Providing Appropriate Acoustic Comforts in Mosques: The Case of Reverberation Time of the Prayer Area at Al-Markaz Al-Islami Mosque, Makassar, Indonesia

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Abstract

Al-markaz Al-islami Mosque in Makassar, as a mosque must be supported by acoustic comfort for the building to function well. One of the standards for good auditory comfort is reverberation time. There is an issue if the prayer area of al-markaz al-Islami Mosque in Makassar city has these standards met. This research therefore examines the reverberation time in the prayer area of this mosque.

The study used a quantitative descriptive method through simulations using the i-Simpa application. Reverberation time simulations at al-Markaz al-Islami Mosque were measured at frequencies of 63 hz, 125 hz, 250 hz, 500 hz, 1000 hz, 2000 hz, 4000 hz and 8000 hz utilizing 32 speakers, each positioned at a height of 2,80 m for columns and 4,40 m for the ceiling.

Based on the analysis of this research, the average reverberation time at the mosque at the 8000 hz frequency is 1,29 seconds. This thus meets the reverberation time standard for a speech room. However, at the frequencies ranging from 63 hz to 4000 hz, it get values <2,74 seconds. This fall into the unacceptable category.

The research thus concludes that the auditory comfort in the prayer area of al-Markaz al-Islami Mosque is not entirely in line with acoustical comfort standards due to reverberation time. It thus requires improvements in the mosque's acoustic conditions to achieve the desired standard reverberation time.

Keywords: Acoustics, Mosque, Reverberation time, I-Simpa.

Introduction

Mosques are recognized as hubs of spiritual growth, serving as spaces dedicated to the worship of Allah (As-Salafiyah, 2020). The mosque, a significant architectural structure in the realm of Islam, has undergone transformations to cater to the demands of the religion. Within these versatile communal areas, many worship practices occur, each necessitating distinct acoustic considerations (Zerhan, 1999). Needless to say, worship considerations primarily shape mosque architecture. These involve three separate or combined activities conducted within a mosque (Eldien and Al Qahtani, 2012). They are as follows.

1. Prayers: Performed individually or in a group led by a leader, called Imam.
2. Sermons: Congregants may participate in a sermon presented independently or as part of the Friday midday prayers.
3. Recitals: Individuals engage in the act of listening to or reciting passages from the holy Quran.

Each of these undertakings demands elevated levels of speech clarity and comprehensibility. Therefore, incorporating acoustic considerations during the design phase of a mosque is necessary to establish optimal listening conditions, as emphasized by Abdou, 2003. In essence, mosques exhibit three discernible acoustic prerequisites:

1. Clarity of the Imam's (prayer leader's) call to prayer
2. Discernibility of the preacher's sermons
3. Engagement in, or harmonization with, the vocal rendition of the holy Quran.

Al-Markaz Al-Islami Mosque, standing tall in the heart of Makassar city, is one of the grand mosques that is an iconic symbol of the city. The establishment of this mosque is also intended to be a center for religious and social activities for Muslims and communities in Makassar. With such a purpose, the Mosque has become the largest and most magnificent mosque in the Eastern Indonesia region. The mosque is built over three floors on a land area of 6,932 m² (Mariani and Nurlaela, 2008).

In the context of such a grand and large mosque, various facilities are required to support the activities within the mosque. One of these considerations is the clarity of sound produced by the sound amplification systems within the mosque, which affects the vibrations and the quality of the sound itself. Architectural design plays a crucial role in how sound can be distributed appropriately. The acoustic conditions of the mosque space should receive special attention.

Research on Mosque Acoustic Performance in Indonesia lists five general acoustic requirements for mosque spaces: sufficient sound intensity, even proper distribution, optimal reverberation time affecting speech clarity, freedom from auditory defects, and low noise levels. A fundamental issue when managing sound within a room is the duration of reverberation time, as it significantly influences the acoustic quality of a space (Dewi and Syamsiyah, 2020).

Figure 1 illustrates the existing interior condition of the prayer area in Al-Markaz Al-Islami Mosque in Makassar. The flooring material across all segments is granite, and the walls are covered with granite, along with ornamental details. The mihrab wall features black granite with additional calligraphy ornamentation. This calligraphy consists of several verses and chapters from the Quran, including "Laa ilaaha illallah, muhammadr Rasulullah." The ceiling material used for the first-floor segment employs a gypsum ceiling that follows the dome's shape.

Fig. 1: Existing interior.
Source: Author, 2023

In this case, the Al-Markaz Al-Islami Mosque experiences poor sound quality when the mosque is crowded due to improper distribution and unfavorable reverberation and echo effects caused by the amplification system. Therefore, an analysis of auditory comfort within the prayer area of Al-Markaz Al-Islami Mosque is essential to assess the acoustic conditions of the mosque objectively.

This paper aims to conduct this analysis to serve as a parameter for sound clarity within the Al-Markaz Al-Islami Mosque.

Its objectives are as follows.

1. To support effective planning in architectural design that requires meticulous planning to ensure that the building meets the intended standards and specifications.
2. To carry out a virtual simulation analysis tool, such as the I-Simpa software, in order to incorporate time into the planning process efficiently.

The expected results are that they can be used as consideration and reference material in designing prayer spaces in mosques to improve the acoustic quality of the space in order to create a comfortable atmosphere and full concentration in worship.

