AN ASSESSMENT OF ROOM ACOUSTICS PERFORMANCE OF BAITURRAHMAN GRAND MOSQUE

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Abstract : Acoustical design as part of the audio comfort influences the architectural design strategy of a mosque significantly. As belonging to the speech room criteria, a mosque should meet some acoustic room requirements to deliver the solemnness to the worshipper during the prayer. Concerning this, the study aims to assess the indoor acoustics performance of Baiturrahman Grand Mosque, Banda Aceh. Baiturrahman grand mosque is an important place of worship for Acehnese and becoming a landmark of Banda Aceh City. The mosque which contains a lot of history of Aceh was built in heavy construction, i.e. concrete wall, marble coated floor, and concrete dome ceiling. Due to its significance, the room acoustics of the mosque as the primary design considerations in a speech room type is evaluated. The acoustics parameters estimated are Noise Criteria (NC), Sound Pressure Level (SPL), Reverberation Time (RT), and Rapid Speech Transmission Index (RASTI). The background noise was recorded for delivering the noise criteria and being the primary data carried out in the acoustic simulation. The study utilised CATT-Acoustic v7.2 software for simulating predicting SPL, RT, and RASTI.
Keywords : Mosque, Audio comfort, Prayer solemnness, Room acoustics, Simulations.

Abstrak : Desain akustik merupakan bagian dari parameter audio yang mempengaruhi desain arsitektur masjid secara signifikan. Masjid termasuk dalam kategori speech room yang harus memenuhi beberapa persyaratan akustik ruang untuk dapat menghadirkan kekhusyukan kepada jamaah selama sholat. Penelitian ini bertujuan untuk menilai kinerja akustik dalam ruangan Masjid Raya Baiturrahman, Banda Aceh. Masjid Raya Baiturrahman adalah tempat ibadah yang penting bagi orang Aceh dan menjadi simbol Kota Banda Aceh. Masjid yang memuat banyak sejarah Aceh ini terbuat dari dinding beton, lantai berlapis marmer, dan langit-langit kubah beton. Pada studi ini, parameter akustik ruang yang dievaluasi adalah Kriteria Kebisingan (NC), Tingkat Tekanan Suara (SPL), Waktu Gema (RT), dan Indeks Transmisi kecepatan Bicara (RASTI). Kebisingan latar belakang direkam untuk memberikan kriteria kebisingan dan menjadi data primer yang dilakukan dalam simulasi akustik. Studi ini menggunakan perangkat lunak CATT-Acoustic v7.2 untuk mensimulasikan prediksi SPL, RT, dan RASTI.
Kata kunci : Masjid, Kenyamanan audio, kekhusyukan shalat, Akustik Ruang, Simulasi

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Introduction

A mosque is an important place for Muslims for worship. In the first period, Rasulullah Muhammad SAW (*Shalallahu Alaihi Wassalam*) built a mosque as the first building in Madinah for accommodating a variety of different worship activities. Worship considerations mainly influence mosque design. In a mosque, there are three daily activities conducted such as five times daily prayers; the Friday sermon as being compulsory within the Friday noon prayers; and listening to or reciting the Holy Quran (Eldien, Qahtani, 2012). All these distinct activities need good room acoustics which covers the speech audibility and intelligibility that can increase the solemnity (Syamsiah et, al, 2014; Othman et al., 2016). Acoustical must be well considered in the design phase for delivering an excellent listening condition (Abdou, 2003). Room acoustics also work to create different effects which can increase the value of the room (Karabiber, 1999).

Concerning the theory, this study aims at assessing the room acoustic in the Baiturrahman mosque. This mosque is located in the capital city of Aceh province, Banda Aceh. This mosque is famous with a lot of historical value of Aceh. Additionally, it has a magnificent architectural charm which makes it as the landmark of Banda Aceh city. This grand mosque is quite old which is believed to be built during the Sultanate of Iskandar Muda (1607-1636). This mosque is made from concrete in dome-roof style. The evaluation on the acoustics may become an essential work due to the remark of the mosque as the landmark of the city that has attracted all tourists in Aceh to visit it, and at the same time, it is a sacred worship place for the Muslim as the majority residents in Aceh.

