverberation time in worship spaces should range between 6-10 seconds. Therefore, the calculation results at Masjid Salman are below the SNI 1726-2012 standard and considered good.

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