Acoustics in Religious Buildings

A study of Acoustics in Mosque

Presentation by
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Synopsis

Aim is to study and identify acoustical problems in worship space and considerations for troubleshooting these issues.

Objectives

To study characteristics and behavior of sound in an enclosed space.
To identify the parameters affecting the acoustics of worship space.
To study the design considerations for worship space according to acoustics.
Drawing out the conclusions regarding ideal “mosque design" through above relative studies.

Scope And Limitations

The study deals with basic properties of sound and acoustics.
The study deals with mosque’s acoustics only.
This study will only include the surveys and analysis in term of acoustical design of Mosque it will not include any software calculations to be done (except the referred ones).
The study does not include materials’ market services.

Methodology

Framing up the acoustic requirements
Identification and analysis through collected material
Analytical study
Identification of design recommendations,
Conclusion

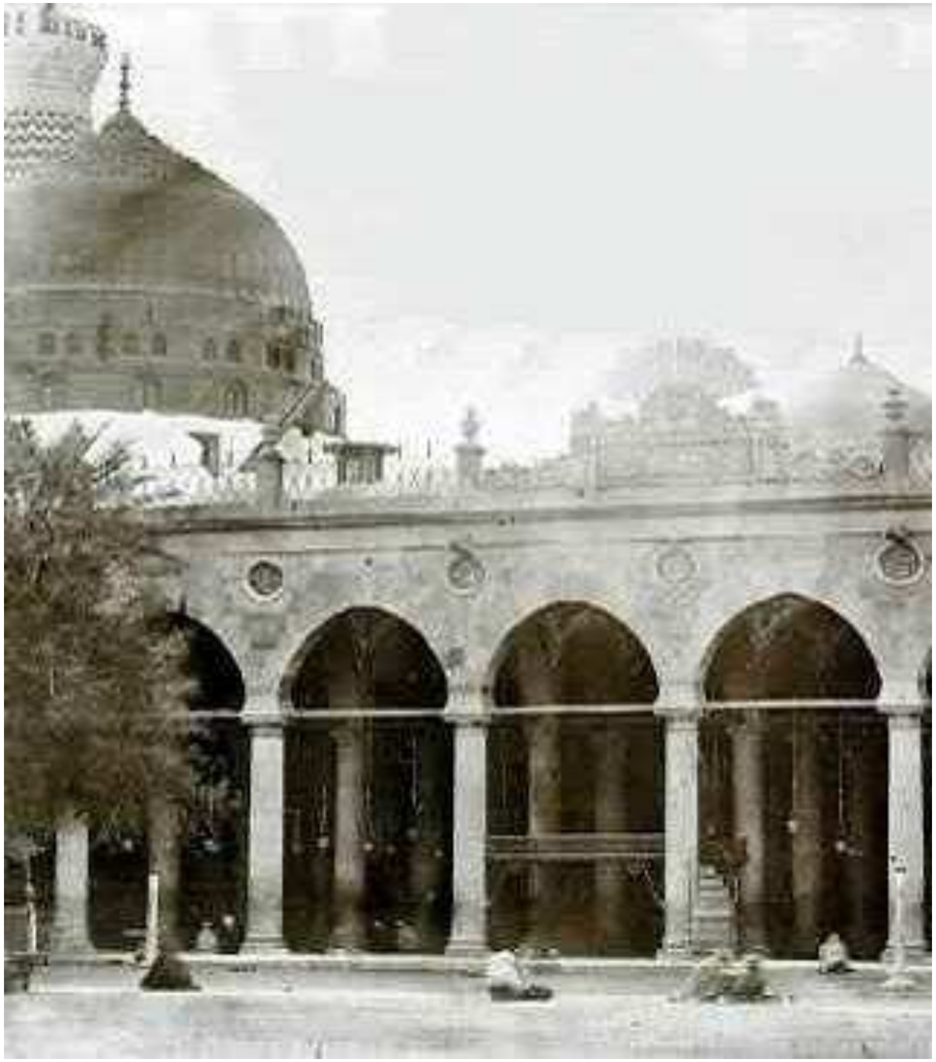


Image-Masjid e Nabavi, Madina

Mosque Architecture and Acoustics:

As a building for worship and one of the important symbols in Islam, a mosque is usually designed with its architectural grandeur. Among of the characteristics is its spacious interior to create a perception so that people will feel 'small' when entering the house of God. Most mosques therefore have high ceiling and are usually constructed with dome shape.

Considering the geometry of mosque and importance of ineligibility of recitation and speech in a mosque, Consideration of Acoustics is one of the most important design consideration.

Evolution of Mosque Geometry

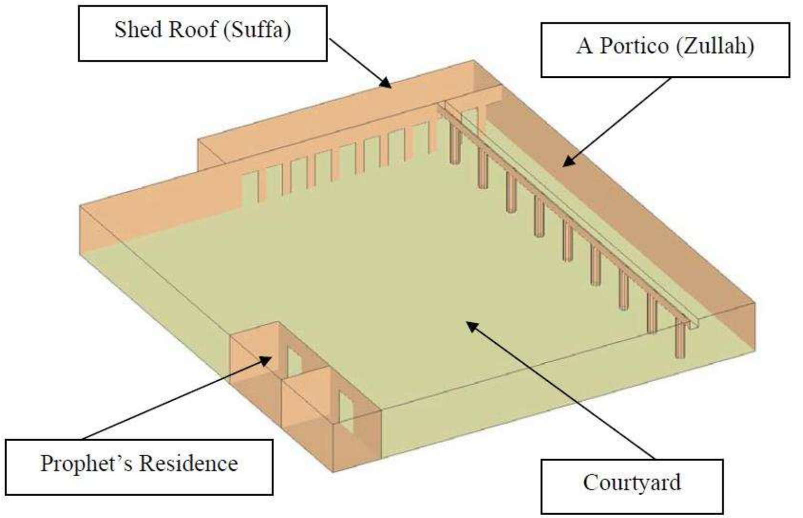
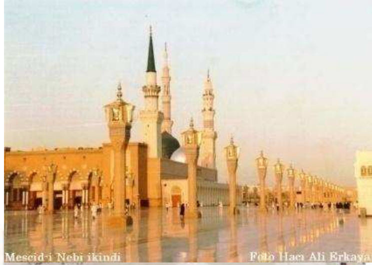
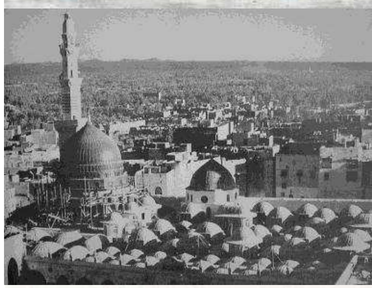


Figure 1 The old former structural configuration of the Prophet mosque in Medina.

Historically, one of the earliest mosque built in *Al-Madinah Al-Monawarah city, Saudi Arabia formed the model for subsequent* mosques throughout the Islamic world13 in its combination of basic elements. It was a simple rectangular, walled enclosure with a roofed prayer hall. The long side of the rectangle is oriented toward the direction of the holy mosque n *Makkah city. This wall is usually described as the qibla* wall. The wall contains a recess in its center in the form of a wall niche called the *mihrab. This wall also includes the minbar which is commonly an elevated floor, to the right of* the *mihrab, from which the Imam preaches or delivers the Friday sermon, the khutba.*





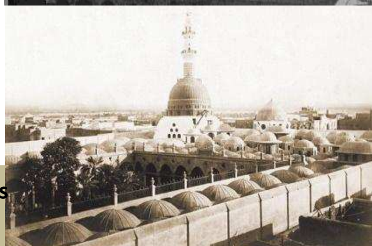


Image and Text Reference: Introductory Article about Mosques Architectural Development and Acoustics *By Dr. Wasim Orfali

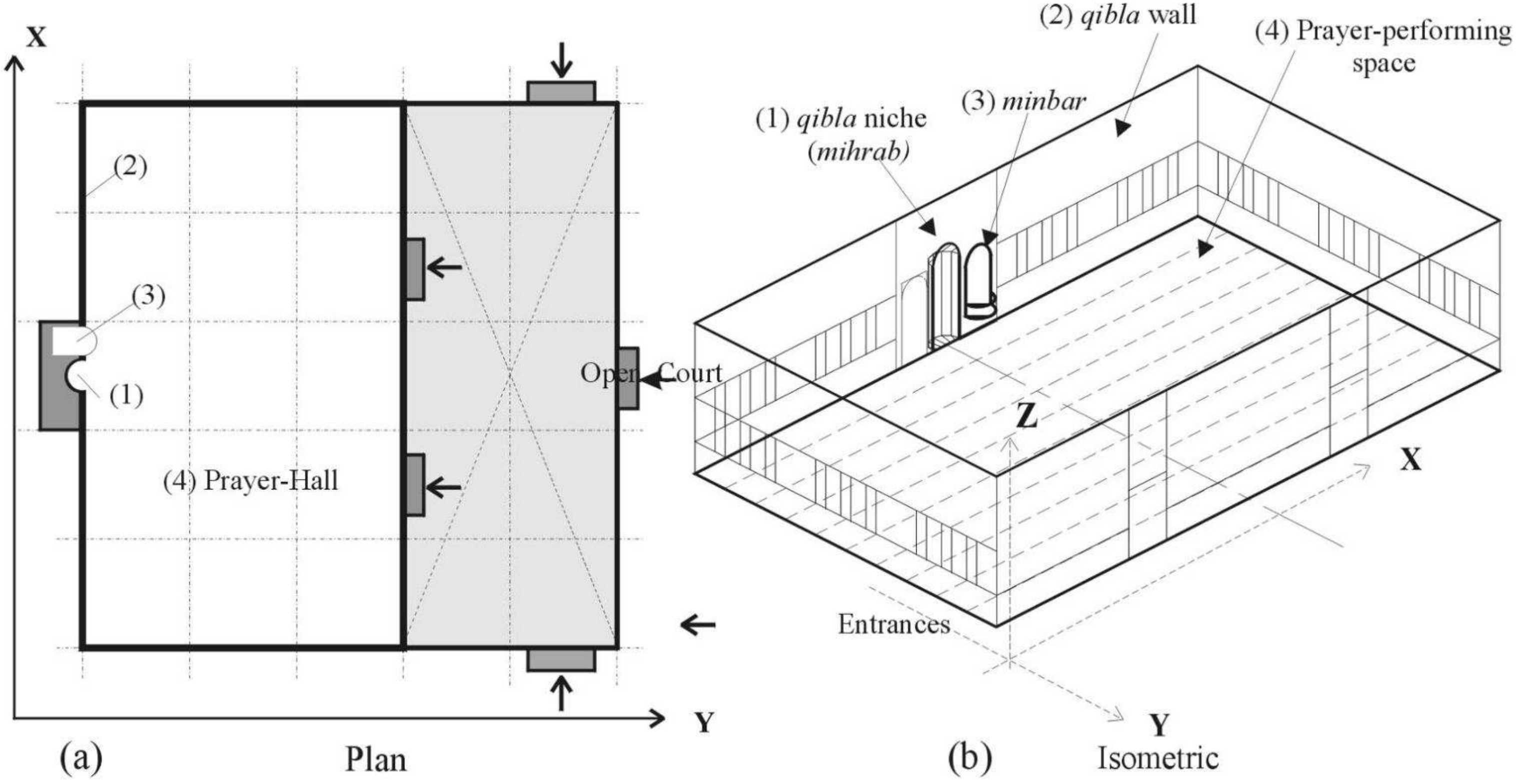


Figure illustrates the plan and isometric of a simple, typical mosque design. The basic design elements are emphasized. Since the construction of the first mosque, the functions of every mosque have remained unchanged. However, the mosque architectural form, space, construction system, and building materials have evolved and developed to a significant and variable extent in different parts of the Islamic world, influenced by many factors mentioned elsewhere.