There have not been published a paper with regard to the acoustic performance of Baiturahman mosque. However, from daily observation, subjectively we found that the echo and background noise inside the mosque is high, creating an unclear sound distribution. Therefore the novelty of this study is to analyse the room acoustics quantitatively through simulation and purpose the possible approach of remedy to be adopted in the mosque. This study developed the assessment through the field measurement of the background noise (NC). NC is essential for indicating another value of room acoustic parameters such as Sound Pressure Level (SPL), Reverberation Time (RT), and Rapid Speech Transmission Index (RASTI).

The History of Baiturrahman Grand Mosque

Some historians say that this mosque was built during the Sultanate of Iskandar Muda (1607-1636). However, some others stated that this mosque had been established long before the reign of Sultan Iskandar Muda. Sultan Iskandar Muda only made a few improvements. The history noted that based on a piece of information from Peter Mundy, a British traveller that came to Aceh in 1046, initially the mosque was built from wooden construction and tiered roof. Later in the Dutch colonialism, the mosque was burned. After being burned down by the

Dutch colonel, the Baiturrahman Grand Mosque was rehabilitated again by Major General K. Van Der Heijden as the Military Governor of the Dutch East Indies at that time on October 9, 1879. Some of the materials used to build this mosque were imported from Penang, marble from China, iron for windows from Belgium, wood from Burma and iron poles from Surabaya. Behind that, this development still raises conflicts of pros and cons from the community. Some of them refused the construction because it was sponsored by the kaphe (non-Muslim). Nevertheless, the development of the building construction can still be done to completion with one dome. The handover ceremony was held on December 21, 1881 (Sabil, 2009).

This mosque has been extended and modified several times. The last modification was in 2015; the Aceh government renovated Baiturrahman Grand Mosque. The project included the addition of several elements in the Baiturrahman Grand Mosque, namely the addition of 12 electric umbrellas, a basement parking lot for two and four-wheeled vehicles, a place for ablution and some improvements to the interior of the building. The results of the expansion can accommodate up to 14,000 worshippers (Fahlevi, 2016).

Figure 1. The facade of Baiturraahman Mosque (*Foto:i.ytimg.com)*

Figure 2. Interior of Baiturrhaman mosque

Mosque and the Functions in Relation with Room Acoustics

The mosque as previously stated accommodates the worship activities which needs good audibility and intelligibility. According to the History of Islam, Muhammed and his followers probably prayed outdoors on their journeys and intents before the first mosque building was constructed. This was a rectangular building, which was built of mud bricks with a date palm-supported roof, 4 m high, 26 m front to back and 30 m wide. This rectangular form has remained the most popular and traditional mosque architectural structures (Kleiner et al., 2010). During the prophet Muhammad PBUH, Bilal, the first person sounding adzan for calling the Muslims to do the prayer, stood on the high place such as a hill for giving the excellent sound distribution. From the history to the present we also see a similar way to provide good sound distribution by the presence of the tower or minaret at the mosque for the place for sounding Adzan.

During the prayer, the leader of the prayer called imam stands at the front near the mihrab. The orientation of the mosque faces the qibla (the Ka'bah in Mecca). Meanwhile, the worshippers stand behind the imam in straight rows to perform the prayers. The rows require around 1.2 m apart. During the sermon, the worshippers sit on the floor facing the imam who stands on a four-step high platform (*mimbar*). All those activities are conducted facing the qibla. Due to this arrangement, the mosque is typically designed and bounded by straight parallel walls which include the Qibla niche. To run well all the worshipping activities, it requires good speech intelligibility and audibility (Eldien and Qahtani, 2012).

