THE EFFECT OF CEILING SHAPE ON THE ACOUSTICS OF INDONESIAN MOSQUES

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ABSRACT

The mosques in Indonesia can be classified according to the roof shape, that is pyramidal –tier roof that is the dominant shape, dome and other non-traditional shape. The ceiling shape commonly follows the roof shape.Computer simulation has been conducted in a typical mosque using ceiling shape as parameter. The typical mosque is characterized by the tropical building design and interior materials which mostly have high sound reflectance. The simulation results to be used as acoustical indicators comprising reverberation time, energy time curve, ray paths, and acoustical defects such as echo and sound concentration.

Key words : ceiling shape, mosque, acoustical defects, computer simulation

INTRODUCTION

The mosques in Indonesia can be classified according to the roof shape that are pyramidal tier roof, dome and non-traditional or modern shape. The dominant shape is the pyramidal tier roof, comprising one to five tiers, but commonly three. The dome roof can be a small dome lying on a flat roof or a large dome covering above the whole plan of the prayer hall. The modern or non-traditional roofs have various shapes such as flat and modification of pyramidal roof.
The ceiling shape commonly follows partially or fully the roof shape, but sometime just horizontal flat ceiling. The ceiling height of the prayer hall of the community and the great mosques is at least of two story building.

The plan of the prayer hall is usually square or semi-square with open corridors surrounding the three sides except the front or *mihrab* side. The walls surrounding the prayer hall except the front wall have large opening in the form of large doors, windows and ventilation openings, or movable partitions that can be fully opened. This is typical design of the mosque in the humid tropical climate to control airflow and natural illumination, and consequently the hall is easily intruded by high ambient noise from outside. The interior materials commonly have high sound reflectance.

The objective of the study is to anticipate the acoustical defects arising from the ceiling shape, employing computer simulation.

THE TYPICAL MOSQUE

The computer simulation has been conducted on typical mosque using ceiling shape as parameter. The typical mosque is characterized by the humid tropical design comprising relatively high ceiling and large openings on the walls except the front wall. The size of the typical mosque corresponding to the community mosque with prayer hall area of 25 m x 25 m, ceiling height of 8 m, surrounded by open corridors except the front or *qibla* side.

The interior materials consisting of wood for the main floor and carpet for the mezzanine floor, plastered masonry wall, glass pane for windows and soft board panel, for ceiling.
There are five ceiling shapes to be used as parameter, comprising :

- (a) Flat ceiling
- (b) Dome roof, with 15 m dome diameter
- (c) Large dome roof, with 25 m dome diameter
- (d) Single tier-pyramidal ceiling, with 30^o ceiling slope
- (e) Three tiers-pyramidal ceiling, with 30^o, 45^o, 60^o ceiling slopes