*Image and Text Reference: Introductory Article about Mosques Architectural Development and Acoustics *By Dr. Wasim Orfali*

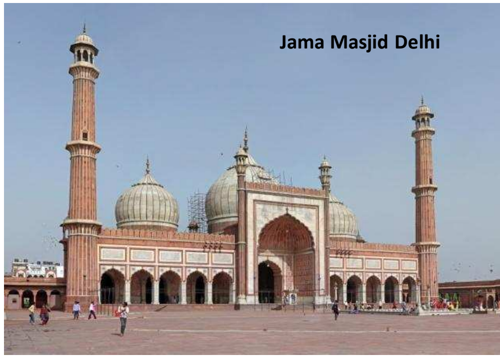
Classification of Mosques

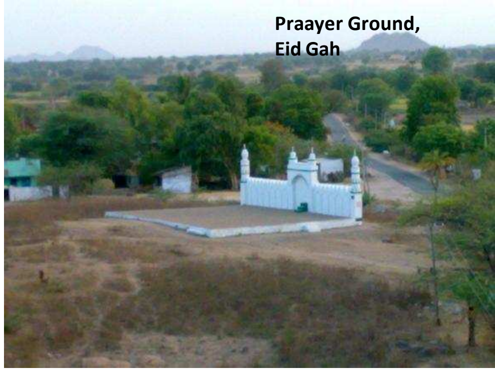
1) Small (local) mosques,
residential clusters whose population ranges between 500 and 1500 inhabitants.
walking distance from dwelling 150 to 200 meters.

2) Friday (congregational) mosques, located in the center ofneighborhoods
population ranges between 3000 and 8000 inhabitants
walking distance to a Friday mosque is in the range of 250 to 300 meters.

3) Eid mosques, which are only used for prayer on feast days and related religious **ceremonies, at the town level. It is preferable to locate Eid Mosques on the outskirts of the town in large open spaces and, therefore, they would be accessible by vehicles.**

Local Mosques would be considered for this study.





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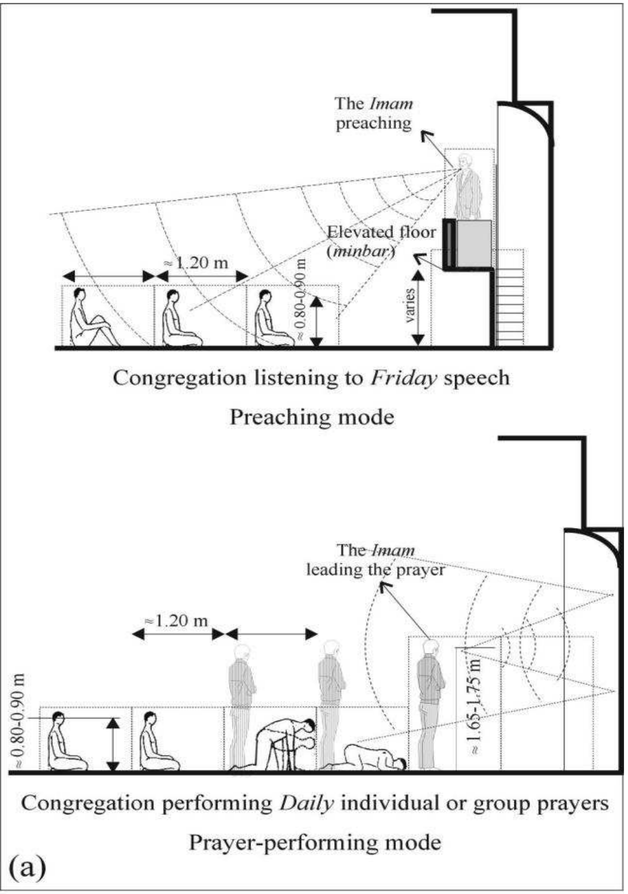
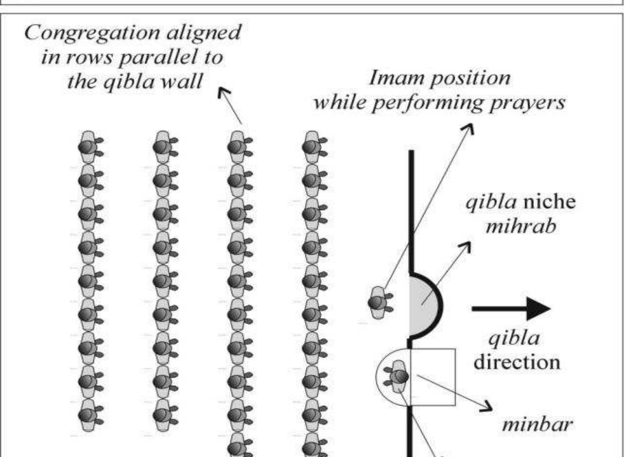




Worship Modes from where Acoustical requirements Evolve

The mosque design is mainly influenced by worship considerations. Worship in a mosque consists of two major modes.

•The first mode, namely the *prayer mode, involves* performing prayers either individually or in a group, as religiously prescribed. Group prayer must be performed with worshippers standing, bowing, prostrating, or sitting behind the *Imam, on the same floor level, aligned in rows parallel to* the *qibla wall with distances around 1.2 m apart.*

•*The second* mode is the *preaching mode(Friday prayers), where worshippers are directly* seated on the floor in random rows listening to the *Imam* preaching or delivering the *khutba while standing on the* elevated *minbar floor. The minbar floor height varies from* one mosque to the other.

•The third is preaching mode after morning and evening prayers.

*Image and Text Reference: Introductory Article about Mosques Architectural Development and Acoustics *By Dr. Wasim Orfali*

Acoustical requirements of Mosque

Intelligibility and Audibility of the prayer orders and recitation of Holy Quran from Imam (prayer leader)

Listening and understanding of the speech that the Imam say in the prayer or Khutba (lecture)

Listening to the recitation of the Holy Quran and the lecture in the morning and evening preaching's and certain other occasions.

Sound audibility means that sound receive to all audiences equally.
Speech intelligibility means that sound should be clear for various positions of the listeners in the audience area.

Identifying the Basic Parameters Affecting the behaviour of Sound in Mosque

1.Geometry

Overall Building Forms /
Domed Ceilings etc

2.Internal Surfaces

Absorption and Reflectance of Surfaces

3.Presence of Appliances

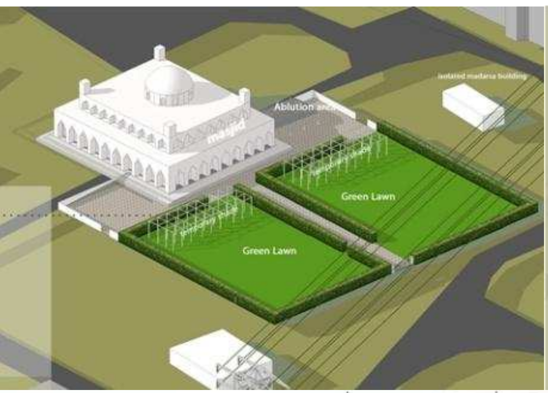
Fans/ HVAC Systems

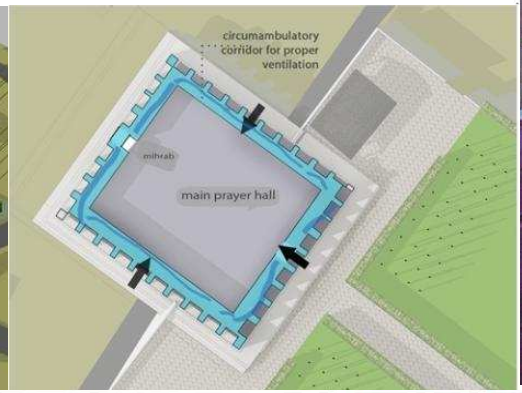
4.Sound Enhancement Systems

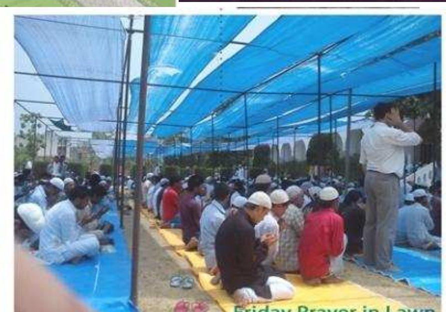
Case Study Under Consideration : Ishaat e Islam Mosque

