The acoustical performance of mosques main prayer hall geometry in the eastern province, Saudi arabia

Hany Hossam Eldien, Hani Al Qahtani

ACOUSTICS 2012

The acoustical performance of mosques' main prayer hall geometry in the eastern province, Saudi arabia

H. Hossam Eldien and H. Al Qahtani

Dammam Univ., P O Box 2397, 31451 Dammam, Saudi Arabia
hany.hossam@gmail.com

Abstract

The study of mosque acoustics, with regard to acoustical characteristics, sound quality for speech intelligibility, and other applicable acoustic criteria, has been largely neglected. In this study we discuss how mosque design is influenced by worship considerations. In this study the acoustical characteristics of typically constructed contemporary mosques without domes in Saudi Arabia had been investigated. Extensive field measurements had been taken in varies representative mosques of different forms and architectural features in order to characterize their acoustical quality and to identify the impact of its prayer hall form on their acoustics performance. Objective room-acoustic indicators such as reverberation time (RT) and the early decay time (EDT) have been tested. The speech transmission index (STI) had been measured without the operation of existing sound reinforcement systems. The results will show the acoustical quality in the investigated mosques, unoccupied case.

1 Introduction

The mosque as an important building type of Muslim architecture has evolved to meet Islamic needs. A variety of different worship activities happen within these multifunctional public spaces; these different uses have different acoustical requirements. As in many other religions, worshippers sometimes need solitude while at other times they want to feel in absolute unity with the others present. Acoustics are one of the basic means of creating different effects [1]. The architect Sinan's mosques have been studied in a European Commission Fifth Framework INCO-MED Program called "Conservation of the Acoustical Heritage by Revival and Identification of Sinan's Mosques' Acoustics (CAHRISMA) [2]. The goal of this project is the identification, revival and conservation of Hybrid Architectural Heritage (visual + acoustical heritages) in a real-time virtual environment. Sinan.s Mosques and Byzantine Churches, which are worship spaces well known for their good acoustical qualities, are chosen as the building types to be utilised for the realisation of that goal [2].

Fausti, Pompoli and Prodi compared the acoustics of mosques and churches [3]. They found that reverberation time, in the unoccupied condition, is very long, giving them a unique feeling of majesty. In another study, Karabiber and Erdogan [4] compared the ancient mosque of Kadırga Sokullu Mehmet Pasa with a recent one, Sisli Merkez. They concluded that although there was no great difference between the total sound absorption of the spaces, the acoustics in the ancient mosque was better. Sinan's important mosques have been analyzed in other studies besides the CAHRISMA project (Kayili, 2002; Topaktas, 2003). Kayili (2000) [5,6].

The Architectural works of Sinan are among the most successful applications of acoustic science. Sinan designed a total space for the interior of the mosque, not divided into spaces and reduced to the size of room. The interior volume of the Selimiye Mosque is approximately 75,000 m3 and, naturally, it is evident that the problem of the power of the sound source will arise. To overcome this problem, Sinan placed the muezzin's mahfil exactly in the centre of the total space. The dome and also cavity resonators are directly above the sound source [7].

The acoustical quality of the mosques has also been discussed in the literature [1-8]. Mosque design is mainly influenced by worship considerations; three distinct activities are carried out in a mosque, either separately or together:

- One is prayers, either individually or in a group led by a leader, the Imam.
- The second is attendance at a sermon being delivered on its own or within the Friday noon prayers.
- The third is listening to or reciting some verses from the Holy Quran.

All these activities require a high level of speech audibility and intelligibility. To ensure good listening conditions acoustical needs must be considered in the design phase [8].

In summary, there are three distinct acoustical requirements for mosques:

- Audibility of the prayer orders of the Imam (prayer leader)
- Recognizable sermon of the preacher
- Listening to or joining in the recital of the musical versions of the Holy Quran.

Thus, intelligibility of both speech and other sounds is extremely important, especially important for holy tones that must be both spacious and effective. Several acoustical parameters govern speech audibility, intelligibility and spaciousness of sound; the parameters usually employed in the acoustical analysis of mosques are reverberation time, sound pressure level distribution and sound transmission index.