Theoretical Framework

The mosque is a sacred place dedicated to worship (Al-Homoud, Adel and Ismail, 2009). It serves as a venue for Muslims to engage in their daily prayers symbolizes the essence of Islam, and provides a setting for social interactions, learning, and community engagement (Kahera *et al.*, 2009). The Mosque is a crucial factor in advancing civil society within Islam. In his role as a trailblazer, Prophet Muhammad laid the foundation for a model of communal living through the Mosque, which served as the epicenter of its endeavors (Fahmi, 2017).

Architectural acoustics is a crucial element in architectural planning, emphasizing verbal communication and musical experiences, particularly in structures like concert halls and sacred spaces like mosques. Architectural acoustics commonly involves evaluating the interactions between sound sources and listeners within different zones, employing acoustic parameters like reverberation, sound intensity, articulation, initial lateral reflections, and speech intelligibility (Othman *et al.*, 2016).

The acoustic characteristics within a mosque experience variations due to a combination of factors (Lamancusa, 2000). Architectural attributes like mosque design and acoustic elements such as ambient noise levels and reverberation shape the acoustic environment (Azizah Adnan *et al.*, 2018). The clarity of speech can be compromised by an excessive duration of reverberation, often measured as T60. T60 is quantified as the time it takes for the sound level to decay by 60dB within an auditorium after the sound energy is removed (Ismail, 2013).

Every mosque necessitates acoustic planning. Mosques serve as versatile communal spaces accommodating diverse worship practices, each with distinct acoustic prerequisites (Khabiri, Ahmad and Kandar, 2013). The acoustic arrangement of mosques is of paramount importance, especially when considering the patterns of speech and musical activities within these sacred areas (Zühre and Mehmet, 2013).

Reverberation time is required for sound energy to decay by 60 dB from its initial sound pressure level. In its evolution, reverberation time is not solely based on the 60 dB decay but also the influence of direct sound and early reflections or neglect occurring at levels less than 60 dB, such as 15 dB (RT15), 20 dB (RT20), and 30 dB (RT30) (Basuki, 2017).

Wallace Clement Sabine formulated a simple formula for reverberation time, which is:

$$\mathrm{RT}_{60} = \frac{0{,}16\ \mathrm{V}}{\mathrm{A}}$$

RT60 = Reverberation Time (s)
V = Total room volume (m3)
A = Total room absorption (Sabin m2)

(Mariani and Nurlaela, 2008)

Table 1: Absorption coefficients of building materials
Source: Sutanto, 2015.

Materials	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Ordinary window glass	0,35	0,25	0,18	0,12	0,07	0,04
Thick glass	0,18	0,06	0,04	0,03	0,02	0,02
13 mm Gypsum Board	0,29	0,1	0,05	0,04	0,07	0,09
5 cm Wood Panel	0,1	0,1	0,05	0,05	0,04	0,04
Marble Floor	0,01	0,01	0,01	0,01	0,02	0,02
Ceramic Floor	0,01	0,01	0,02	0,02	0,02	0,02
6 mm Plywood	0,3	0,3	0,13	0,16	0,12	0,1
6 mm Plywood with 25 mm air gap filled with fiberglass	0,6	0,3	0,1	0,09	0,09	0,09
9 mm Plywood	0,28	0,22	0,17	0,09	0,1	0,11
12 mm Plywood	0,03	0,08	0,17	0,13	0,13	0,11
Acoustic Tile, Suspended	0,5	0,7	0,6	0,7	0,7	0,5
Acoustic Tile, rigid mount	0,2	0,4	0,7	0,8	0,6	0,4
Uncolored Brick Wall	0,02	0,02	0,03	0,04	0,05	0,05
Colored Brick Wall	0,01	0,01	0,02	0,02	0,02	0,02
Rough Concrete Beam	0,36	0,44	0,31	0,29	0,39	0,25
Painted Concrete Beam	0,1	0,05	0,06	0,07	0,09	0,08
Unpainted Cast Concrete	0,01	0,01	0,02	0,02	0,02	0,03
Painted Cast Concrete	0,01	0,01	0,01	0,02	0,02	0,02
Thick Curtain	0,14	0,35	0,55	0,72	0,7	0,65
Thin Curtain	0,03	0,04	0,11	0,17	0,24	0,35
Regular Carpet	0,1	0,14	0,2	0,33	0,5	0,6
Thick Carpet on Concrete	0,02	0,06	0,14	0,37	0,6	0,65
Thick Carpet with Underpad	0,08	0,24	0,57	0,69	0,71	0,73
AC Grille Opening	0,33	0,33	0,33	0,33	0,33	0,33
Air Absorption /m³	0	0	0	0,003	0,009	0,024

Table 2: Reverberation Time values based on activities
Source: Kusno et al., 2021

	0,8-1,3	1,4-2,0	2,1-3,0	Optimum
Speech room	Good	Fair-Poor	Unacceptable	0,8-1,1
Contemporary Music	Good	Fair	Poor	1,2-1,4
Choral Music	Fair	Fair Good	Good-Fair	1,8-2,0

Review of Literature

There has been a lot of research conducted on reverberation time in mosque prayer rooms, but each mosque has different characteristics and research, especially in terms of simulation. Here are some previous research regarding acoustical in mosques:

1. Mariani and Nurlaela (2008) with the title Description of the Acoustic Conditions of the Al Markaz Al Islami Makassar Mosque Room. This research was carried out by directly measuring sound pressure levels and noise levels using a sound level meter, as well as measuring reverberation time and speech intelligibility levels using mathematical analysis. The results of the research show that the distribution of sound from speech activity is less even in conditions where the room is filled with a small number of worshipers, namely during regular worship services where there is a difference in sound pressure levels of >3 dB. The background noise level in the mosque room exceeds the recommended figure for hearing conditions. it is good. The buzz level in the mosque room when it is empty and filled with few worshipers is very high. The level of clarity of speech in conditions where the room is filled with a small number of people is poor to poor.
2. Dewi and Syamsiyah (2020) with research title Space Acoustic Quality in Mosques with Opening Wall Design Character (Case Study: Al Qomar Mosque, Purwosari,

Surakarta. This research was carried out with the aim of determining the influence of the geometric shape of space and the effect of material use on reverberation time and calculating the level of external noise (background noise) and reverberation time. This research was carried out by measuring using an omni-directional microphone connected to a laptop and Adobe Audition 1.5 software to record the sound of a balloon burst when collecting impulse response data. The measurement results show a background noise level of 51.5 dB because the mosque is located on the edge of a fairly busy highway. Reverberation time T20 0.644 seconds and T30 0.58 seconds. This value is in the good category (0.5 – 1.0 seconds). Meanwhile, the ratio value of the sound energy received to the total sound energy produced (definition) on the D50 is 59.88%. This value is still included in the good speech intelligibility category with a standard of 45-70%.

3. Yani (2021) with the title Assessment of the Acoustic Quality of the Raudhaturrahmah Padang Tiji Mosque Using Ecotect Simulation. This research aims to determine the conditions, causes and improve the acoustic quality by adding ceilings and absorbent materials, so that they suit the needs of the mosque's conversation space. The main focus of the research is to calculate the background noise level and reverberation time. The research method used is a quantitative method with a quantitative approach in the form of numerical analysis and simulation methods. The method used is simulation using Ecotect software which is capable of analyzing acoustic performance. The research results show that the reverberation time (RT) calculations and background noise measurements do not meet the established criteria. The resulting values for RTs with 0%, 50%, 100% occupancy are 18.29 s, 7.80 s, and 4.71 s. while the results from background noise are 60 dB. This research produces a solution to improve reverberation time and background noise by adding ceilings and absorption materials. After adding the ceiling and absorbing material, the resulting acoustic value is more optimal than the existing condition.
4. Dewi and Syamsiyah (2020) with the title Acoustic Quality of the Main Room of the Siti Aisyah Mosque, Surakarta. The focus of this research is to analyze sound pressure levels, element performance and subjective evaluation of sound comfort by users of the main room of the Siti Aisyah Mosque, Surakarta. The research uses measurements of sound pressure levels and analysis of sound mapping in space as well as users' spatial perception through online questionnaires. Measurement of sound pressure levels using a Sound level meter and sound mapping using the Surfer 11 application. The measurement results show that the average sound intensity in the room is 53.30 dBA when the room is in a condition where there is little activity, and 70.45 dBA when the room is in a condition where there is religious study activity. The results of mapping when there is little activity in the room are that sound is evenly distributed, but when the room is used for research, wave interference occurs in the form of sound amplification which causes noise. The results of the questionnaire show that users of the Siti Aisyah Mosque are not disturbed by noise, whether noise originating from inside the building or from outside the building, because mosque users have prepared themselves with the intention of praying so that they can adapt to the conditions in the main room of the Siti Aisyah Mosque.
5. Priandi (2008) with the title 5. Acoustic Performance of the Raudhatur Rahman Padang Tiji Mosque. This research aims to determine the acoustic performance that occurs and to determine the effect of sound source intensity on acoustic defects, as well as finding solutions to overcome the acoustic defects that occur.

   This research method was carried out using a computer simulation method through modeling tests using CATT Acoustic v7.2e software. The research results showed that improving the acoustic conditions of the room was able to reduce the average RT for Sabine by around 0.79 – 1.8 seconds. The G10 value is reduced to -12 – 10 dB.

The studies above have different perspectives on mosque acoustics with various simulation methods and tools. Even though there are similarities in location in the research conducted by Mariani and Nurlaela (2008), there are significant differences in the methods and analysis. This research was conducted with the aim of explaining the objective conditions of the acoustics of the Al-Markaz Al-Islami Makassar mosque and the factors that influence these conditions. This research uses quantitative research methods with analytical methods and computer simulations, and uses questionnaires or distribution of questionnaires. This research aims to analyze the reverberation level at the Al-Markaz Al-Islami Mosque in Makassar, and it is hoped that it will have benefits in worship.

Research Methods

Data Collection Techniques

This research employs a quantitative research method with analysis and computer simulation techniques. According to (Cooper and Schindler, 2006), quantitative research aims to achieve precise measurements of something. This study focuses on determining the noise level within the prayer area of Al-Markaz Al-Islami Mosque in Makassar.