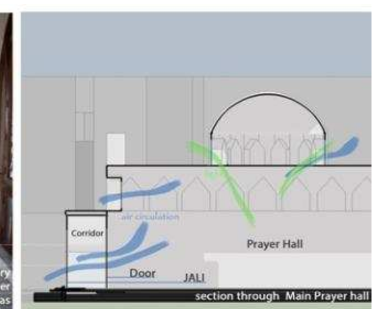
Location: D-block, AFE, Jamia Nagar

Prayer Hall Dimensions: 24 x 24x 7.5 mts





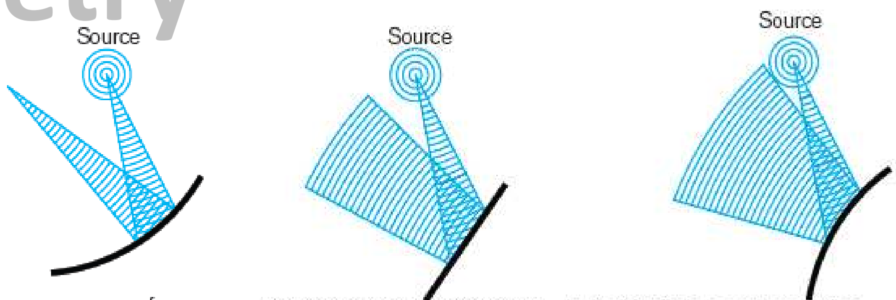




3D Images: Courtesy Ar.Aamir Equbal

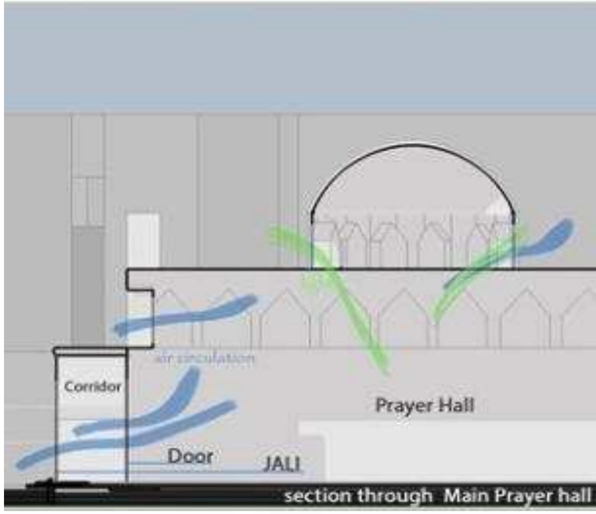
Geometry

Behavior of Sound according to geometry Inside the space

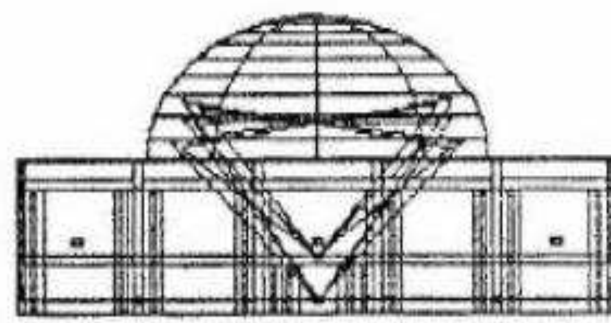


Reflection from a concave surface. Reflection from a linar surface. Reflection from a convex surface.

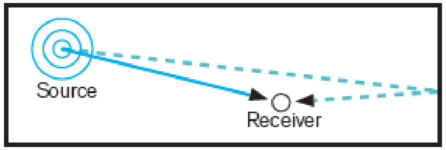
ill. 62.2 - Diagram reflections



Inside a domical ceiling sound reflections would form a focal point and in case of late reflections this may cause echo due to delayed reflections.

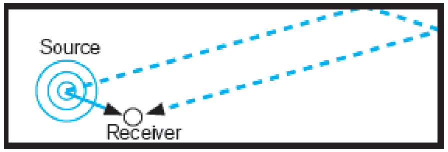


To prevent echoes it is important that the difference between the direct and the reflected sound is less then 50ms or 17m. This can be done be shaping the room in the right way and using materials to absorb the sound waves in troubled areas. Long rooms can be hard to create in a way where the echoes do not exist because of the distance to the rear wall/the reflectors in relation to the length of the direct sound.



The difference between direct and reflected sound should maximum be 50 ms
= (340 m/s x 0.05sek) = 17m

ill. 63.1



Rectangular rooms often has problems with echo.

**Mosque in Nordicc Contest by Mehtab Aslam*

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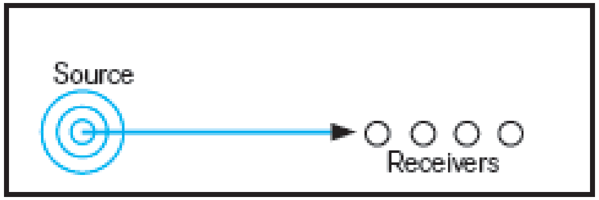
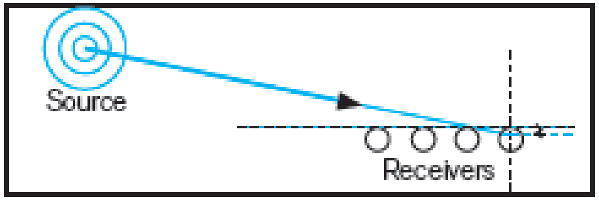
Position of Source



Example of a bad solution. The direct sound is not optimal for the recievers far behind.



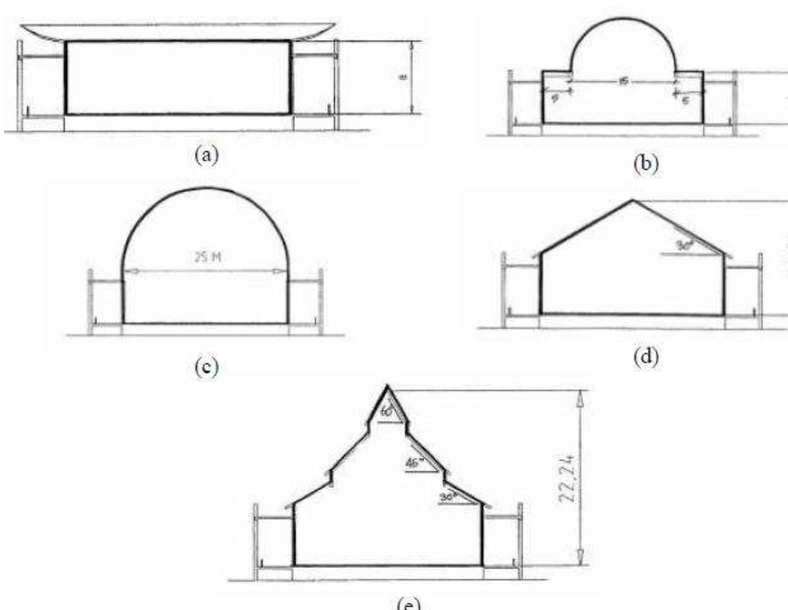
The direct sound should be able to reach the receiver without screening from others

***Mosque in Nordicc Contest by Mehtab Aslam**

The organization of the receivers in a room is related to the position of the sound source. For the receivers to get the right amount of sound they have to be organized in a way where they do not screen for each other. This can be solved be placing the sound source high in the room or creating a surface that is sloping upward for the receivers.

Effect of Ceiling Shape

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



Researxh Paper THE EFFECT OF CEILING SHAPE ON THE ACOUSTICS OF INDONESIAN MOSQUES by Soegijanto (1) ; Henriza

Excerpts from a Research Paper "COMPARISON OF THE ACOUSTICAL PERFORMANCE OF MOSQUE GEOMETRY USING COMPUTER MODEL STUDIES" by Adel A. Abdou King Fahd University of Petroleum and Minerals, Saudi Arabia

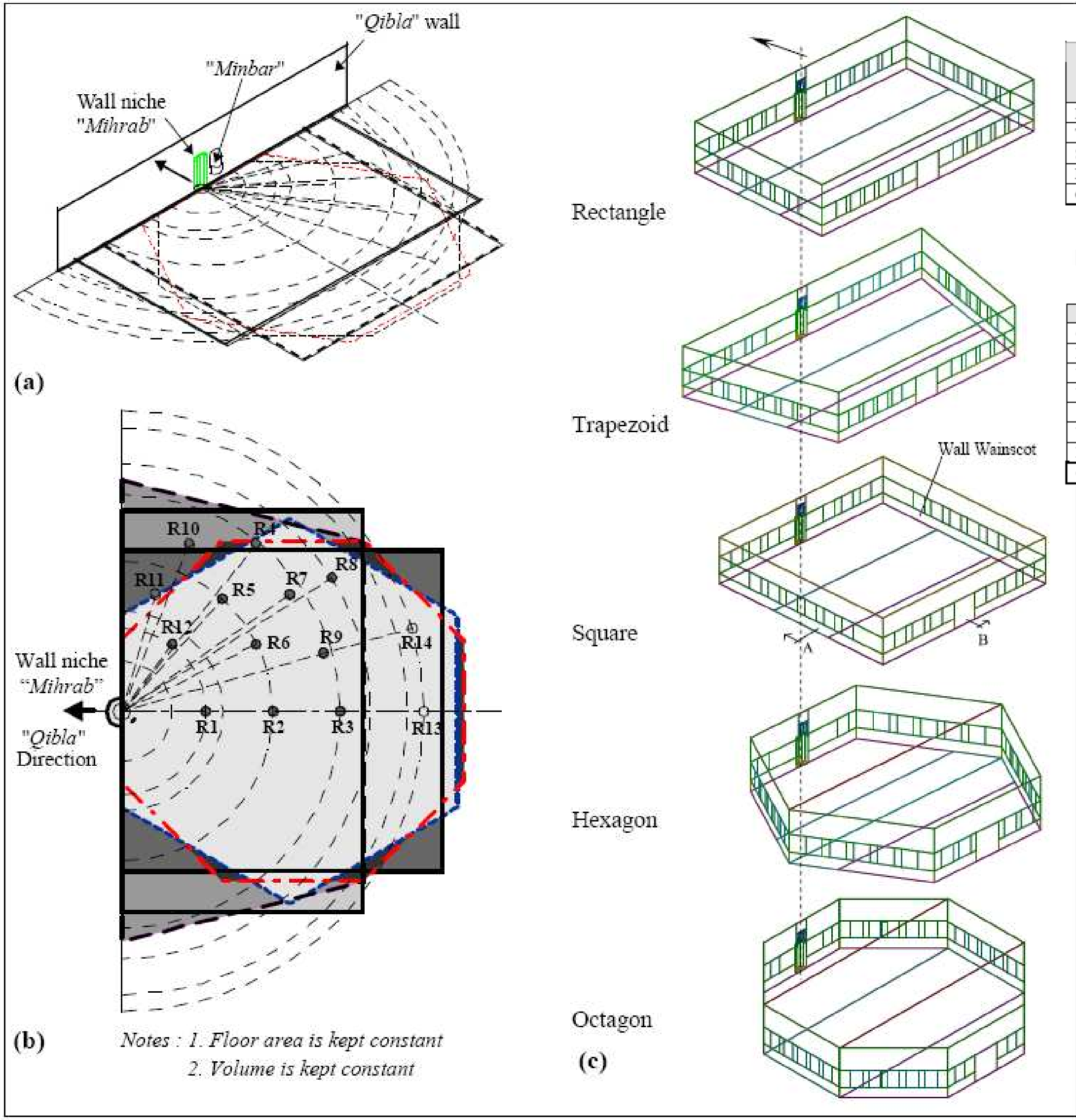


Figure1 (a) The main design elements and features of the mosque prayer hall, (b) The investigated mosque geometry overlaid, and (c) 3D illustrations of the modeled mosque forms.