In this study, two types of Mosques will be chosen as an example of the architectural style concrete mosques to investigate this specific condition and its outcome in mosque acoustics. In order to clarify of the manner, the purpose of this study is also to evaluate and predict the acoustical quality of Mosques prayer halls by assessing these parameters as major variables. This paper focuses on the acoustical effect of the architectural configuration of prayer halls mosque in relation to mosques and in particular: a case study of 2 types of mosques in Eastern Province, Saudi Arabia. It explores the acoustical impact of its principal form with various shapes and configurations.

1.1 Worship Considerations and Their Influence on Spatial Arrangement

The distinct worship activities inside mosques include prayer, public speaking, preaching, lecturing, and *Qur'an* recitations. The activities are performed by people either individually or in conjunction with others. The activities may be categorized into one of two primary worship modes: prayer mode or preaching mode. In prayer mode, all mosque users are either standing, bowing, or prostrating, always on the same floor level, and aligned in rows parallel to the *Qibla'* wall (front wall), with the *imam* (speaker) facing away from listeners. In preaching mode, the listeners are sitting on the floor in rows parallel to the Qibla' wall, while the imam is standing on a four-step high platform (*minbar*) facing the listeners. The worship activities generally require adequate speech audibility and intelligibility. The leader or imam generally stands in front of the gathering, near the *mihrab*, a distinct area provided for him. General mosque orientation is based on the position of the mihrab, which is intended to face the Qibla' (a cubical building at Mecca, Saudi Arabia). Prayer from the imam is to address the gathering from his position. For certain prayers such as *Jumma* (Friday) prayers, the imam addresses the gathering with preaching, or *khutba*, from the minbar, which in general is considered to be high enough for the gathering's visibility (see Figure1).

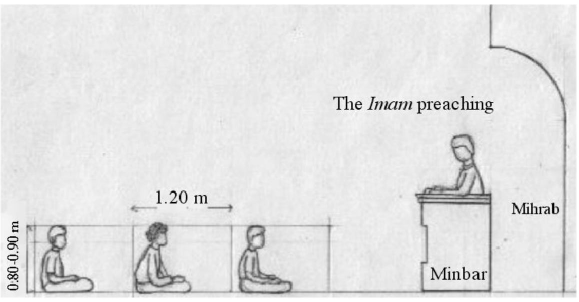


Figure 1. Preaching inside the prayer hall.

The congregational capacity of the mosque is usually determined by the floor area divided by the area required per worshipper to perform various prayers motions. This is approximately 0.80 x 1.2 = 0.96 m^2 (Figure 2).

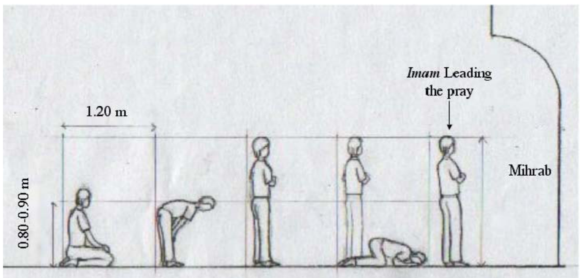


Figure 2. Praying inside the prayer hall, the imam is leading the prayer followed by the worshippers.

Most parts of the interior of mosques are intended to be finished with acoustically reflective materials such as painted plaster and tile (both marble and ceramic). However, the floor area was to be covered with heavy carpet. The ceilings, including the dome, will be finished with painted plaster and ornamentation. Arches made from concrete and finished with painted plaster will be used as joint elements between the columns to strengthen the construction and to provide interior decorative elements.