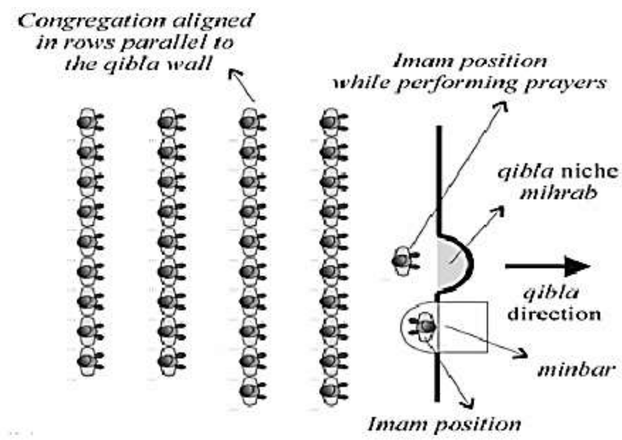

Figure 3. The position of the congregation during the prayer (Eldien and Al Qahtani, 2012)

The prayer hall rarely has furniture to allow many worshipers to be accommodated in the mosque for performing the prayer. In contrast to the history where the mosque was built in open layout supported with lightweight construction, the contemporary mosque has been constructed widely in heavyweight structure and materials. The roof is made in a dome style with painted plaster. The majority of the mosque is finished with ornamentation.

From the descriptions of the mosque, a large prayer hall where the worshippers follow the leader, the acoustics should be the most significant determinant of the architectural design strategy (Hammad, 1990). The acoustical environment in the mosque is expressed concerning its reverberation time (RT) value (Eldien and Qahtani, 2012; Ismail, 2013). Other requirements to be fulfilled are sufficient loudness, widespread sound distribution, low background noise, and high speech intelligibility (Prawirasasra and Mubarok, 2017).

Materials and Methods

Room description

The total of the interior area of the mosque is about 3,500 m^2. However, in this study, the measurement only took place in the main prayer area (2,500 m^2) which is protected by the seven domes. The acoustical measurement includes the field measurement and the analysis using computer-aided simulation, i.e. CATT-Acoustic v7.2 software. The measurement of the background noise of Baiturrhaman Grand Mosque was recorded using Sound Level meter Nor 131 which was calibrated by Calibrator Nor 125. It was on Sunday from 10.40 am to 15.50 pm. These hours during the weekend is the time where the highest number of various activities are conducted, including both the quietest and the noisiest activities. The activities carried out by the visitors during the weekend usually are worshipping, marriage ceremony, Quranic class for kids, and resting while enjoying the interior of the mosque. The sound level meter was assigned in the two positioned (figure 4), which is about 1.50 m above the floor surface corresponding to imam's mouth position and any other sound and noise source. The two positions, namely T1 and T2, were selected as the activities are commonly conducted there.

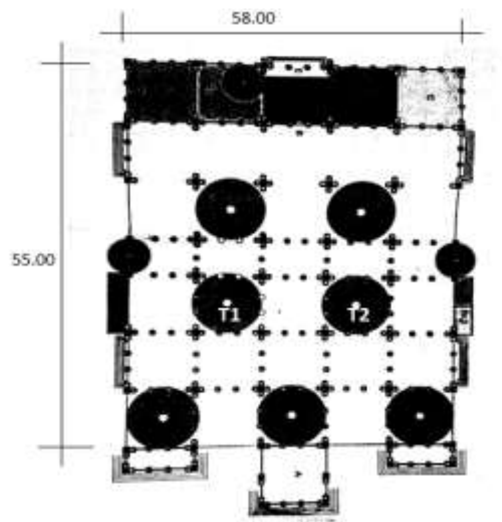

Figure 4. The position of the measurement on the mosque layout plan

The background noise was measured is in order to identify the noise criteria which defines the room acoustics comfort. For other acoustic parameters such as the distributions of sound pressure level, reverberation time and RASTI (Rapid Speech Transmission Index) are evaluated through the simulations due to limitations of the measuring tools, condition and time constraints. This study used CATT-Acoustic v7.2 software by utilising the real data of the background noise for carrying out the simulations.