Geometric information of mosque shapes (note values are rounded to nearest integer)

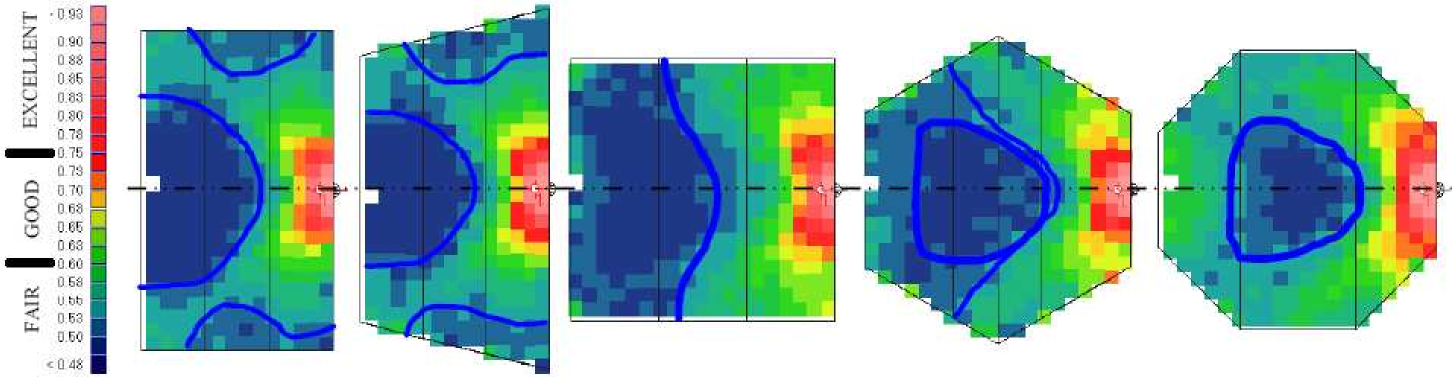
Shape	Dimensions (W, L, H, m)	Floor Area m^2	Volume m^3	Wall Surfaces m^2	Windows		
					Area, m^2	To Wall Area %	To Floor Area %
Rectangular	14.40 x 24.00 x 4.80	346	1659	387	56	14	16
Trapezoidal	14.40 x 27.00 x 4.80	346	1659	373	57	15	16
Square	19.20 x 19.20 x 4.50	369	1659	369	52	14	14
Hexagon	Side = 11.54, H = 4.80	346	1662	332	50	15	14
Octagon	Side = 8.45, H = 4.80	345	1656	325	52	16	15
	Mean	**350.0**	**1659.0**	**357.0**	**53.0**	**15.0 %**	**15.0 %**
	Standard Deviation, STD	±10.0	±2.0	±27	±3	±1	±1

Material assignment for interior surfaces of all mosque configurations

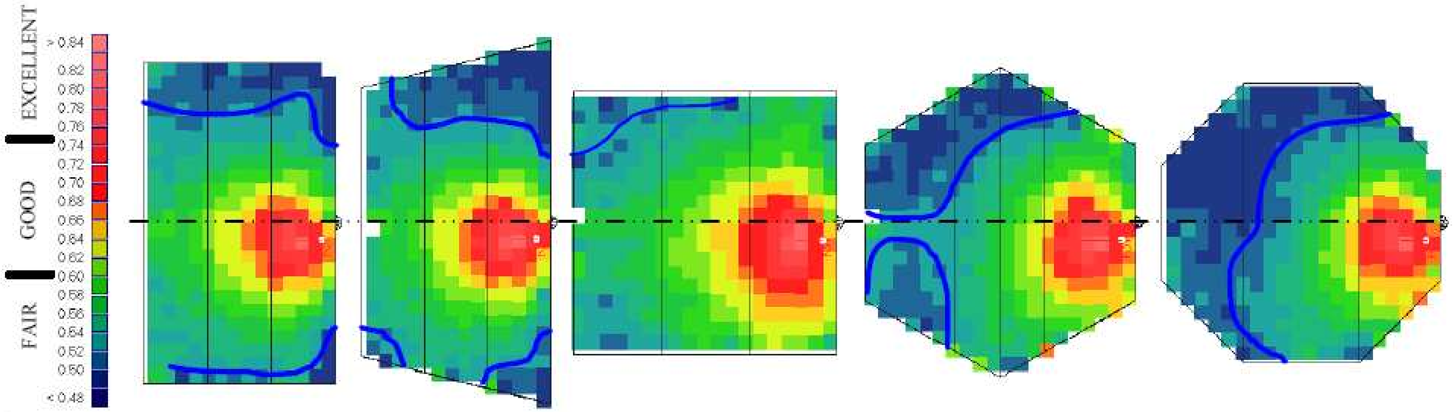
Surface	Assigned Material	Diffusion Coefficient
Ceiling	Lime, cement plaster	0.25, with beams
Floors	9 mm tufted pile carpet on felt underlay	0.15
Walls	Concrete blocks with plaster, painted	0.10
Wall Base (height 1.0 m)	Cladding of marble tiles (see *Figure 1*)	0.10
Qibla wall niche (*Mihrab*)	Ceramic tiles with smooth surface	0.10
Windows	Single pane of glass, 3 mm	0.10
Door	Solid wooden doors	0.10
Congregation (worshippers)	Congregation performing prayers standing in rows 1.20m apart.	0.70

These five shapes were acoustically modeled for comparison. *Figure 1(b,c) shows the architectural* forms and the main features of mosque geometric configurations that were investigated. These prototypes can be considered to be medium-size, community mosques with a mean volume of approximately 1659.0 m3. Since a comparison of the acoustical impact of alternative mosque geometry is the subject of this study, the mosque geometric parameters such as volume, floor area, walls and windows areas and ratios were kept constant for a valid comparison of the impact of the mosque geometry.

Geometry



(a) Performing " *Daily*" group prayers



(b) Listening to "*Friday*" prayer's speech

Figure 3 Spatial distribution patterns of STI assuming a background noise level and spectrum of NC-25. Values are simulated for fully occupied mosques when the worshippers are

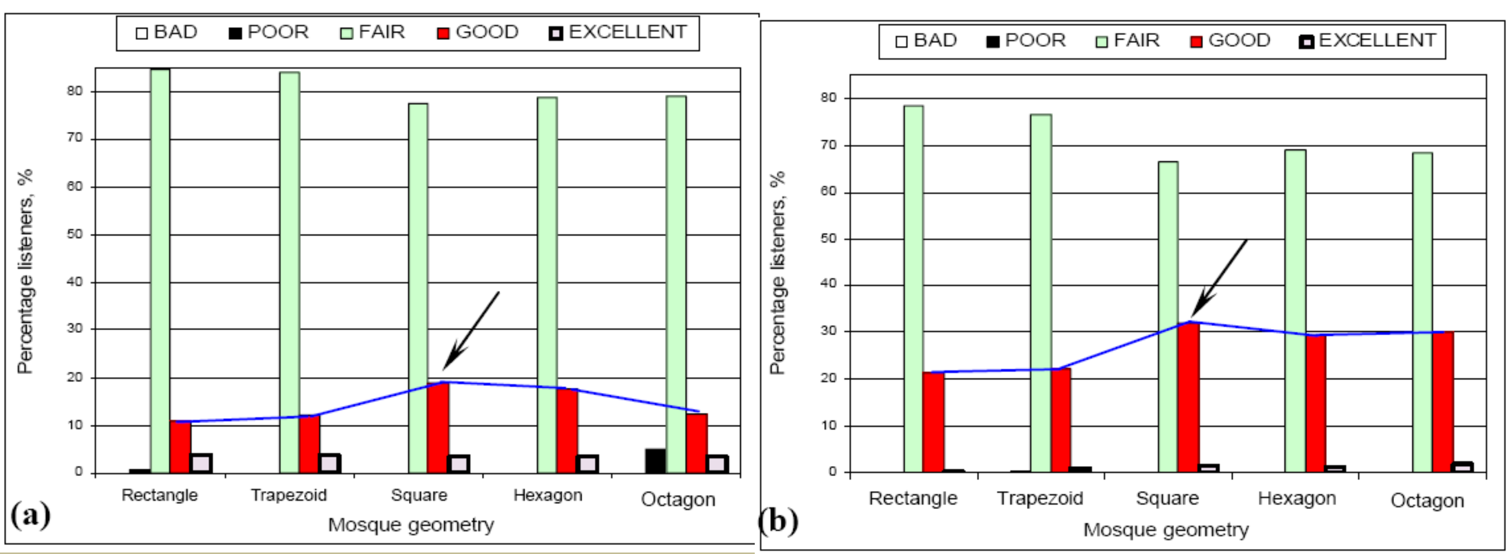
(a) performing daily group prayers, when the Imam is facing the Qibla niche, and

(b) sitting on the floor carpet listening to the Imam

Geometry

	Prayer Mode			Preaching Mode		
	Excellent %	Good %	Fair %	Excellent %	Good %	Fair %
Rectangle	5	10	85	1	22	78
Trapezoid	5	12	85	2	22	76
Square	5	19	78	3	32	67
Hexagone	4	17	79	2	29	69
Octagone	4	12	79	3	30	68

In Order of Preference
Square > Trapezoid > Rectangle > Hexagon > Octagon



*COMPARISON OF THE ACOUSTICAL PERFORMANCE OF MOSQUE GEOMETRY USING COMPUTER MODEL STUDIES by Adel A. Abdou King Fahd University of Petroleum and Minerals, Saudi Arabia