Collection was carried out by observing in the field, namely measuring the volume of the room, classifying the area, adjusting the sound volume, recording the type of wall, ceiling and floor surface material. measure and record sound pressure levels from the prayer room using a sound level meter, and distribute questionnaires to mosque users. After collecting and measuring data using a sound level meter, the obtained data is simulated using the I-Simpa application and subsequently analyzed to derive outcomes related to the acoustic comfort issues within the Al-Markaz Al-Islami Mosque prayer area in Makassar. Following the software simulation and manual calculations using Wallace Clement Sabine's formula for reverberation time. Validation is carried out by calculating the relative error using the tolerance formula, which is less than or equal to 20%.

$$\text{RER}\ (\%) = \frac{a - b}{a} \times 100$$

RER = Relative Error
α = Calculation Result
b = Simulation Result

Source: Mardaljevic, 2000

Data Analysis

After collecting data from the field, the data is tabulated and simulated. Subsequently, data analysis is performed by describing or depicting the collected data as they are, without intending to draw general conclusions. The analysis technique used in this study is Reverberation Time Analysis, conducted through manual calculations using Sabine's formula and simulation using the I-Simpa software.

I-Simpa is an open software dedicated to the modelling of sound propagation in 3D complex domains. I-Simpa is well adapted for energetic models (ray-tracing, sound-particle tracing, theory of reverberation, etc), it can be extended to use ondulatory approaches. I-Simpa not only a calculation software but is equivalent to a pre and post-processor for acoustic codes. I-Simpa has been initially developed as a research tool (for research laboratories) but can also be a very efficient tool for a professional, as well as for education.

Results And Discussion

Research Findings

Reverberation time simulations were measured at frequencies of 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1,000 Hz, 2,000 Hz, 4,000 Hz, and 8,000 Hz. This was accomplished using 32 speakers, each placed at a height of 2.80 meters for columns and 4.40 meters for the ceiling.

Table 3: RT30 Prayer area of Al-Markaz Al-Islami Makassar.
Source: Author, 2023

Frequencies	T1 (s)	T2 (s)	T3 (s)	T4 (s)	T5 (s)	T6 (s)	T7 (s)	T8 (s)	T9 (s)	Average
63 Hz	3,67	3,63	3,56	3,64	3,59	3,61	3,58	3,60	3,60	3,61
125 Hz	3,52	3,60	3,54	3,61	3,56	3,59	3,45	3,47	3,64	3,55
250 Hz	3,79	3,82	3,80	3,72	3,82	3,68	3,87	3,72	3,89	3,79
500 Hz	3,83	4,09	4,00	3,89	3,93	3,95	4,04	3,86	3,96	3,95
1000 Hz	3,94	4,17	4,26	3,94	4,07	4,09	4,12	4,12	4,03	4,08
2000 Hz	3,76	3,83	3,79	3,87	3,82	3,79	3,83	3,78	3,85	3,81
4000 Hz	2,93	3,03	2,98	3,01	3,07	3,04	3,00	3,10	3,01	3,02
8000 Hz	1,25	1,33	1,27	1,25	1,34	1,26	1,26	1,35	1,27	1,29
Average	3,34	3,44	3,40	3,37	3,40	3,38	3,39	3,38	3,40	

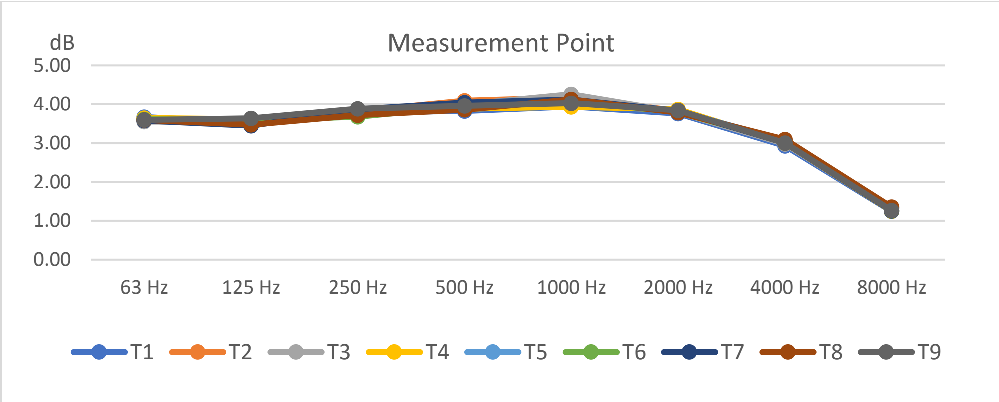
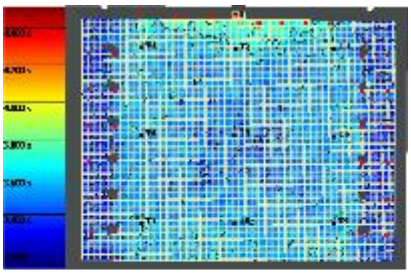


Fig. 2: RT30 Graph of the prayer area.
Source: Author, 2023

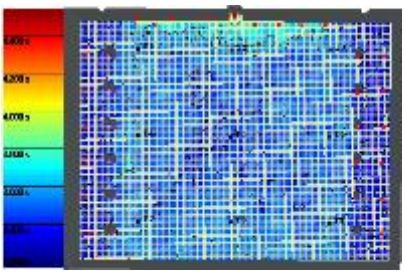
Based on the simulation results in the Fig. 2 and the Table 3, it can be observed that the RT values for frequencies ranging from 63 Hz to 8000 Hz are above 0.80 seconds (s). The lowest value at the 8000 Hz frequency is at point T1, which is 1.25 seconds (s), while the highest value at the 1000 Hz frequency is at point T3, which is 4.26 seconds (s).