Figure 5. Sound Level Meter Utilised in the data collection

Results and Discussions

Noise Criterion (NC)

The background noise measured in several times in the location of T1 and T2 were plotted in NC graph which then presents the value of Noice Criterion (NC) for each frequency (figure 6-11). The study shows that overall, the NC values of the background noise data at Baiturrahman Grand Mosque are categorised as very noisy for the standard of a mosque. It is higher than the recommended noise criterion interval for religious space such as mosques and churches, that is the NC25-30 (ref:31).

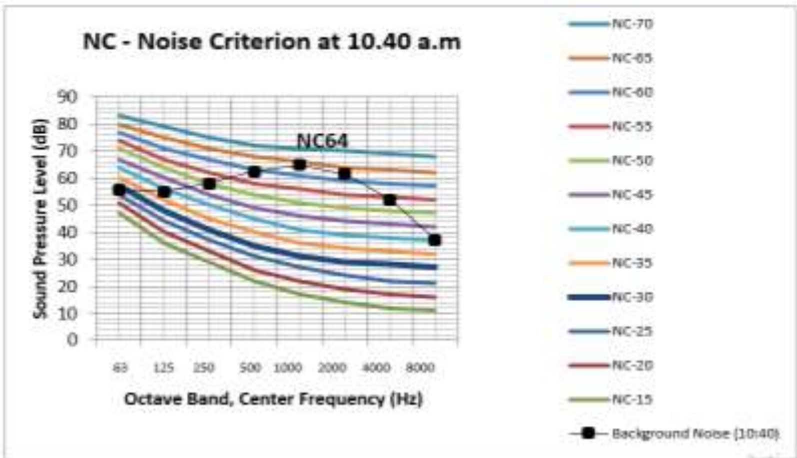

Figure 6. Noise Criteria at 10.40 am

Figure 6 shows the highest NC value that is NC64 which is found in the background noise data at 10:40 am. During this time, there were Quranic activities conducted by the students of Masjid Raya Baiturrahman. During this time, the Muslim wedding ceremony also takes place which triggered the high noise levels during the measurement of the background noise. While the low NC values which are NC58 and NC57 respectively are at 12:50 pm (figure 8) and 03.50 pm (figure 11). This is because the activities carried out at this hour are Zuhur and Ashar prayer activities which are not conducted in a high volume of voice.

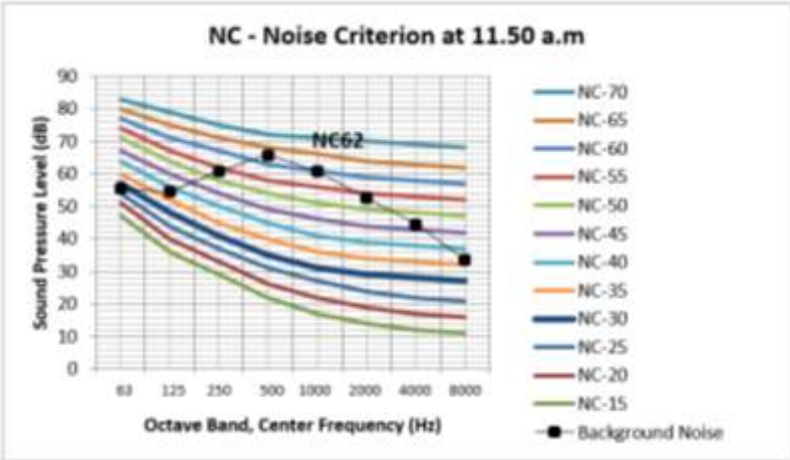

Figure 7. Noise Criteria at 11.50 am

At 11.50 am, NC62 is also relatively high due to the same activities as at 10.40; however, the loudness of the noise is slightly decreasing. While place as well as some other activities such as tourism and Islamic speech in some community groups.