The sections of each ceiling shape can be seen in Figure 1**.**

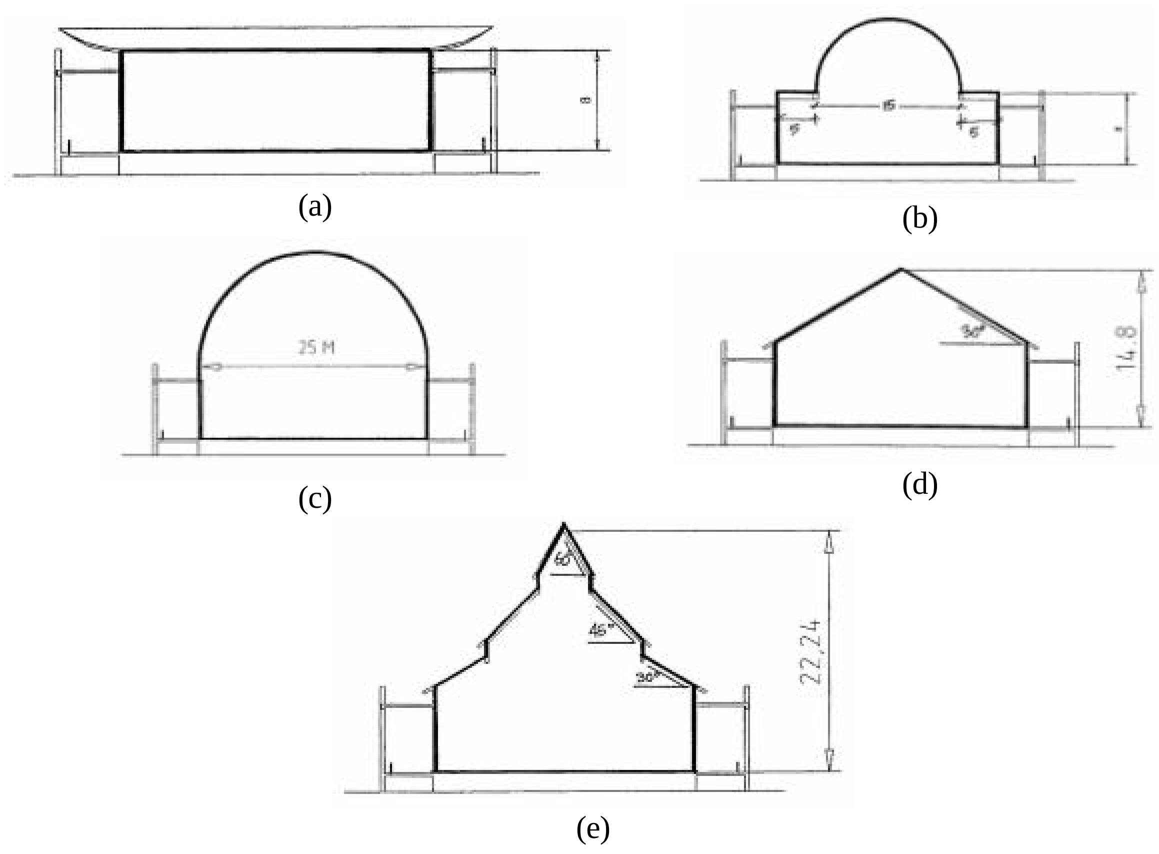

Figure 1. Section of the five ceiling shape

A loudspeaker as a sound source was placed above the platform which is located at the *mihrab*, with omni-directional characteristics or directivity factor Q = 1 and sensitivity 90 dB (1m, 1watt). The background noise is 50 dBA.

SIMULATION PROCEDURE

The simulations were conducted for fully occupied prayer hall, representing Friday prayer, with all the doors are fully opened

The duration of the simulated Energy Time Curve or reflectogram is 200 ms starting after the arrival of direct sound and the number of reflection considered for a given beam was three or three bounces involving three reflective surfaces. The total number of points to be simulated was 8, comprising 6 points on the main floor and 2 points at the balcony. See Figure 2.

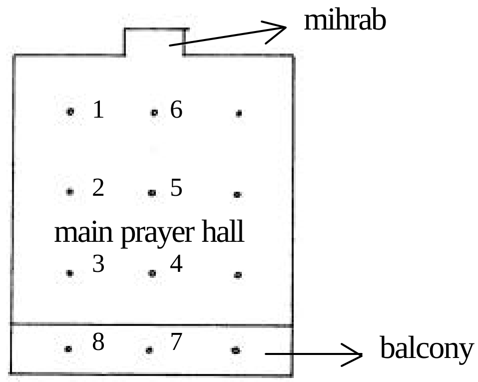

Figure 2, Location of simulation points.

