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ENVIRONMENTAL MANAGEMENT EFFORT IN MINIMALIST-STYLED MOSQUE WITH AUDIAL COMFORT AND NOISE MANAGEMENT

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ABSTRACT

Places of worship should ensure comfort for their users. Comfort in buildings can be categorized into three types, namely thermal, visual, and audial comfort. Audial comfort itself has several parameters including reverberation time. The greater the reverberation time, the longer the noise in the room will decay, causing noise accumulation. This will certainly be very disturbing, especially if the room accommodates activities of preaching and worship. Many things affect the amount of reverberation time, including the shape of the building, room volume, interior design and interior materials used. Buildings with concave ceilings, such as mosques with domed roofs, have poor acoustic performance compared to buildings that have convex or flat ceilings because sound tends to be reflected and the reflections are accumulated at several points. The sound distribution is also less even when compared to buildings with flat or convex ceilings. BaitulIzzah Mosque at the Adhi Tama Institute of Technology has a typical design of mosques in general, with a concave ceiling and hard materials in its interior, so it tends to reflect sound. The location of the mosque, which is on the edge of a main road, also allows noise pollution to occur in the worship space. This study aims to evaluate the performance of acoustics, in this case the reverberation time, analyzing the impact of the mosque location on the main road, and provide acoustic design solutions for the mosque of Adhi Tama Institute of Technology Surabaya. In general, the applied method was correlational research with relationship study strategy. The results were obtained by examining the relationship between several variables that affect the reverberation time, particularly the type of interior material and the surface area of the absorbent field used. The results showed that the acoustic comfort in the BaitulIzzah mosque can be obtained by adding absorbency and replacing wall, ceiling and floor materials. This solution can also be used for noise management in similar mosques.

KEY WORDS : Audial, Noise, Management

INTRODUCTION

A place of worship is a place where humans are directly connected to God as well as a place to obtain knowledge and strengthen interpersonal relationships. Buildings with any function must certainly be able to provide comfort for its residents (Lechner, 2007). According to Olgyay (1972) Comfort in buildings include: Thermal comfort (related to temperature), Visual comfort (related to the amount of light) and audial comfort (related to room acoustics). Audial comfort parameters include noise entering the room and reverberation time.

Audial comfort in a building is closely related to the interior materials of the building, the shape of the building, and the interior design of the room itself (Tampleton, 2010). Satwiko (2004) and Szokolay (2004) states that rooms with concave ceilings have the worst acoustic performance compared to flat or convex ceilings because in rooms with concave ceilings, the spread of reflected sound tends to be uneven; most of the sounds will be accumulated only at several points. Most mosques in Indonesia use dome or joglo roofs, so the reflection of sound tends to be centered, not spread evenly. In addition to building shapes and ceiling models, interior materials also affect the reverberation time (Setiyowati and Nastiti, 2008). Previous studies have shown that mosques with hard interior materials tend to have poor acoustic performance. Typologies of mosque forms in Indonesia include (Faqih, 1991): Flat and domed roof, Pyramid roof combined with dome, A growing roof, and 'Javanese vernacular' form.

The design of mosques, similar to the design of rooms used for speech, should pay attention to at least the following five things (Doelle, 1993):

a. Can provide the optimum reverberation time according to standards.
b. Minimize acoustic defects.
c. Maximize loudness. The loudness of the Imam's voice must be sufficient to be received by the congregation.
d. The level of noise in the room can be minimized by the building shape design, the orientation of openings to noise sources from the environment, as well as the selection of exterior materials that can inhibit incoming noise from outside.
e. Provides an artificial system where it is needed.

ITATS Baitul Izzah Mosque has a rectangular shape with a joglo roof. This rectangular shape enables a high level of sound uniformity. The problem with this building is that the congregation cannot clearly hear the voice of the sermon or the voice of the Imam. This research aims to evaluate the acoustic performance, particularly the reverberation time of BaitulIzzah mosque at Adhi Tama Institute of Technology (ITATS) Surabaya, and provide interior design solutions for the building.