Sound Distribution Pattern

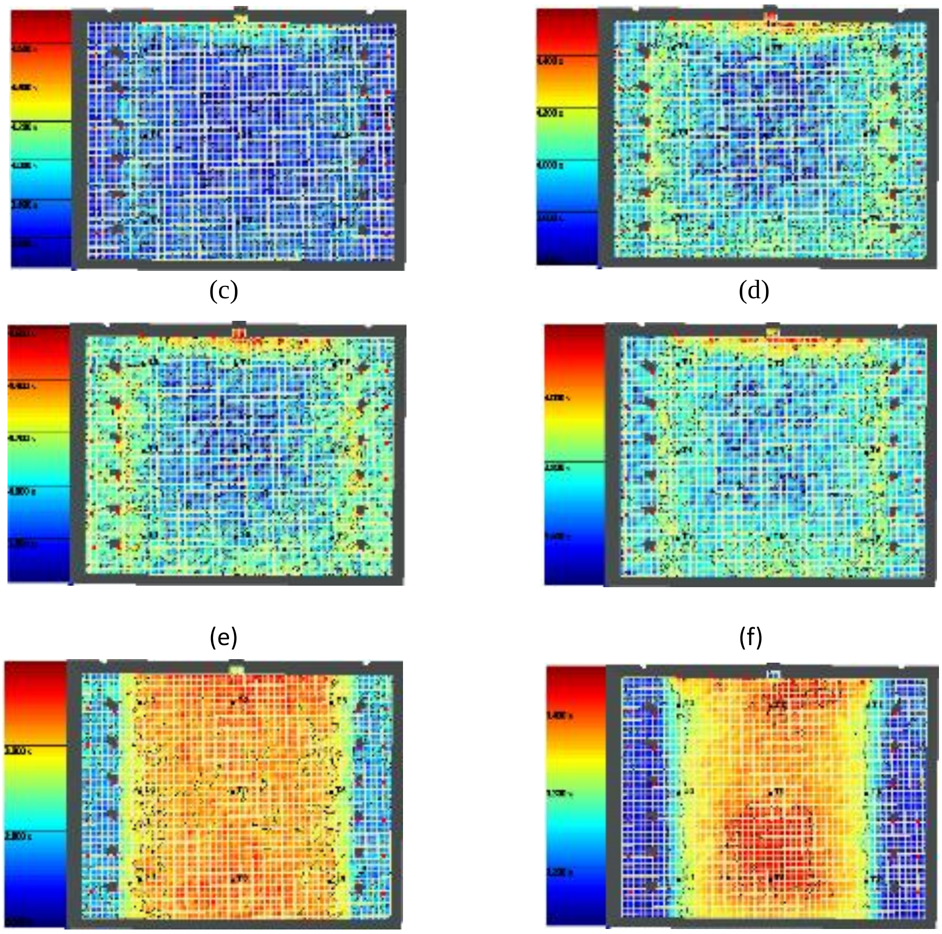
The simulation results in the form of sound distribution patterns within the mosque's prayer area provide a visualization generated by the sound source (speaker) that depicts the reverberation time (RT30) pattern within the room.



(a)



(b)



(c) (d)

(e) (f)

(g) (h)

Fig. 3: Sound Distribution Pattern of Reverberation Time. (a) 63 Hz, (b) 125 Hz, (c) 250 Hz, (d) 500 Hz, (e) 1000 Hz, (f) 2000 Hz, (g) 4000 Hz, (h) 8000 Hz.
Source: Author, 2023

1. Based on (a) and (b), it can be observed that the contour color spacing at frequencies 63 Hz (a) and 125 Hz (b) is 0.200 seconds (s). The highest and lowest values of the contour colors for both frequencies are the same, where the lowest RT value is 3.200 seconds (s), and the highest is 4.400 seconds (s).
2. In Frequencies of 250 Hz (c) and 500 Hz (d), it is evident that the contour color spacing remains consistent at 0.200 seconds (s). The lowest RT value is 3.600 seconds (s), and the highest is 4.400 seconds (s).
3. In (e) and (f), it can be seen that the contour color spacing at frequencies 1000 Hz and 2000 Hz is 0.200 seconds (s). However, the lowest and the highest RT values differ. For the lowest RT value, at a frequency of 1000 Hz (e), it is 3.800 seconds (s), and at a frequency of 2000 Hz (f), it is 3.600 seconds (s). The highest RT value, at a frequency of 1000 Hz €, is 4.600 seconds (s), and at a frequency of 2000 Hz (f), it is 4.000 seconds (s).
4. Based on (g) and (h), it can be observed that the contour color spacing at a frequency of 4000 Hz (g) is 0.200 seconds (s), and at a frequency of 8000 Hz (h), it is 0.100 seconds (s). The lowest RT value at a frequency of 4000 Hz (g) is 2.600 seconds (s), and the highest is
5. 3.000 seconds (s). Meanwhile, at a frequency of 8000 Hz (h), the lowest RT value is 1.200 seconds (s), and the highest is 1.400 seconds (s).