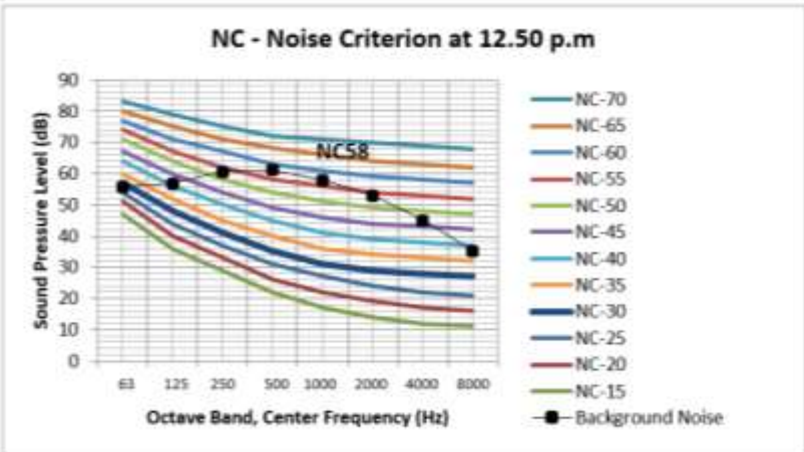

Figure 8. Noise Criteria at 12.50 pm

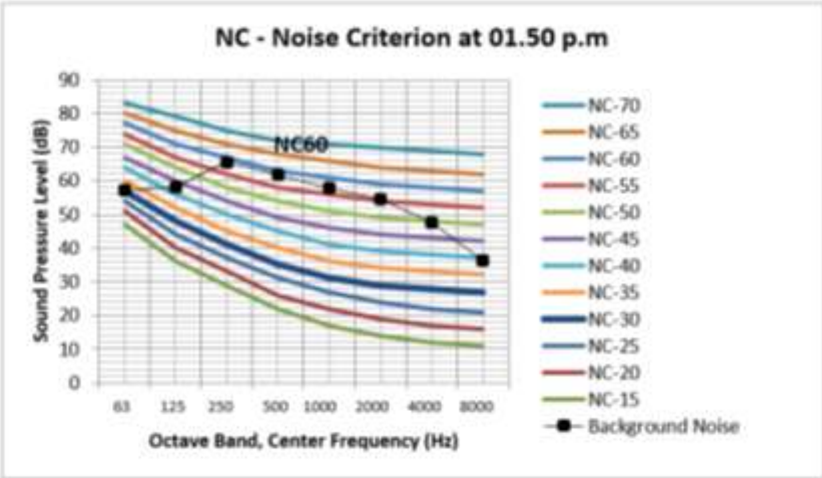

Figure 9. Noise Criteria at 01.50 pm

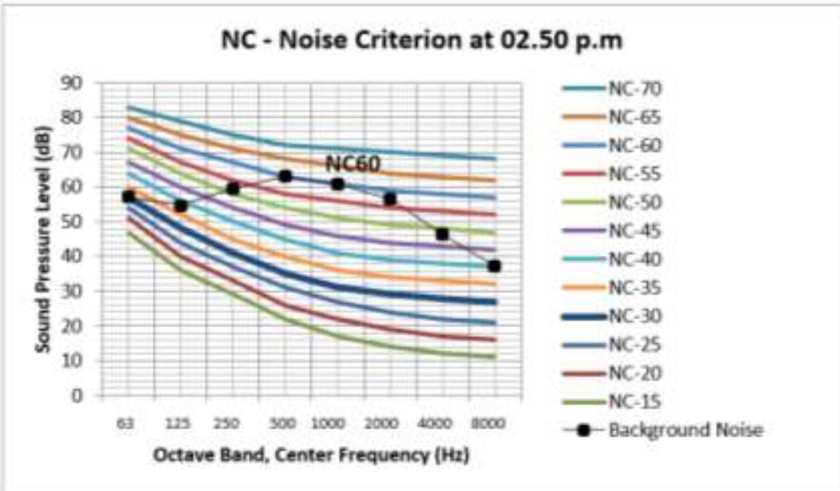

Figure 10. Noise Criteria at 02.50 pm

At 3.50 pm the activities are running down because there is no more wedding ceremony during this time. However, this slightly low noise criterion which is NC57 is still higher than the acceptable standard.