The points were positioned at 0.75 m above the floor, corresponding to the average ear height of the congregations. The simulation results to be analyzed comprising of Sabine reverberation time, energy time curve, ray tracing, and acoustical defects such as echo and sound concentrations

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SIMULATION RESULTS AND ANALYSIS

Reverberation Time

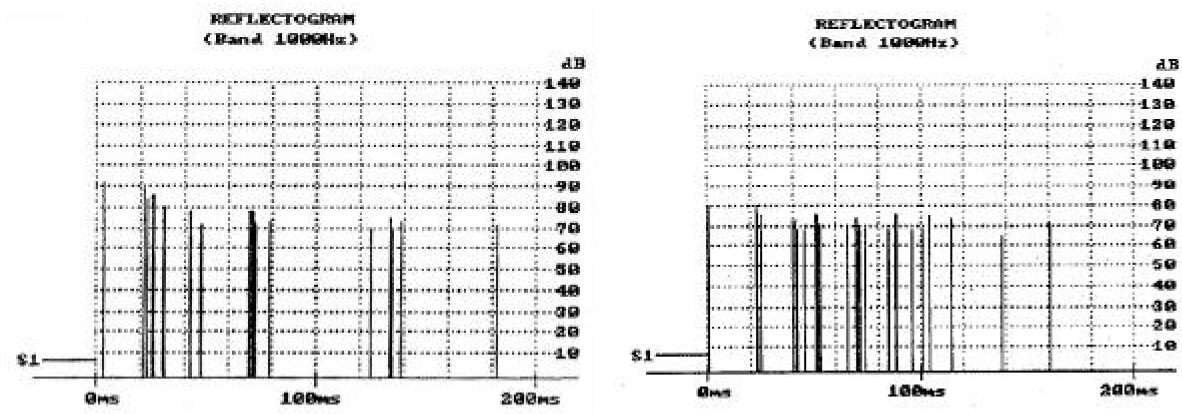
The reverberation time for fully occupied prayer hall were mostly higher compared to the desired one (see Table 1) for all types of ceiling shapes, at the frequencies up to 1 k Hz and the discrepancies increases with the room volume, while at 2k and 4k Hz the reverberation time were slightly lower. This is due to the low absortance of the interior materials at low and mid frequencies, and the increasing room volume.

Table 1, Desired and simulation results of reverberation time

Ceiling Shape	Volume m^3	%	Reverberation time (s) Desired	Simulation results 125	250	500	1k	2k	4k
(a)	5225	100	0.95	1.1	0.9	1.0	0.9	0.8	0.8
(b)	6046	116	0.95	1.1	1.0	1.1	1.0	0.9	0.8
(c)	8761	168	1.0	1.5	1.3	1.4	1.3	1.1	1.0
(d)	6656	127	1.0	1.3	1.2	1.2	1.1	1.0	0.9
(e)	7003	134	1.0	1.3	1.2	1.3	1.2	1.0	0.9

Energy Time Curve

The ETC produced at the test points for each ceiling shape showed the level of direct and reflected rays and its arrival times. The reflected rays potential of producing echoes can be identified by the arrival time different of more than 50 ms[1],[2] and sound level different of less than 10 dB compared to the direct ray and higher by several dB to the ray group in front of and behind it. For illustration, two simulation results of reflectogram of test point no. 6 of ceiling shape (a) – the flat ceiling, and test point no.4 of ceiling shape (e)- the three tiers-pyramidal ceiling, are shown in Figure 3.a and 3.b. respectively. As shown in Figure 3.a.there was no reflected ray potential of producing echo, while in Figure 3.b. there were several of it.



(a) (b)

Figure 3. Reflectogram, without (a) and with (b) reflected rays potential of producing echo

The surfaces encountered by the reflected rays cannot be identified in the reflectogram; instead it can be done in the ray- tracing diagram.

<u>Ray Path</u>.