RESEARCH METHOD

This research is qualitative research that used the method of correlational research, which involved a variable magnitude test and aims to discuss the relationship between the independent variables and the dependent variable. The independent variables in this study are the material of worship space walls, floors, and ceilings with parameters including absorptance and acoustic absorption fields. The dependent variable in this study is RT (reverberation time).

To obtain the existing RT, a field measurement was carried out. RT was measured with Sound Level Meter (SLM) from Solo brand. The reverberation time was measured using the impulse response method by blowing up small firecrackers as a source of sound. The voice from the firecracker was received by SLM and entered into a computer so that the data of the sound decay in the room were visible. Then, the amount of RT in the room was calculated. The measurement point to calculate RT was the midpoint of the room (Figure 1). The measured frequency ranges were 125 Hz, 250 Hz, 500 Hz, 1KHz, 2 KHz, and 4 KHz.

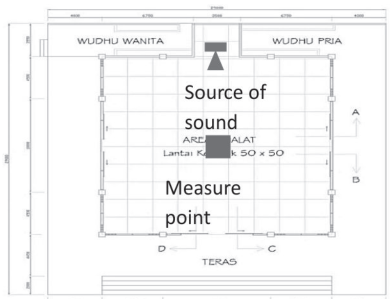


Fig. 1. Placement of firecrackers as a source of sound and RT measurement point

After discovering the RT, the evaluation was done by means of mathematical calculations as in previous studies (Mariani and Rauf, 2008). Interior design solutions for mosques were obtained through wall, ceiling, and floor material replacement simulation. The simulation used mathematical calculations in equations 1 and 2 to find the right value of the reverberation time of the room.

For the analysis of noise pollution and audial comfort of the mosque, a random sampling method was applied, in which samples were taken randomly from 5 prayer times on weekdays.

RESULTS AND DISCUSSION

The Existing Condition of ITATS Mosque

The ITATS Mosque was built in a modern minimalist style. Slightly different from mosques in general that use a domed roof, this building has a square shape with a joglo roof (Figs. 2). The worship area of this mosque is 17 x 19 m (Fig. 2).

The interior material of the mosque's worship area is dominated by hard materials, which tend to reflect sound, using a 50x50 cm tile floor without

Fig. 2. Front view of ITATS Mosque and The front wall of ITATS Mosque

carpet. The walls of the Imam area use black granite tiles that are 2.5 m high. On top of the granite is a 1 m high ceramic air partition. The structure column uses concrete with white paint finishing. Walls are dominated by 6mm glass windows with aluminum sills. The door used 12 mm tempered glass. The areas of worship for women and men are separated by movable wooden partitions.

The roof of the mosque uses a joglo-shaped steel construction. The ceiling inside the mosque is formed following the shape of the roof. The ceiling materials are 9 mm gypsum boards

Criteria for Room Acoustics

Worship activities in the mosque, in addition to prayers, include the delivery of sermons from the Imam to the congregation. The basic criteria for rooms with speech functions is sound clarity. Many factors affect sound clarity (Doelle, 1993; Lawrence, 1970), including physical factors: the ability of the sound source or the Imam in speaking and the audience or congregation's sense of hearing, language factors: word construction, the way the Imam delivers sermons, and clear pronunciation of sentences. Both of these factors have nothing to do with the design of the acoustic environment, but they are quite influential on the sound clarity.

Objective Criteria for Conversational Functions are

a. Loudness of sound
b. Clarity of sound
c. Sound clarity is related to the direct sound or original sound produced by the sound source and directly received by the listener. The clarity of sound is related to the shape of the room.
d. Reverberation Time

Reverberation time (RT) is often used as a starting point for designing building acoustics. Reverberation time (T60) is defined as the time required by indoor sound pressure to decay by 1/1000 of the initial sound pressure or to decrease by 60 dB since the source of sound is stopped.