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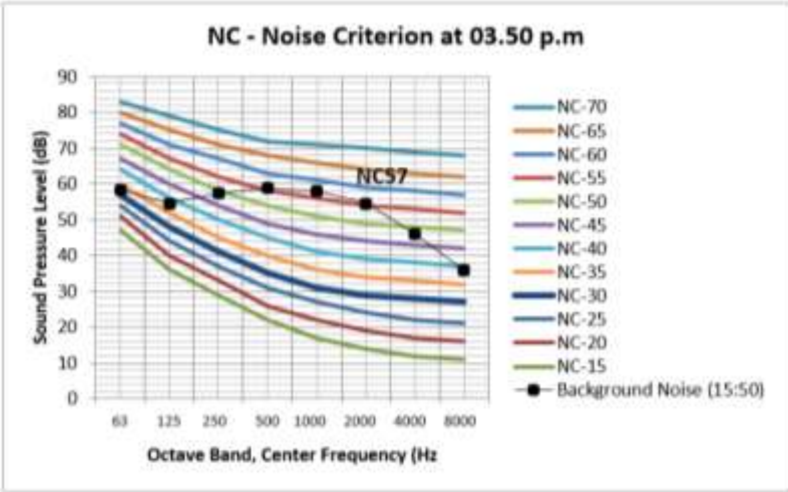

Figure 11. Noise Criteria at 03.50 pm

Simulation Results

The acoustic simulations carried out at the Baiturrahman Grand Mosque are based on the actual shape and dimensions of the mosque. However, the round columns are removed to match the limited software capabilities. The software used for this simulation is CATT-Acoustic v7.2. The type of material used in the model is adjusted to the absorption coefficient of material at frequencies of 125Hz, 250Hz, 500Hz, 1kHz, 2kHz, and 4kHz, which is shown in table 2. The wall is smooth concrete which is painted in white. The wall is designed with glass windows. The floor is smooth marble. The ceiling is plasterboard which is also painted in a light colour.

Table 2. The coefficient of Material Absorption

Material	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
Smooth Concrete, painted	0.01	0.01	0.01	0.02	0.02	0.05
Plasterboard (13mm) (on frame, 100 mm cavity)	0.08	0.11	0.05	0.03	0.02	0.03
Smooth marble	0.01	0.01	0.01	0.01	0.02	0.02
Glass(4mm)	0.3	0.2	0.1	0.07	0.05	0.02

(Source: www. Akustik. ua)

The sound source for the simulation is from one source type that is the omnidirectional speaker. The position of the sources was placed in the area of the priest standing at an altitude of 1.7 m. In the simulation, the utilised background noise data was the real data obtained from the field measurement. From some of the data generated, the data to be used is the data with the highest noise level at 10:40. The inputted temperature level was adjusted to the measured temperature at the same hour as the background noise measurement time used.

The simulation results of A-weighted sound level (SPL-A)

The sound pressure level is the most commonly used indicator of the acoustic wave strength, correlating with human perception of loudness. The A-weighted sound level (dBA) is the single number measure of loudness that ignores low-frequency sound energy content similar to the human ear. Distribution maps of SPL-A are given in Figure 12. Average SPL-A is 60 dBA, while the minimum value at the main hall is 50 dBA and the maximum is 75 dBA. The mapping of the sound pressure level distribution at Baiturrahman Grand Mosque generated by the software shows that in general, the distribution of the sound pressure level within 0.000<t<20.0 ms are uneven. On the interval, the sound pressure level does not reach some areas particularly the area far from the qibla and distracted by the poles. The poles reflect the sound that creates the loss of sound distributions. Within 20.0 < t < 50.0 ms, the sound distributions reaches the further area from the qibla. However, the best range works on the time interval 50.0 < t < 80.0 ms where the sound looks good in the overall area, While within 80.0 < t < 200.0 ms the distribution of the sounds still seems good. However, it slowly decreases.