Simulation result of ray tracing were displayed in a tabular form as well as in a ray-tracing diagram. The table comprising of reflection arrival time starting from the direct ray, number of reflection of each reflected ray and the surfaces encountered, and its sound level. For example, a table of simulation result of test point no.3- ceiling shape (e),
comprising 44 reflected rays, of which 32 rays are involving ceiling reflection or 72% of the total reflected rays. One of the rays ex. ray number 18, arriving 44 ms after the direct ray, number of reflection is one and sound level of 77 dB. The sound level of the direct ray was 84 dB and of the ray group before and after the ray number 18 are several dB below 77 dB, this ray is potential to generate echo. The ray diagram of this ray is illustrated in Figure 4which showing the effect of inclined high ceiling on the ray path

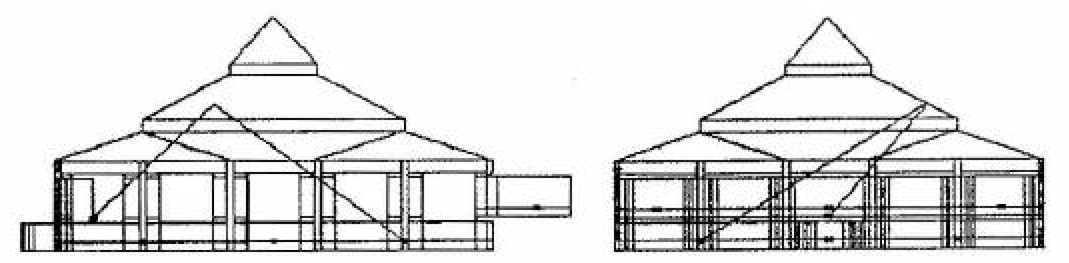


Figure 4. Ray tracing diagram of a ray for ceiling shape (e)

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Another example is for point no, 5, ceiling shape (b), the table comprising 39 reflected rays, of which 30 rays involving ceiling reflection or 77% of the total reflected rays. Rays number 32 to 37; have the same arrival time of 139 ms, three times of reflection and 71 dB sound levels. These rays can produced sound concentration as focused echo. The ray diagram of these rays is illustrated in Figure 5,which showing the effect of dome ceiling on the ray path.

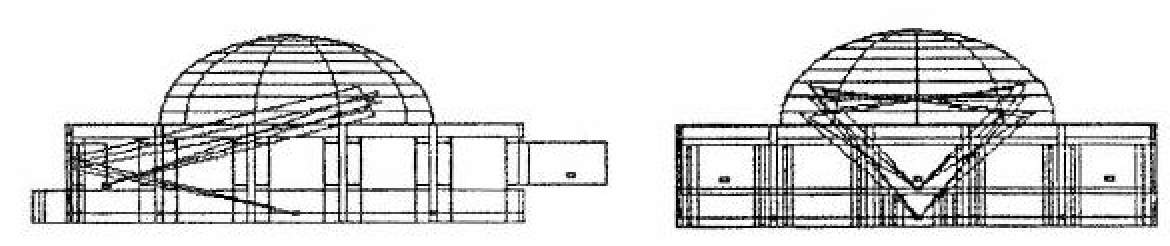

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Figure 5. Ray tracing diagram of several rays forming sound concentration for ceiling shape (b).

Ceiling Shape Performance

The ratio of the number of ceiling reflections to the total number of all interior surfaces reflections, that are 60%, 60%, 72%, 66% and 69% for ceiling shape (a). (B), (c), (d) and (e) respectively indicated the dominant of ceiling reflections for all type of ceiling shape.

The number of echoes and sound concentrations involving ceiling reflection will be assessed by the performance for each ceiling shape in producing acoustical defects

The best to the worst ceiling performance is as follows, the flat,. the single tier-pyramidal, the dome, the three tier-pyramidal and the large dome ceiling shape respectively.

CONCLUSION

The large opening and fully occupied hall resulting in the dominant of ceiling reflection compared to other interior surfaces. The acoustical defects arising from ceiling reflections are significantly effected by the ceiling shape, which should be anticipated in the current design of mosques in Indonesia, especially for the dominant ceiling shape that is the three tier-pyramidal ceiling.

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