The larger the volume of the room, the longer the reverberation time. Conversely, the greater the coefficient and area of the building materials, the shorter the reverberation time. The reverberation time (RT) parameters of auditoriums differ depending on their use. RT that is too short will cause the room to feel 'dead', while a long RT will give the room 'alive' atmosphere.

Effect of Interior Material on Room Acoustic Quality

Each building material has different acoustic performance and sound characteristics. There are materials that can be utilized for sound absorption (absorber), sound spreader (diffuser), and sound reflector. In choosing interior materials to maximize acoustic performance, the following characteristics must be paid attention[4].

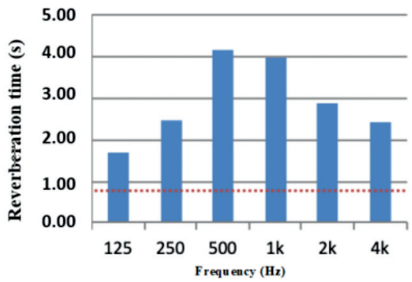
a. Has an absorption coefficient (á) that suits the absorption requirements
b. Has the appearance that is suitable to the aesthetic characteristics of the room. For example, a cheap-looking plain white factory-made acoustic board will damage the aesthetic image of a building with a luxurious concept.
c. Fire resistant
d. Adequate installation cost
e. Easy installation and maintenance, consider the access to routine maintenance, especially if the acoustic material is mounted on a high ceiling.
f. Durable and resistant to temperature, humidity, mold, condensation, and even insects.
g. Has the amount of reflected light in accordance with the design of the room lighting.
h. Integrated with other elements in the room
i. Easily shifted, not too heavy, and flexible.

Evaluation of Reverberation Time

After measuring the reverberation time of the ITATSBaitulIzzah mosque, it is found that the reverberation time of the mosque far exceeds the standards (Figure 3). With the average reverberation time of 2.92 seconds, it is certain that the congregation cannot hear the Imam's voice clearly. This will be very disturbing and the delivery of sermon material will be ineffective.

The reverberation time is quite high because the building's interior materials use hard materials and tend to reflect noise (Table 1). A lot of sound absorbing materials are required to lower the reverberation time.

Sound-absorbing materials can be installed on floors, walls, ceilings, or even windows. For finished buildings, efforts should be made to add absorbent materials that are easily applied. Changing the existing structure should be avoided as much as possible. If the addition of absorbent material still cannot reduce the reverberation time, there is no other choice but to change some parts of the building with sound-absorbing materials.



Note: RT of every frequency
— Limit of reverberation time for speech (0.8 s)

Fig. 3. Graph of ITATS mosque reverberation time

Evaluation of Sound Pollution

Noise pollution is unwanted sound at a certain level and time and can endanger health. There is something called the hearing threshold and pain threshold. Normally, humans may be exposed to sounds of 80 dB for a maximum of 8 hours. 80 dB is equivalent to the noise of motorized vehicles on a main road. With sound above 80 dB, people will suffer from earaches. The design of this mosque as seen in Figures 2 and 4, has a lot of openings in the building envelope. This allows audial discomfort in a room, which can be called noise or sound pollution, to increase.

Table 2 shows the results of a survey of several worshipers. At dawn, the congregation relatively did not experience audial discomfort in the room because in addition to the small number of people, the activities carried out outside the mosque and the number of motorized vehicles passing were still few. During the afternoon and the evening, particularly zuhr and ashr time, more problems occurred regarding voice clarity; the voice of the Imam could not be heard clearly by the congregation. Noise from outside actually occurs at night, during maghrib and isha, because at that time there is often a massive buildup of students who go to their night classes and students who come home from their morning classes. Sometimes they gather in front of the mosque, so the produced sound disturbs the congregation. Noise from the main road is relatively low.

Design Approach for Noise Management

The reverberation time can be reduced by covering the floor with material with higher absorber like carpet. Carpet has a noise absorption coefficient that is greater than ceramic's (Table 3).