Geometry

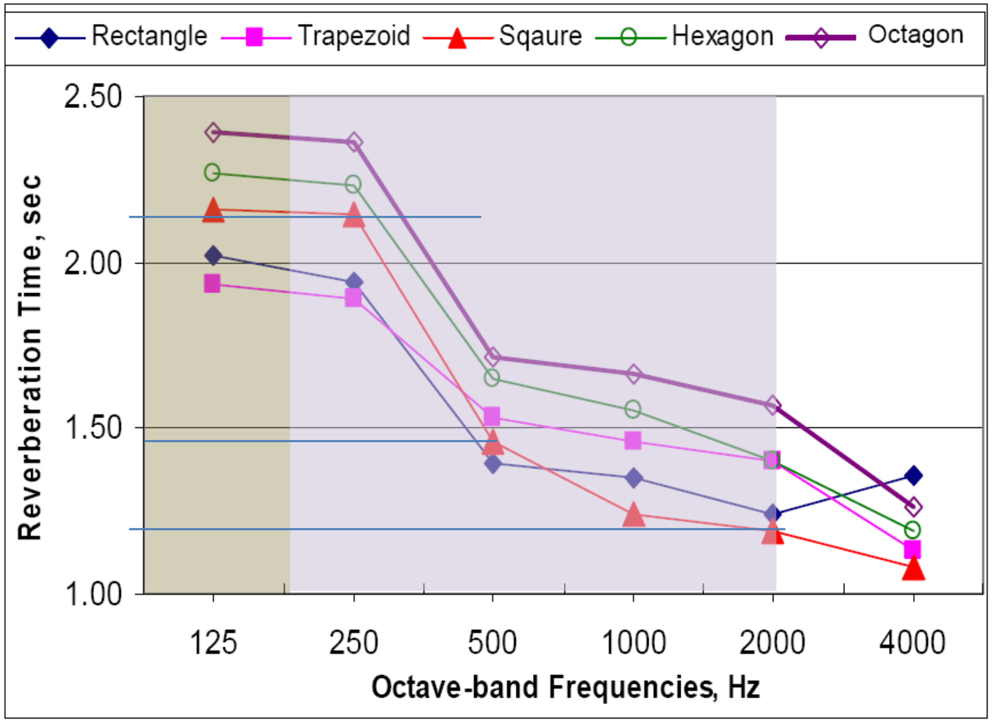
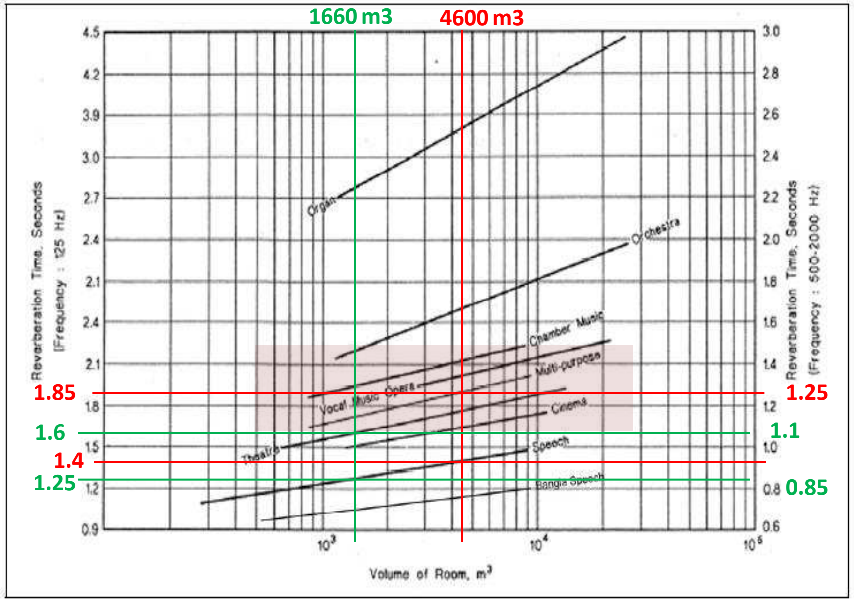


Figure 7 RT spectra in the simulated five mosque geometric configurations

For optimum listening conditions for speech intelligibility RT values must be in the range of 1.2 second at mid-frequencies (i.e., average of RT at 500 and 1000 Hz one-octave bands i.e. RTm). RT value at lower frequencies can be acceptable upto 1.8 second.

For Recitation optimum RT of 0.9 to 1.4 sec is range (500-2000)
At lower frequency 1.5 to 2.0 seconds is acceptable.



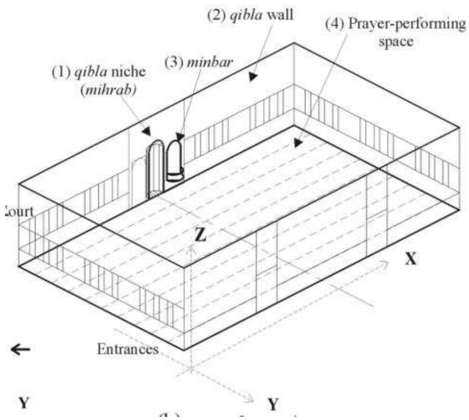
Depicts the global RT spectra obtained from the five mosque models in the case of one-third occupancy, as is usually the case during performing *"Daily" prayers. It* shows similar RT spectra with variable values. The geometry of the octagon mosque resulted in the highest RT values at all octave-band frequencies particularly at low frequencies (i.e., 125-250 Hz). Global RT values in the hexagon became the second highest. This is also expected in round enclosures or cylindrical forms as reflected sound from boundaries add to the reverberant sound fields. The square geometry resulted in the lowest RT values in the mid frequencies range (i.e., 500-2000 Hz) where most of the speech sound energy is dominant.

***COMPARISON OF THE ACOUSTICAL PERFORMANCE OF MOSQUE GEOMETRY USING COMPUTER MODEL STUDIES by** Adel A. Abdou King Fahd University of Petroleum and Minerals, Saudi Arabia

Geometry

Design of Mihrab

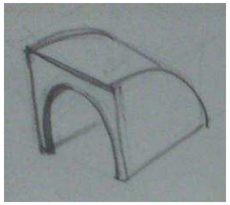
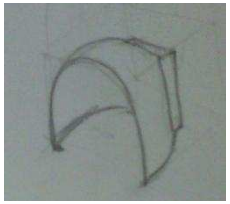
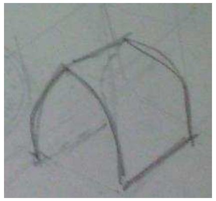
The first Mihrab was *Mihrab Mujawwaf which formed in semi-circular and concaved.*
According to El Gohary (1986), a good curved niche as a Mihrab gives the feeling of being concealed and protected. Those feelings are most conducive to total attention (*khusyu') towards the prayer ; and* achieving *khusyu' in prayer is very much recommended in Islam. Mihrab provides a special place* deserved by the *imam in leading the congregation prayers. Semi circular concave Mihrab was first* designed and built during the Caliphate of al Walid and governorship of Umar bin Abdul Aziz in 706 (Whelan, 1986). Another historical mosque built in the 16th century that employed semi circular concave Mihrab is Babri Mosque in India. According to an architect from the 18th century, Graham Pickford, the projection of voice from the Mihrab is considerably advanced for a 16th century building. He also mentioned when one whispers from the Mihrab, he could be heard clearly at the other end about 60 meters away. The acoustic figure had been studied by modern architects and confirmed that the recess in the wall (Mihrab) functioned as resonator and this helps to disseminate the Imam's voice to the congregation (Abdur Rahman, 1987).
Mihrab today is known as a functional space for *imam and as an orientation device for prayer.*

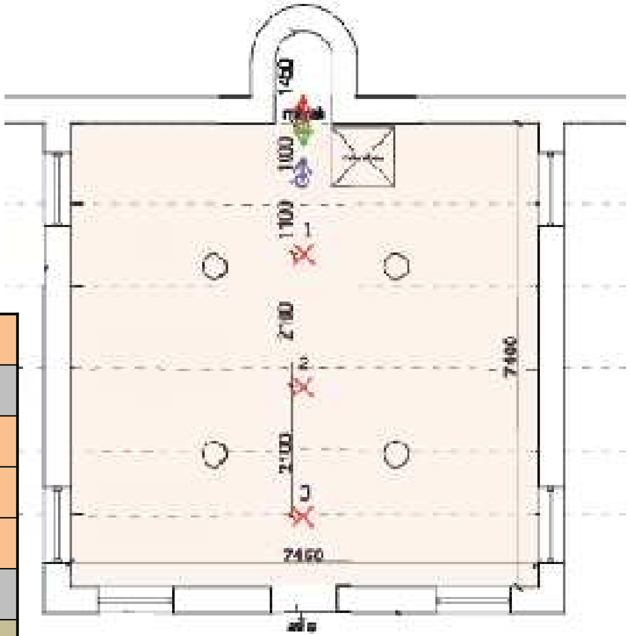


Geometry

Design of Mihrab

Starting SPL - 85

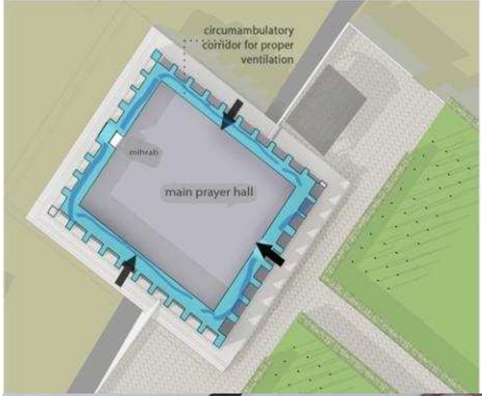


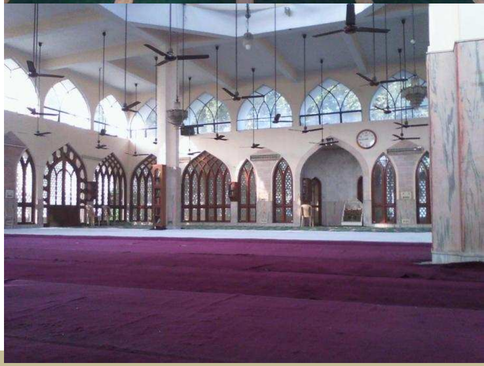
	A		B		C		D	
	SS1	SS2	SS1	SS2	SS1	SS2	SS1	SS2
1	70.9	73.2	77.7	80.7	77.1	75.8	69.8	70.1
2	67	68	74.4	77.4	75.2	72	66.4	67.5
3	65.1	66.4	71.8	71.1	71.4	70.7	65.9	67
Decrease in SPL								
0 to 1	14.1	11.8	7.3	4.3	7.9	9.2	15.2	14.9
1 TO 2	3.9	5.2	3.3	3.3	1.9	3.8	3.4	2.6
2 TO 3	1.9	1.6	2.6	6.3	3.8	1.3	0.5	0.5
1 TO 3	5.8	6.8	5.9	9.6	5.7	5.1	3.9	3.1

SS1 – PRAYER MODE
SS2 – PREACHING MODE

From the results preferred shapes are B or C, as it helps to propagate sound well.
In case of type A sound may be trapped and result in multiple reflections because of an obstructing elements which partly covers the opening of the mihrab.
Beside the geometry internal surface quality is also important as it should be lined with reflective materials for more propagations.