Manual Calculation Results

Table 4: Manual calculation results of reverberation time.
Source: Author, 2023

Object	Material	Coef.	Quantity	Area (m2)	Total Area (m2)
Floor	Granite	0,01	1	2019,6	2019,6
Wall	Granite	0,01	1	595,7	595,68
Ceiling	Gypsum	0,05	1	2863,2	2863,2
Concrete Beam	Paint	0,06	10	33,6	336
Concrete Beam	Paint	0,06	8	43,2	345,6
Concrete Beam	Paint	0,06	12	4,8	57,6
Main Column	Granite	0,01	12	1,5	18,36
Dome	Wood	0,1	1	361,0	361
Pulpit	Solid Wood	0,05	1	3,4	3,4
Main Door	Large Glass + Wood	0,04	9	7,2	64,8
Side Door	Wood + Small Glass	0,18	1	1,8	1,76
Window 1	Glass + Aluminum	0,18	28	10,0	280
Window 2	Glass + Aluminum	0,18	69	5,1	351,9
Window 3	Glass + Wood	0,1	9	11,4	102,6
Speaker	Speaker	0,45	32	0,5	15,36
				Total A	383,94
				Volume	10598,40
				RT	4,42

Based on Table 4, the manual calculation of Reverberation Time in the prayer area of Al-Markaz Al-Islami Mosque in Makassar using Sabine's formula at a frequency of 500 Hz is 4.42 seconds. However, the simulation result from the I-Simpa software is 3.95 seconds. The difference between the computerized simulation and manual calculation is relatively small, at 0.47 seconds.

$$RER\ (\%) = \frac{a-b}{a} \times 100$$
$$RER\ (\%) = \frac{4{,}42 - 3{,}95}{4{,}42} \times 100$$
$$RER\ (\%) = \frac{0{,}47}{4{,}42} \times 100$$
$$RER = \ 10{,}54\ \%$$

Table 5: Validation of measurement data and simulation result
Source: Author, 2023

	RT Value
Calculation (a)	4,42
Simulation (b)	3,95
Relative Error (RER)	10,54%

Table 5 shows the relative error values calculated using the relative error formula. After comparing the calculation results with the simulation in the prayer area of Al-markaz al-islami mosque, a relative error of 10.57% was obtained. This indicates that the measurement results and simulations differ by 10.57%, which is within the tolerance limit of less than or equal to 20%.

Discussion

Based on the analysis of the Reverberation Time in Al-Markaz Al-Islami Mosque, the average reverberation time produced at a frequency of 8000 Hz is 1.29 seconds (s), which meets the reverberation time standard for a speech room. However, at frequencies from 63 Hz to 4000 Hz, the value is <2.74 seconds (s), categorized as unacceptable.

Considering the primary function of the Al-markaz Al-islami mosque as a place for worship and religious activities, a high level of tranquility is required. Therefore, paying attention to the acoustic comfort in the mosque is crucial.

Acoustic Improvement

Based on the analyzed simulation results using I-Simpa, it can be concluded that acoustic improvement is necessary to achieve the standard reverberation time. The simulation with I-Simpa is conducted to find an optimal design solution that aligns with the reverberation time standard, thus ensuring acoustic comfort in the mosque. One way to address the reverberation time issue is by adding sound-absorbing materials to the elements within the Al-Markaz Al-Islami Mosque. An alternative solution for the mosque could involve replacing the gypsum ceiling with a 9 mm plywood, using carpets for the flooring, and adding heavy curtains to windows 1 and 2. These measures would help achieve the reverberation time by the acoustic comfort standards for the mosque.

Table 6: RT30 for the acoustic improvement of the prayer area.
Source: Author, 2023.

Frequencies	T1 (s)	T2 (s)	T3 (s)	T4 (s)	T5 (s)	T6 (s)	T7 (s)	T8 (s)	T9 (s)	Average
63 Hz	1,51	1,48	1,46	1,45	1,50	1,45	1,48	1,54	1,49	1,49
125 Hz	1,51	1,47	1,48	1,44	1,52	1,48	1,42	1,50	1,49	1,48
250 Hz	0,99	0,97	1,01	1,01	1,03	1,00	0,95	1,01	0,97	0,99
500 Hz	1,24	1,23	1,16	1,25	1,37	1,19	1,21	1,29	1,16	1,23
1000 Hz	1,07	0,96	0,97	0,98	1,02	1,04	1,03	1,11	0,98	1,02
2000 Hz	0,94	0,97	0,99	0,97	1,02	1,03	0,91	1,02	0,97	0,98
4000 Hz	1,16	1,21	1,26	1,16	1,24	1,12	1,14	1,26	1,15	1,19
8000 Hz	0,76	0,74	0,75	0,70	0,74	0,75	0,69	0,74	0,70	0,73
Average	1,15	1,13	1,14	1,12	1,18	1,13	1,10	1,18	1,12	