The wall in the Imam's area uses granite tiles, which also reflect sound. This concept is already good. For spaces with speech functions, it is better to use sound-reflecting materials behind the desired sound source (speaker or the Imam in this study) so that the sound from the source is immediately reflected to the listener and the congregation can hear the sound source more clearly even without a microphone. Conversely, in the back of the congregation there should be sound-absorbing materials so that the sound from the source is not reflected again and disturb the congregation. Besides, if there is noise from the back rows of the congregation, it can also be absorbed and not disturb other worshipers in front of them.

There was a relationship between noise level with an increase in blood pressure and health disorders in the sense of hearing that is a decrease in the value of the hearing threshold that can be non-pathological temporary threshold shifts and \permanent

Table 1. Data on absorptance (á) of existing wall materials

Ele-ment	Material	Absorption coefficient (á)					
		125 Hz	250 Hz	500 Hz	1 KHz	2 KHz	4 KHz
Floor	Ceramic Floor	0.01	0.01	0.01	0.02	0.02	0.02
Wall	Plastered red brick	0.01	0.01	0.02	0.02	0.02	0.02
	Ceramic Air Partition	0.01	0.01	0.01	0.02	0.02	0.02
	Granite Tiles	0.01	0.01	0.01	0.02	0.02	0.02
	Painted fine concrete	0.01	0.01	0.01	0.02	0.02	0.02
Cei-ling	Gypsum	0.15	0.10	0.05	0.04	0.07	0.09
Door	12 mm tempered glass	0.10	0.06	0.04	0.03	0.02	0.02
Window	6 mm clear glass	0.10	0.06	0.04	0.03	0.02	0.02

Source: Tampleton (2001)

threshold shift due to pathological factors due to being in locations that have high noise and the presence of acoustic trauma.Therefore, noise management is something that needs to maintain carefully.

In this case, it cannot be applied because the back of the worship area is the main entrance of the mosque and the opening is very wide. It is possible to replace the glass doors with wood and cover the windows with walls and insulation panels, but this will lead to greater cost consequences because the existing wall structure has to be dismantled. In this case, a sound-absorbing material, particularly thick carpet on mineral fibrous boards were installed on the wall in the Imam area. In order for the sound distribution from the sound source to be received well by the receiver, the sound source must be assisted with a microphone and speakers. The brick wall around the congregation area can be covered with the same material as the one installed on the Imam's area. The shape of the wall can also be modified, as described in a previous study that worship buildings should use concave walls to sharpen the voice of the Imam[13]. Changing the gypsum ceiling with 12 mm plywood perforated ceiling material will improve the acoustic performance of the room (Table 4). Adding curtains to the window can also help reduce the reverberation time. In this case, the curtains used were thin curtains installed approximately 90 mm from the window.

Using the treatment that has been explained earlier, the noise based on the calculation of the reverberation time of the mosque's worship area has fallen from the average of 2.92 s to 0.61 s (Figure 4). At a frequency of 125 Hz, the reverberation time still slightly exceeds the limit standard, whereas noise at low frequencies tends to be more difficult to be muted because low frequency sounds can propagate through the building structure[5]. Even though the sound at the frequency of 125 Hz is still slightly above the limit, the reverberation time at 250 Hz to 4 KHz has dropped to meet the required standard.

BaitulIzzahMosque also has very large windows.

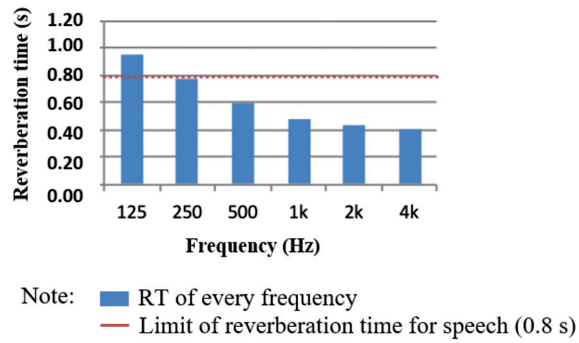


Fig. 4. Graph of ITATS mosque reverberation time after treatment

Table 2. Questionnaire results of the audial discomfort felt by mosque congregation