Geometry





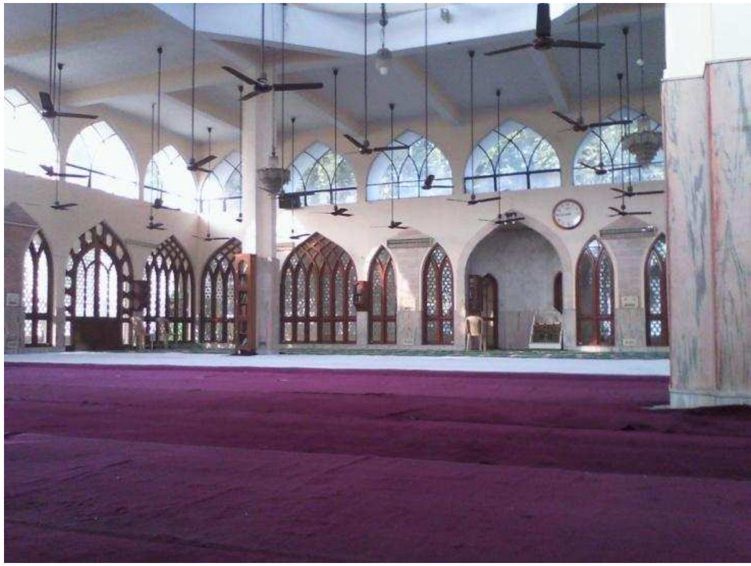
Recommendations:

•Geometry-wise square shape in plan shows better acoustical performance, and forms like octagon, hexagon or circle should be avoided as it yields poor acoustical results.

•As far as the shape of the ceiling is considered a dome like void should be avoided from the inside volume of main prayer hall.

•The design of Mihrab Should incorporate the concave surfaces for well propogation of sound and any obstructing elements that layers its opening edge should be avoided.

Surface Quality: Floor



Floor : Marble Floor but Main prayer Hall Floor has carpet laid over.

Carpet is Highly Absorptive

The value of absorption coefficient of carpets ranges from 0.15(@250Hz) to 0.45(2000Hz).

In addition to this when the space is occupied by devotees, the sound absorption phenomenon is again increased with a certain percentage.

The value of absorption coefficient for adult-male ranges from 0.25 to 0.5 (This value applies for 1 person only in a group of 10 people).

As a result is 0.4 is an average value of absorption by people, the 40% of total sound is absorbed by people first and then from the remaining quantity again 30% (if average absorption coefficient is 0.3 for carpets) is absorbed by carpet, and diffusion will cause its dispersion.
Overall floor gives absorption quality to the acoustics of space.

Absorption Values: http://www.engineeringtoolbox.com/accoustic-sound-absorption-d_68.html

Surface Quality: Walls

Analyzing a typical wall elevation

- 3 different types of opening
- Fixed glazing on upper level
- Marble Cladding up to 1 mts and in opening type 3
- Remaining plastered/painted surface

	nos	Wood Area	Glass Area	Marble Area
Opening 1	4	2.36	7.09	
Opening 2	2	1.2	3.6	4.8
Opening 3	1	3.31	6.152	
Fixed Glass	7		5.076	
Marble Clad Strip	8			0.375

Total plastered area of wall (deducting openings and cladding from total wall elevation surface) = **75.006**

Plastered Surface For all four side walls = 75.006 x 4 = 300.024

	Total Material Areas for 1 wall		
	wood	Glass	Marble
	9.44	28.36	0
	2.4	7.2	9.6
	3.31	6.152	0
	0	35.532	0
	0	0	3
	15.15	**77.244**	**12.6**
For All 4 Side Walls	60.6	308.976	50.4

Absorption Values: http://www.engineeringtoolbox.com/accoustic-sound-absorption-d_68.html

Surface Quality: Ceiling

The Surface quality of Ceiling shows plastered - painted surface with grid of beams , and a dome. There are few small opening in dome .

Total Flat Ceiling Area	**465.12**
Dome Internal Surface Area	**163.34**
Total Ceiling Area	**628.46**

For Calculation purpose a beamless ceiling area is considered (ignoring beams and small openings in dome), so the thing to be kept in mind is that considering these elements will ultimately give an increased value of reverberation.
Again an increased factor has to be considered for geometry of dome.

Absorption Values: http://www.engineeringtoolbox.com/accoustic-sound-absorption-d_68.html

Surface Quality

Material	Area	abs co-eff (starting range)	abs co-eff (terminal range)	Avg Abs Co-eff	Absorption Power (Area x Abs coeff)
Plastered	300.024	0.01	0.05	0.03	9.00072
Polished Wood	60.6	0.1	0.04	0.07	4.242
Glass	308.976	0.06	0.02	0.04	12.35904
Marble	50.4	0.01	0.02	0.015	0.756
Plastered (Ceiling)	628.46	0.01	0.05	0.03	18.8538
Carpet Floor	576	0.15	0.45	0.3	172.8
people(150X1.4)	210	0.25	0.5	0.375	78.75
					296.76156

150 Nos of people are considered for calculation which is for starting five rows of devotees (that represents average no. of devotees for daily prayers) and 1.4 sq.mt of surface area of human body in standing position.

Sabine's formula

T = 0.16 V / A

where T is the reverberation time, V is the volume of the room and A= total absorbing power

V- Volume = (24 x 24 x 7.5) + (2/3 x ∏ x (5.1)3)

A- Absorption power = 296.76

T= 0.16 x (4597) / 296.76

T = 2.47 Seconds

Absorption Values: http://www.engineeringtoolbox.com/accoustic-sound-absorption-d_68.html

Surface Quality

From Sabine's Formula we found

T = 2.47 Seconds

Factors that will add up to more reverberance.

- Dome shape of ceiling (Geometry)
- Beams Projection in Flat ceiling area
- Surface area of Columns that are cladded with marble upto 2.1 mts height.
- Jambs of Arch openings.
- Furniture elements kept inside.
- Decorative elements like chandeliers hanging
- Surface Area of Appliances like Fans, Lights, Coolers

Factors that will help to reduce reverberance.

- Curtains laid at three entry Arch openings.
- Increased no. of people offering prayer

Overall Effect

- The overall effect considering above will ultimately give some rise in reverberation time than whatever is calculated (2.47 seconds)

Surface Quality

The resultant reverberation time is anyhow more than **2.47** Seconds.

The Range required for optimum reverberation time for a volume of about 4500 cubic meter is

1.25 seconds
(for recitation where frequency range 500-2000 Hz)

To

1.4 seconds
(for preaching/speech where frequency range is 100-155 Hz)