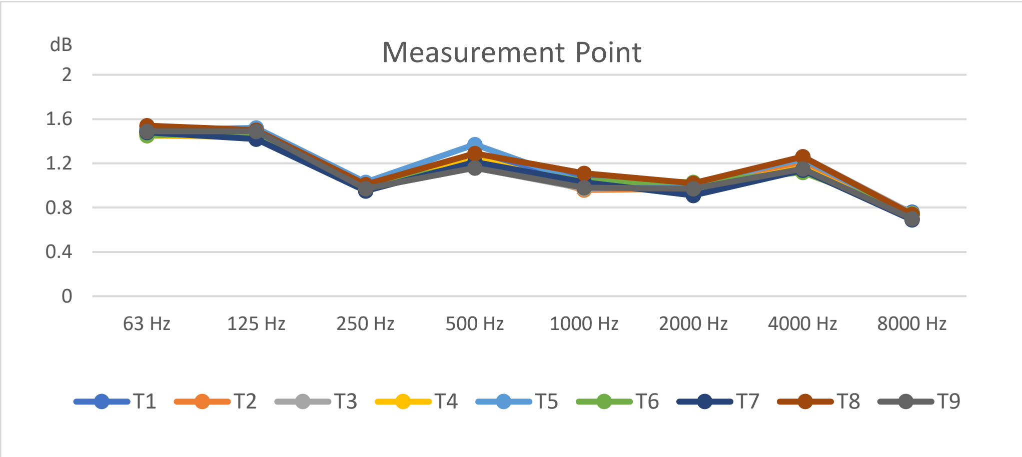
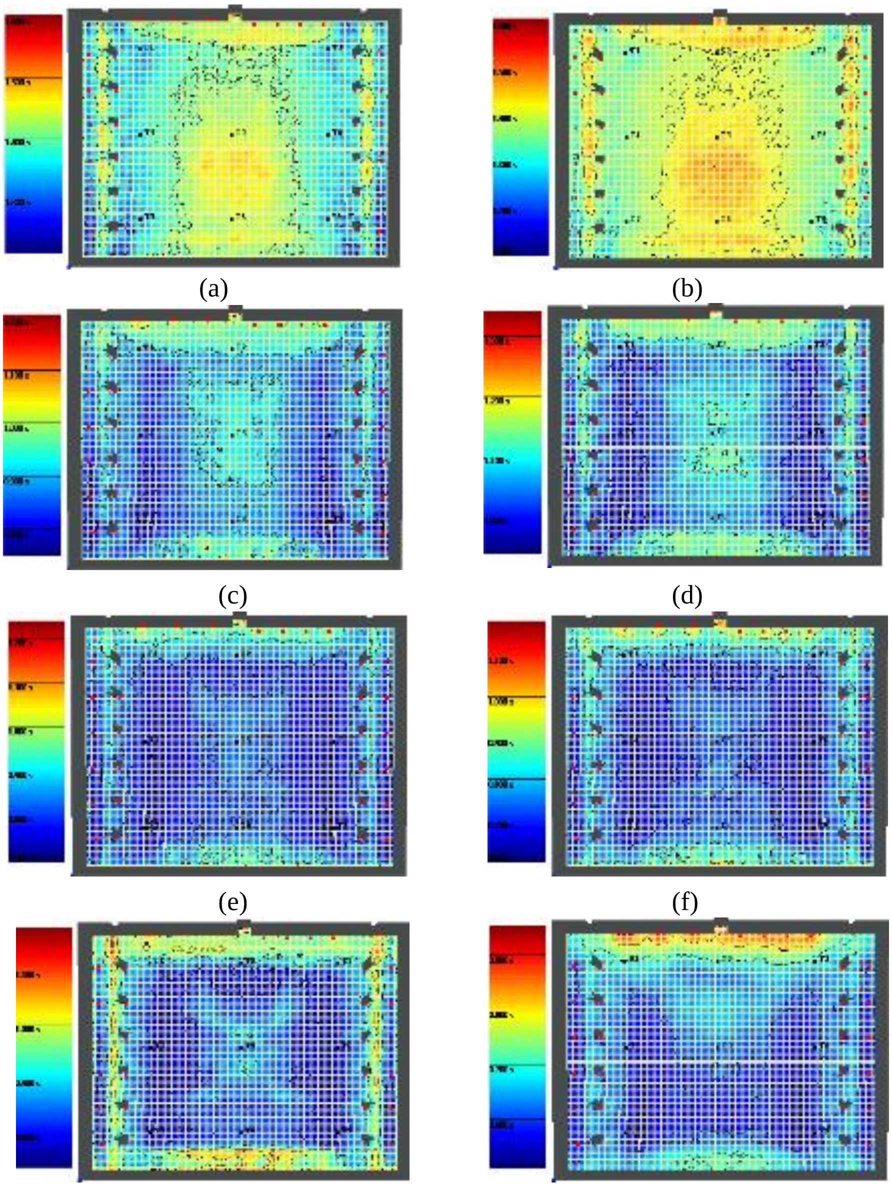


Fig. 4: Graph of RT30 for the acoustic improvement condition in prayer area.
Source: Author, 2023.

The results of the acoustic improvement simulation can be seen in the Fig. 11 and the Table 6, which indicate that the RT values from 63 Hz to 4000 Hz are above 0.80 seconds (s). The lowest value at 8000 Hz is at point T7, which is 0.69 seconds (s), while the highest at 63 Hz is at point T8, which is 1.54 seconds (s). The average RT value for a frequency of 500 Hz is 1.23 seconds (s).

Sound Distribution Pattern in Acoustic Improvement



(a) (b) (c) (d) (e) (f) (g) (h)

Fig. 5: Sound Distribution Pattern of Reverberation Time. (a) 63 Hz, (b) 125 Hz, (c) 250 Hz, (d) 500 Hz, (e) 1000 Hz, (f) 2000 Hz, (g) 4000 Hz, (h) 8000 Hz.
Source: Author, 2023.