1.2 Prayer hall

The prayer hall, also known as the Musalla, rarely has furniture; chairs and pews are generally absent from the prayer hall so as to allow as many worshipers as possible to line the room. Some mosques have Arabic calligraphy and Qur'anic verses on the walls to assist worshippers in focusing on the beauty of Islam and its holiest book, the Qur'an, as well as for decoration. Usually opposite the entrance to the prayer hall is the qiblah wall, the visually emphasized area inside the prayer hall. The qiblah wall should, in a properly oriented mosque, be set perpendicular to a line leading to Mecca, the location of the Kaaba. Congregants pray in rows parallel to the qiblah wall and thus arrange themselves so they face Mecca. In the qiblah wall, usually at its center, is the mihrab, a niche or depression indicating the direction of Mecca. Usually the mihrab is not occupied by furniture either. Sometimes, especially during Friday prayers, a raised minbar or pulpit is located to the side of the mihrab for a khatib or some other speaker to offer a sermon (khutbah). The mihrab serves as the location where the imam leads the five daily prayers on a regular basis. Most of mosques have typically a simple rectangular form, walled enclosure with a roofed prayer-hall. The long side of the rectangle is always oriented towards the holy mosque in Makka and to its right an elevated floor (Minbar) is used by the Imam to deliver the religious "Friday" speech preceding the prayers. Figure3 illustrates the congregation performing daily individual or group prayers and congregation listening to Friday speech. Interior finishing materials of mosques are varying from one country to another. However, mosque walls are commonly finished with painted plaster. Wall wainscots are sometimes covered with marble tiles or wooden boards or panels tongued and grooved to compose a vertical pattern. The floor area is always carpeted. Plastered and painted concrete ceilings with simple to elaborate decorations and /or inscriptions are commonly used. Depending on the climatic conditions, the mosque may be equipped with an air conditioning system, in concert with some ceiling fans.

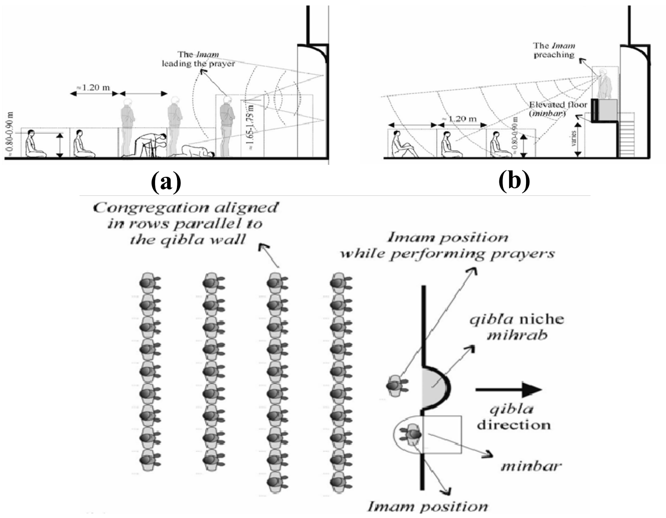


Figure 3. a) congregation performing daily individual or group prayers, b) congregation listening to Friday speech.

2 Methodology

Group prayer must be performed with individuals standing, behind the Imam, in straight rows around 1.2 m apart and parallel to the Qibla wall. Consequently, it is desired that the mosque shape be bounded by straight parallel walls, one of which includes the Qibla niche.

Religious preference is higher for those praying in the first rows compared to late arriving individuals. Hence first rows are preferred to be longer or at least equal to the subsequent remaining ones. Majority of mosques in eastern province have rectangular 1:2 and square plans with a long side perpendicular to the direction of the Qibla. These two forms were acoustically studied. These prototypes can be considered to be medium-size, community mosques with a prayer hall plan of approximately 1600.0 m2 and 4.00 clear heights and without a dome. Table 1 presents the prayer halls geometric information of the proposed mosques. Table 2 shows the intern finishing materials of the selected mosques

Table 1. Geometric information of mosque shapes

Mosque Form	Dimensions W, L, H	Floor Area m^2	Volume m^3
Rectangular 1:2	14.15 x 28.30 x 4.00	400.44	1601.76
Square	20.00 x 20.00 x 4.00	400.00	1600.00

Two different worship scenarios were examined by the experimentation. In the first scenario the congregation (worshippers) is performing the prayer behind the Imam who is reciting in a standing position facing the Qibla niche using his raised voice. It is natural that persons delivering speech without the aid of Electro-acoustic sound system tend to raise their voice.

Table 2. The intern finishing materials of the selected mosques.