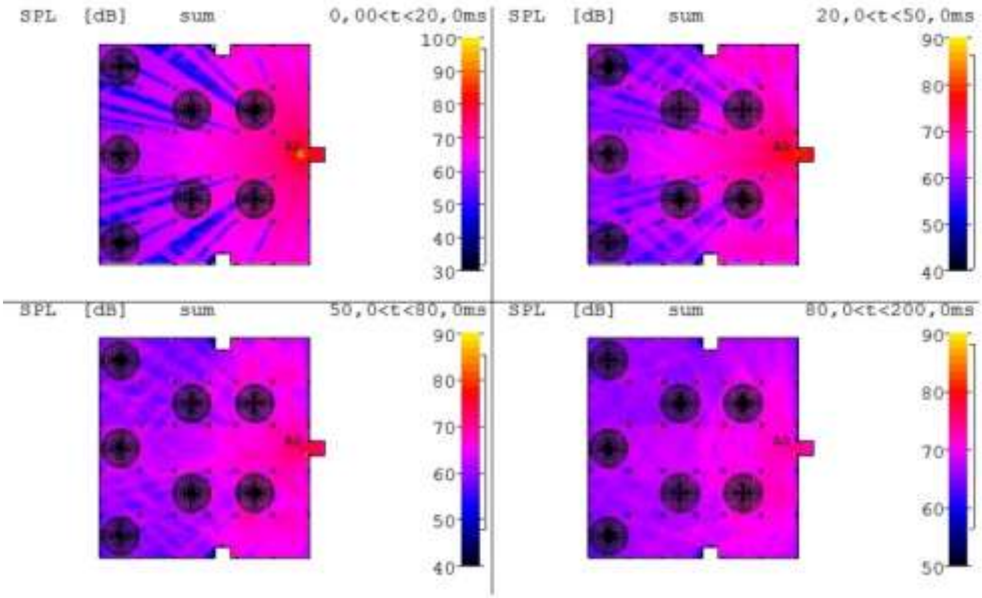

Figure 12. The simulation result of SPL within 0-200 ms interval

The simulation result of Reverberation Time (RT, T30)

Reverberation time is defined as the time required for the average sound energy density to decay by 60dB after stopping a sound source. By simulating the real data of NC, the reverberation time mapping of Baiturrahman mosque is shown in figure 13. The average T30 is 2.65s, while minimum value at the main hall is 0.5 dBA and maximum is 4.8 s. A mosque is categorised as speech room which should meet the standard of the reverberation time of 1.5-2 second. The perfect reverberation time is 0.75 second.

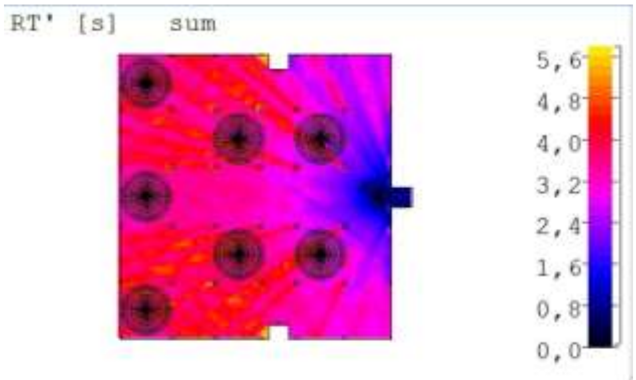

Figure 13. The simulation result of reverberation time (RT)

Figure 13 shows that the lowest RT is obtained in the area closed to the sound source. While the higher ones stand behind the poles, which is caused by the reflection of the sound among the poles. In this case, the high reverberation time is also caused by the dome ceiling and the reflective materials of the floor, wall, and ceiling. Elements with less absorption value will give a high sound reflection and therefore high reverberation time.

The simulation result of Room Acoustics Speech Transmission Index (RASTI)

Figure 14 shows the effect of Room Acoustics Speech Transmission Index of Baiturrahman mosque which is simulated in two conditions, namely no noise and with noise conditions. In the state of no noise, the Baiturrahman Grand Mosque did not appear to be well distributed. The far position of the sound source received the level of sound clarity within 5% to 35%. This is far from the standard required for the speech room category, which should be more than 45%. The only audiences who are close to the sound source that can receive the sound clearly. In conditions with background noise, it looks worse than the no noise state.