Sabine's formula

For T = 1.4 seconds

T = 0.16 V / A

V- Volume	= (24 x 24 x 7.5) + (2/3 x ∏ x (5.1)з)
A- Absorption power	= A

1.4 = 0.16 x (4597) / A

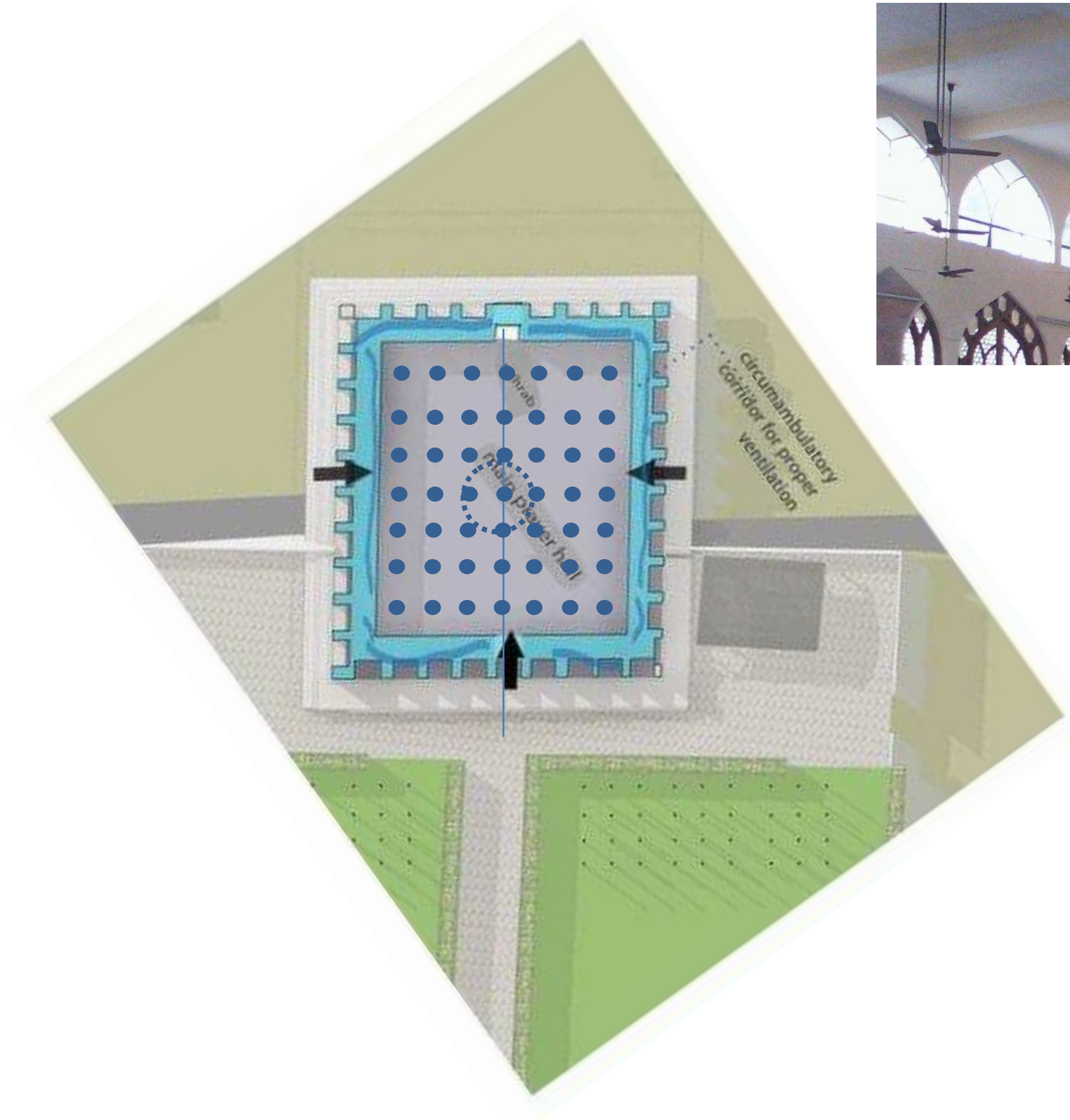
A = 525

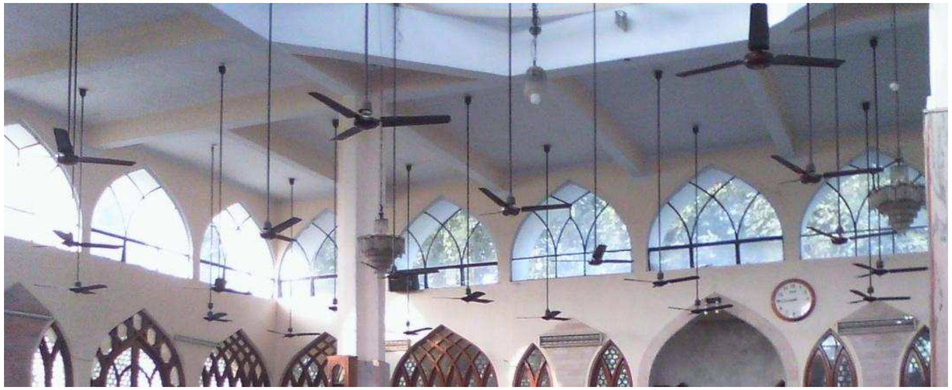
Deduction of available absorption power = 525 – 297 = 228

Recommendation: An equal area of whatever is existing absorbing surfaces is required to be added to achieve optimum reverberation time.

Appliances

Behavior of Sound according to Appliances





A large number (49 nos) of Ceiling Fans are hanging from ceilings.
Average noise rating of an average quality of fan is about 5-6 decibels.

For Collective noise created by All the fans:

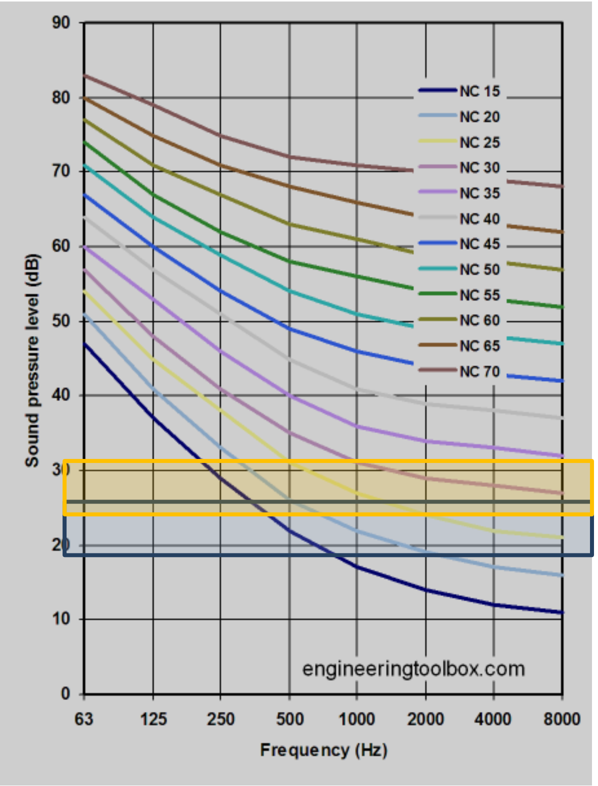
Decibels are logarithmic "units", they may not be added linearly like other figures.
considering all fans of as equal noisy sources

Total noise = Noise of 1 fan + 10log 48 (no. of fans)

= 5 + 10 1.68

= 21 dB

Appliances



Indoor noise is found due to Fans is 21 decibels.
Since Fans are hanged via too long rods 3.5mts, it will again increase noise due to vibration.

Again 16 nos of Desert Coolers are placed in the circulation passage all around, it adds up to a lot of noise.
So the actually noise level found in the space would be much above 21 dB.

Recommended Indoor noise level rating for mosque is NC 20 and NC 25.
According to which range of noise levels at mid frequencies (500-2000) should be less than 19 decibels.

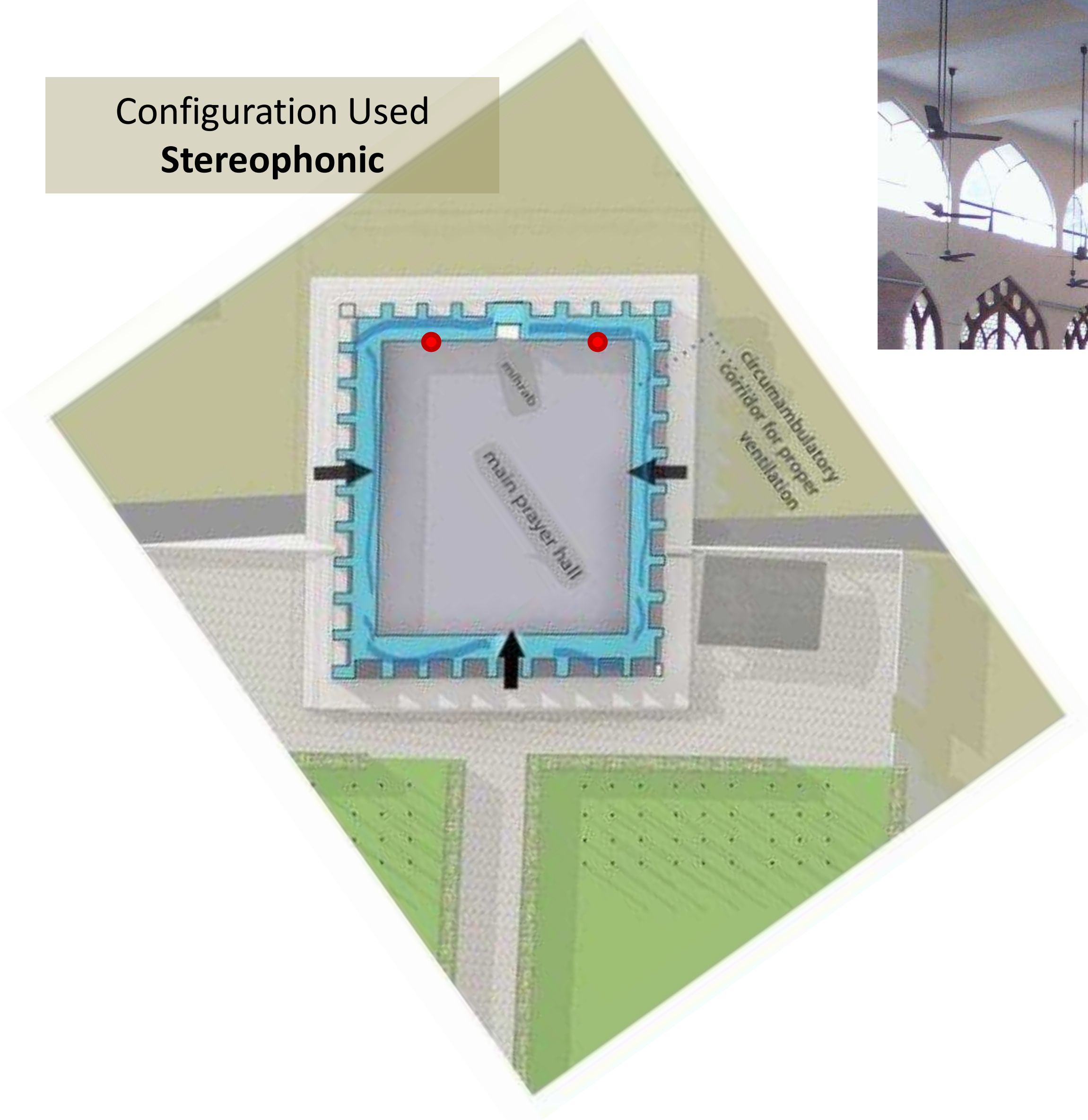
Recommendations:

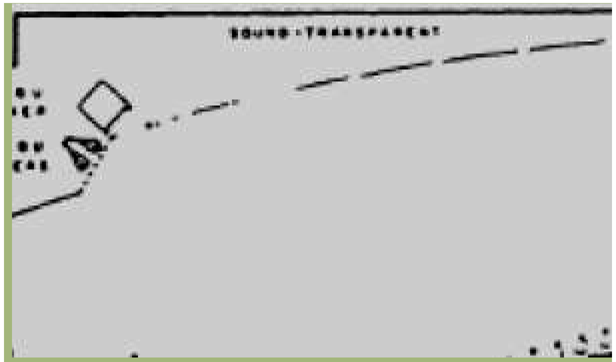
- **Regular Maintenance of Mechanical ventilations Equipments that includes cleaning, tightening of screws and checking blade balance.**
- **Stand provided for Desert Coolers may be equipped with Vibration absorbing Bases so as to reduce the noise.**
- **Using equipment with low noise rating**
- **Installing systems which has noise producing appliances kept outside and provide air inside via ducts etc.**