No	Types of acoustic problems	Number of Respondents				
		Fajr	Zuhr	Ashr	Magh-rib	Isha
1	Cannot hear the Imam clearly	0	15	9	17	4
2	Engine (air conditioner or fan) noise	0	0	1	0	2
3	Motorized vehicle noise	0	11	8	7	9
4	Noise from student activities	0	3	4	19	8
5	other	0	2	0	1	0

Table 3.á comparison between ceramics and carpets, source: Tampleton (2001)

	125 Hz	250 Hz	500 Hz	1 KHz	2 KHz	4 KHz
ceramic tiles	0.01	0.01	0.01	0.02	0.02	0.02
9 mm pile carpet, tufted on felt underlay	0.08	0.08	0.30	0.60	0.75	0.80

Table 4.á comparison between gypsum board and plywood

	125 Hz	250 Hz	500 Hz	1 KHz	2 KHz	4 KHz
Gypsum	0.15	0.10	0.05	0.04	0.07	0.09
12 mm thick perforated plywood	0.40	0.90	0.80	0.50	0.40	0.30

Source: Tampleton (2001)

Table 5. Design Guideline for green tropical mosque

No	Design Aspect	Design Strategy
1	Building Form	Rectangular
2	Building Orientation	Depend on the Qibla
3	Façade material	Material with low conductivity, high density better for thermal and audial performance
4	Windows to wall ratio	Maximum 20% for better thermal and audial performance. For minimize noise transmit from outside and reverberation time inside
5	Interior	Using thick carpet, soft or porous material or another material with high sound absorbtance.
6	Site conviguration	Add sound masking or obstraction from outside noise

The effect of the aluminum frame on the window is quite huge and the quality of the acoustics depends on the quality of the glass used[14]. Another alternative that can be used in the new design of this mosque is opening the wall on the south side, which does not face the source of noise directly, as has been done in previous research[15]. A mosque building with an open wall can have a good effect for thermal comfort, but it can allow noise in the building, but that can be overcome by installing more absorbent in the interior of the building.

Green Bulding Aspect

Adhi Tama Institute of Technology Surabaya has a strong commitment to making the campus a comfortable and ecological place of study, for this reason existing buildings and facilities should meet the green building concept design rules. This mosque has a modern style with overlapping roof, in terms of the shape and orientation of the building, this mosque is still unable to respond to the humid tropical climate. Large vetilation, high roof can answer the problem of humidity, but the façade material used is still not in accordance with the rules of the design of humid tropical buildings.

The addition of sound absorbing material on the walls and ceiling is actually able to be heat insulation in this building. Further research can evaluate the façade design with thermal performance in buildings.

Many design guides for mosques in the tropics refer especially on vernacular architecture. Mosques in Nusantara has been developed since 16th century, thus give a lot of option and reference for design development for better building performance trough tropical design paradigm. In Table 5 is mentioned about tropical design guideline as resume of this reseach result.

CONCLUSION

The results showed that the acoustic performance of the BaitulIzzah mosque at ITATS was poor due to the high reverberation time, which was 364% higher than required. This caused the congregations to not be able to hear Imam's speech and voice clearly.

To reduce the reverberation time, some treatments that can be applied are covering the floor with carpet, covering the brick walls and granite walls in the Imam's area with wooden boards layered by thick carpets, replacing the gypsum ceiling with 12 mm perforated plywood, and installing curtains made of thick fabric ± 5 cm from the window.

The treatments above can reduce the reverberation time of the room up to 79.2%, so the mosque can meet the required reverberation time standard. Smaller reverberation time means the sound decays faster so that the buildup of sounds is smaller and it helps the congregation listen to the Imam's sermon and voice more clearly. However, these treatments have not been able to make the sound more evenly distributed. Equal sound distribution in the room can be achieved by placing speakers at certain points and possibly there will still be a need for product development, especially audio systems that are adjusted to the conditions of similar mosques.

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