1. Based on the Figures 5 (a) and (b), it can be observed that the color contour spacing at frequencies 63 Hz (a) and 125 Hz (b) is 0.100 seconds (s). The lowest value on the contour for 63 Hz (a) is 1.300 seconds (s), while for 125 Hz (b), it is 1.100 seconds (s). The highest value for both 63 Hz (a) and 125 Hz (b) is 1.600 seconds (s).
2. From the Figure 5 (c) and (d), it can be observed that the color contour spacing is 0.100 seconds (s). The lowest value on the contour for 250 Hz (c) is 0.800 seconds (s), while for 500 Hz (d), it is 1.000 second (s). The highest value for 250 Hz (c) is 1200 Hz and for 500 Hz (d), it is 1.300 seconds (s).
3. In the Figures 5 (e) and (f), the color contour spacing for frequencies 1000 Hz (e) - 2000 Hz (f) is 0.100 seconds (s), while the lowest and the highest RT values differ. The lowest RT value at 1000 Hz (e) is 0.700 seconds (s)

and at 2000 Hz (f), it is 0.600 seconds (s). The highest RT value at 1000 Hz (e) is 1.200 seconds (s) and at 2000 Hz (g), it is 1.100 seconds (s).

4. Figures 5 (g) and (h) show that the color contour spacing for frequencies 4000 Hz (g) and 8000 Hz (h) is 0.100 seconds (s). The lowest RT value at 4000 Hz (g) is 0.800 seconds (s), and the highest is 1.100 seconds (s). For 8000 Hz (h), the lowest value is 0.600 seconds (s), and the highest is 0.900 seconds (s).

Manual Calculation Result of Acoustic Improvement Condition

Table 7: Manual Calculation Result of Acoustic Improvement Condition.
Source: Author, 2023.

Object	Material	Coef.	Quantity	Area (m2)	Total Area (m2)	Object
Floor	Carpet	0,2	1	2019,6	2019,6	403,92
Wall	Granite	0,01	1	595,7	595,68	5,96
Ceiling	6mm Plywood	0,13	1	2863,2	2863,2	372,22
Concrete Beam	Paint	0,06	10	33,6	336	20,16
Concrete Beam	Paint	0,06	8	43,2	345,6	20,74
Concrete Beam	Paint	0,06	12	4,8	57,6	3,46
Main Column	Granite	0,01	12	1,5	18,36	0,18
Dome	Wood	0,1	1	361,0	361	36,10
Pulpit	Solid Wood	0,05	1	3,4	3,4	0,17
Main Door	Large Glass + Wood	0,04	9	7,2	64,8	2,59
Side Door	Wood + Small Glass	0,18	1	1,8	1,76	0,32
Window 1	Thick Curtain	0,55	28	10,0	280	154,00
Window 2	Thick Curtain	0,55	69	5,1	351,9	193,55
Window 3	Glass + Wood	0,1	9	11,4	102,6	10,26
Speaker	Speaker	0,45	32	0,5	15,36	6,91
					Total A	1230,52
					Volume	10598,40
					RT	1,38

In the Table 7, the alternatives that can be used in the prayer area of Al-Markaz Al-Islami Mosque include replacing the gypsum ceiling with 6mm plywood, using carpet for the floor, and adding thick curtains to the windows 1 and 2 to achieve the reverberation time standard for acoustic comfort in the prayer hall. The calculated result in Table 21, 1.38 seconds (s), has met the recommended speech standard range of 0.8-1.3 seconds (s).

$$RER\ (\%) = \frac{a-b}{a} \times 100$$

$$RER\ (\%) = \frac{1{,}38 - 1{,}23}{4{,}42} \times 100$$

$$RER\ (\%) = \frac{0{,}14}{1{,}38} \times 100$$

$$RER = 10{,}43\ \%$$

Table 8: Validation of measurement data and simulation results.
Source: Author, 2023

	RT Value
Calculation (a)	1,38
Simulation (b)	1,23
Relative Error (RER)	**10,43%**

Table 8 indicates the relative error value for the acoustic improvement calculation based on the relative error formula. After comparing the Calculation result with the simulation result in the prayer hall of the Al-Markaz Al-Islami Mosque in Makassar city, a relative error of 10.43% was obtained, with a difference of 0.14 seconds. This result shows that the measurement results compared with the simulation remain within the acceptable tolerance limit, which is less than or equal to 20%.

Based on the simulation and calculation results of the acoustic improvement in the prayer hall, the standards have been met, as the reverberation time falls within the speech room standard range of 0.8-1.3 seconds (s).

Conclusions

Based on the results of the Reverberation Time analysis at the Al-Markaz Al-Islami Mosque in Makassar, at a frequency of 8000 Hz the average reverberation time produced is 1.29 (s), this meets the standard reverberation time for a speech room, while at a frequency of 63 Hz – 4000 Hz <2.74 unacceptable category. The acoustic comfort in the prayer hall of Al-Markaz Al-Islami is not yet fully in line with the auditory comfort standards in terms of reverberation time. Therefore, it is necessary to replace or add materials to the prayer room, namely replacing the material on the gypsum ceiling to 6 mm plywood, adding carpet to the floor and adding curtains to windows 1 and window 2 so that it can reach the standard reverberation time of a speech room, which is in the range of 0.80-1.3 seconds.

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