Noise NC Graph: http://www.engineeringtoolbox.com/nc-noise-criterion-d_725.html

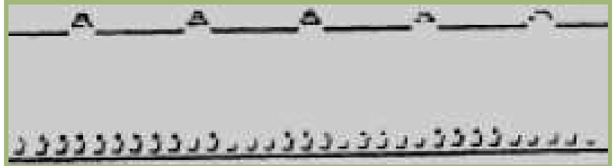
Sound Enhancement

Configuration Used
Stereophonic





Central & Stereophonic

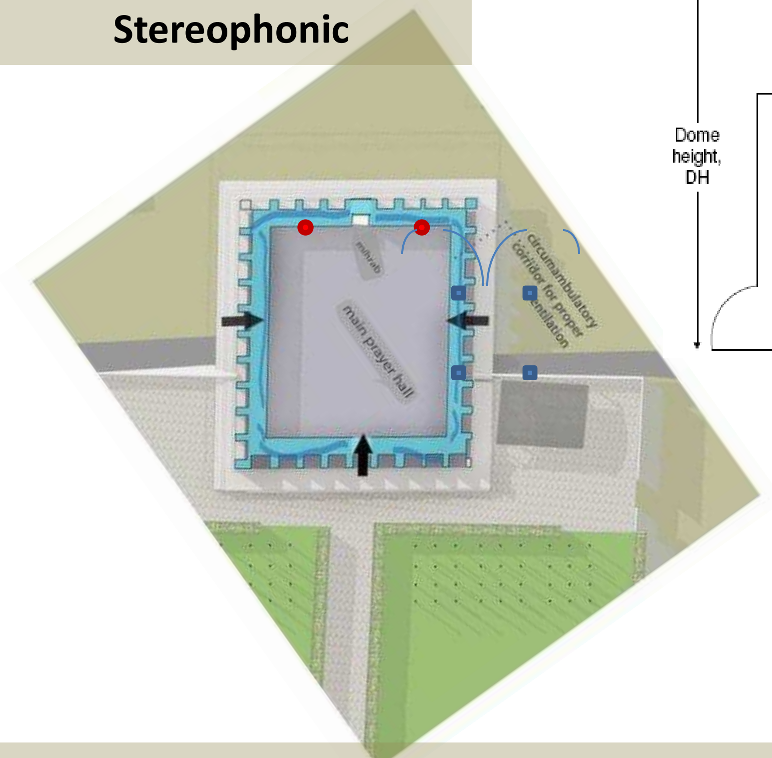


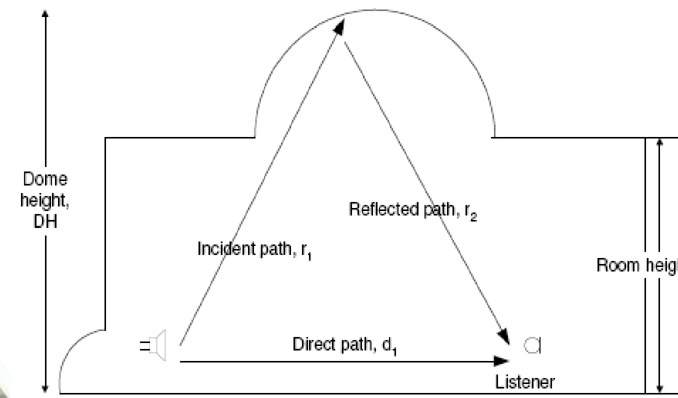
Distributed

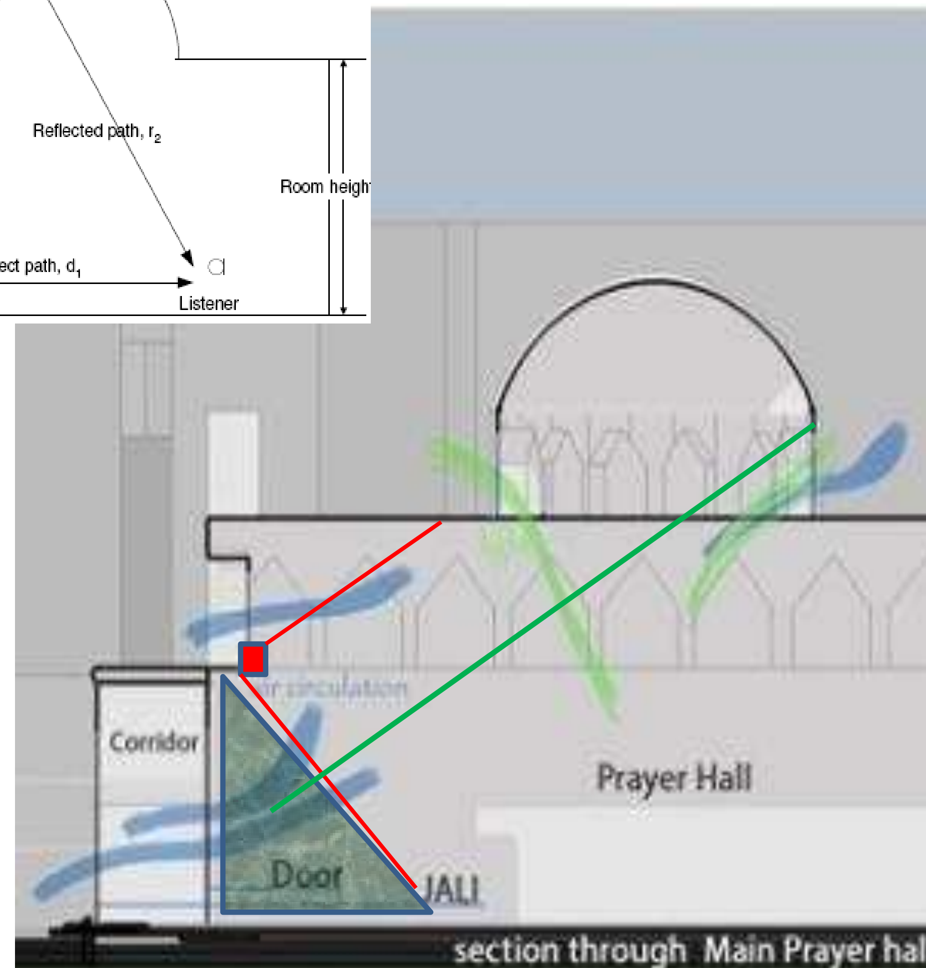
Types

Sound Enhancement

Configuration Used
Stereophonic







Horizontally mounted in stereophonic arrangement
Emits a lot of sound upward cause echo due to delayed reflections and sound foci under dome
Lack of direct sound just under the speakers (delayed reflections and unamplified sound)
Sound shadow due to columns
Difference in amplitude at different locations

Sound Enhancement

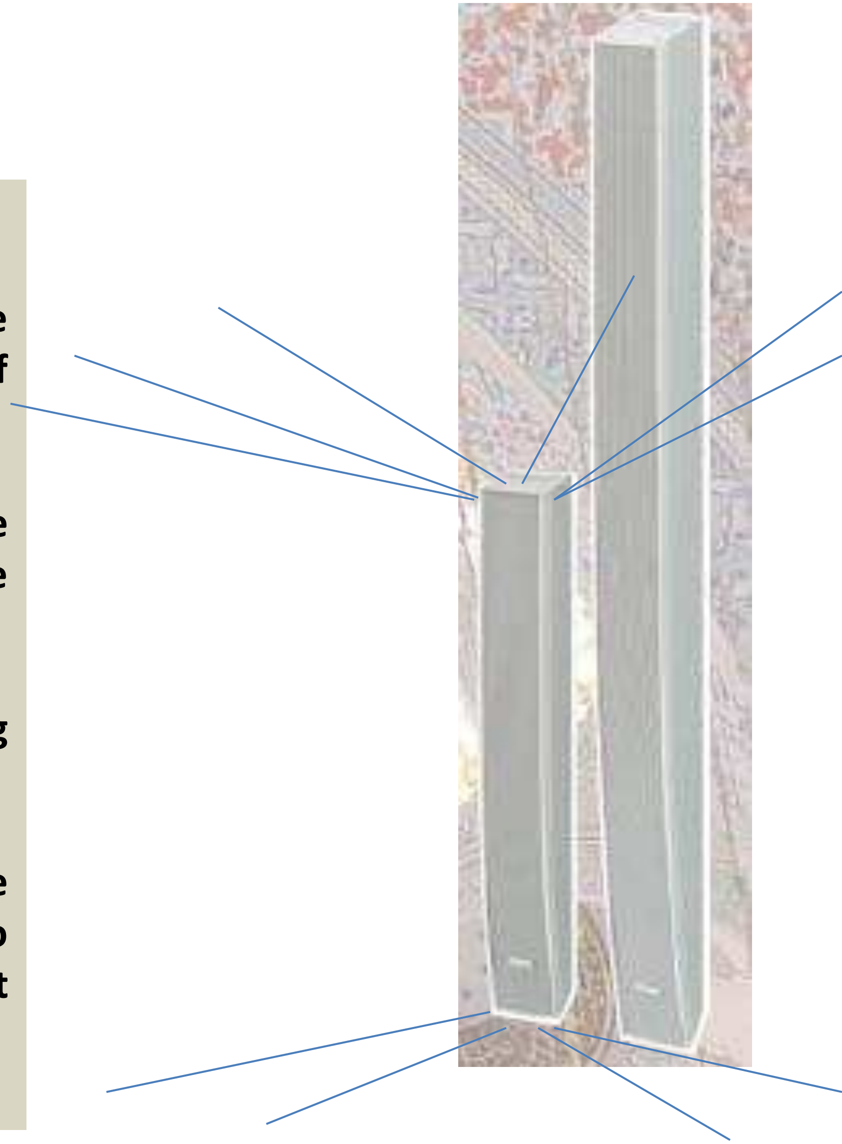
Recommendations:

Speakers vertically elongated are should be preferred as these have more horizontal spread of sound rather than vertical

Array / Distributed System of loudspeaker to be followed for even sound power through out the mosque.

A well distributed array should be designed (paying attention to thirsty areas)

In an array system if the area is too large then there might be delay in sound so a delayed mechanism to be adopted (property of amplifier), delay should not go beyond 1/30th of second



Conclusion

In this work, the acoustic environment of contemporary mosques was discussed. As with acoustics, technical data has been used from various researches and studies already done. The common types of mosque designs (local mosques) were discussed and analyzed.

Behavior of four basic parameters was evaluated through studies and observations: these parameters are Geometry, Internal Surface Quality, Presence of Mechanical Appliances and Sound Enhancement system.

In first study analysis shoes Geometries like square, rectangle and trapezoidal proves to be better in fair sound distribution, while forms like hexagon and octagon yields bad sonic environment.

Regarding Surface Quality beside this study it is a general observation that mosques are not acoustically treated and a lot of reverberance is there due to a large number of reflective surfaces, and domed ceilings, which is needed to be improved.

Mechanical appliances mainly ceiling fans and other Cooling equipments should also be considered to be of low noise rating and necessary measures to be taken to suppress its noise. As far as sound systems are considered in a mosque, it should be installed after consulting sound engineers, to have an optimum output. Array of speakers with proper directionality should be used.

This report concludes general guiding principles based on studies and observations, a further investigation has to be done for accurate and technically enhanced results.