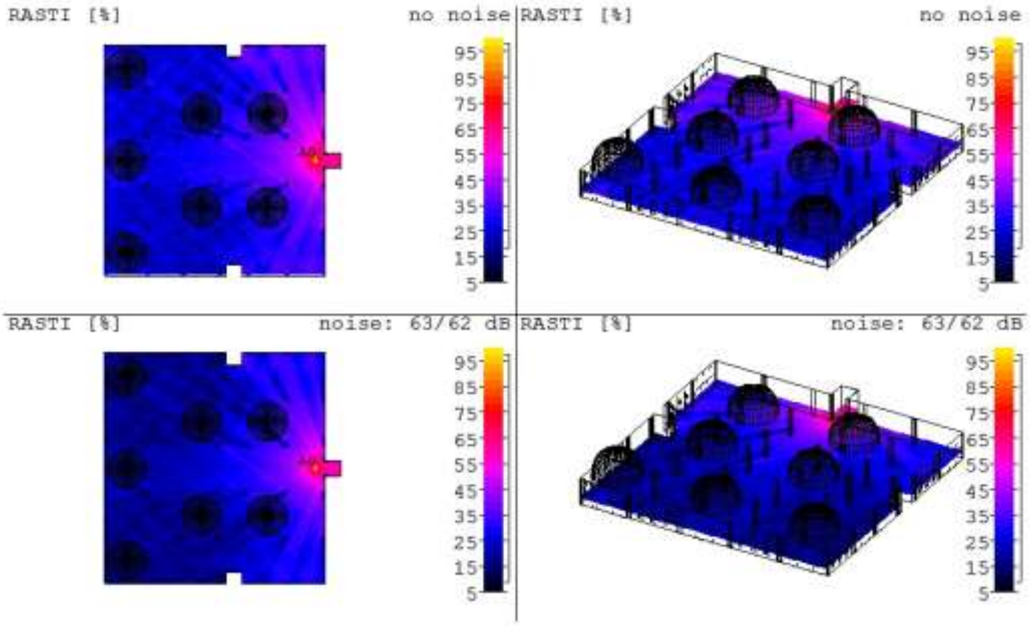

Figure 14. The simulation result of Rapid Speech Transmission Index (RASTI)

It identifies that the background noise inside the Baiturrahman Grand Mosque was so bad that reduced the clarity of the sound distribution across the room. Based on these two conditions, i.e. no noise and with noise, this study found that the relatively harsh material use at the Baiturrahman Grand Mosque has caused the quality of the room acoustics at Baiturrahman Grand Mosque to be not good. These materials create continuous reflection causing the sound produced cannot be absorbed properly — additionally, the shape of the dome that is most likely to cause sound concentration which can lead to acoustic defects, resulting in the receiver not being able to receive undoubtedly what is produced by the sound source.

Conclusion

The paper investigated the room acoustic performance of Baiturrahman Grand Mosque. The evaluated acoustics parameters are the noise criteria, sound pressure level, reverberation time and Room Acoustics Speech Transmission Index (RASTI). The noise level was evaluated through the collected real data of sound pressure level. In general, the room acoustic performance of Baiturrahman Grand Mosque is poor. The lowest noise criteria (NC) which is running during the prayer is around 57dB which is higher than the recommended value of the mosque which belongs to the speech room. The reverberation time obtained from the simulation is high, i.e. 3-4 seconds which is also too long as the speech room criteria.

At last, the sound clarity (RASTI) does not meet the standard either which is only around 3-35% which is lower than 45% of the requirement for sound clarity of the speech room. This condition recommends further research for analyzing the improvement of the room acoustic in particular through design and building materials. The floor, wall and ceiling materials should be improved with the more absorptance-characteristics material to reduce the reflective surface hence lower reverberation time and closer the sound clarity to the standard.

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