Surface	Material
walls 1m &Mihrab	Cladding of Marble Tiles
Walls	Painted plaster surfaces on brick
Floor	Carpet heavy on concrete
corridors	Marble

The background noise in the mosques is measured. The worshippers are assumed to be also standing listening to the Imam as is usually the case during performing the “Daily” prayers. Their ear height is taken to be 1.65 m from the floor. In the second scenario, the Imam is assumed to be delivering the Friday speech in a raised voice, without the aid of sound reinforcement system, from the Minbar which is elevated about 1.25 meter from the mosque floor. His mouth height is around 2.80 m from the floor. The worshippers are assumed to be seated on the floor listening to the speech as is usually the case during Friday prayer. Their ear height is taken to be 0.80 m from the floor. Measurements had been realized when the mosque is assumed empty. Figures 4 demonstrates the positions of Sources and receiver points for all configurations (44 receiver points for the rectangle form and 49 receiver points for square form).

The reverberation time of the mosque had been measured using B&K building acoustic analyzer type 2250, a B&K power amplifier type 2716, a reference Omni Power Sound Source Types 4292 and ½ inch B&K microphone type 4134. Measurements had been carried out, in octave bands, for the frequency range 100Hz to 8 kHz. Measurements of the STI had been performed using B&K speech transmission meter type 3361. The transmitter type 4225 had been located at the position of Imam on the Minber, while the receiver type 4419 had been moved around, following the prearranged grid points.

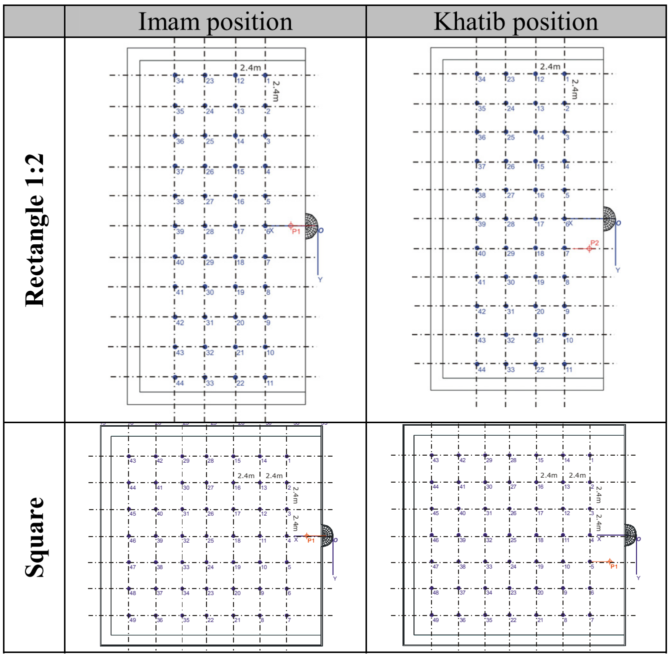
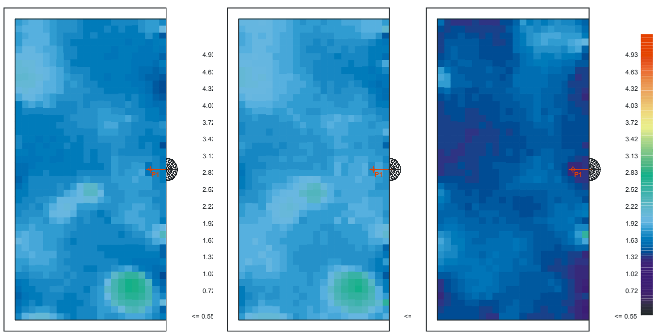


Figure 4. Source and receiver points for 1:2 rectangle and square forms.

3 Results and Discussion

3.1 Triangular form 1:2

Firstly we discuss the results obtained by the 1st scenario (Imam Position). For the given mosque volume (1600.0 m3) the optimum RT_m value for speech purposes should be in the range from 0.6 to 1.9 [9]. The reverberation times are presented in figure 5 as contour maps and in figure 6 as a function of worshipper’s rows. Taking into account the the RT_{30} optimum levels for mosques of these size, which are between 0,60s and 1,90s seconds, we found that all receiver points have long RT_{30} and especially at low frequencies. RT values ranges from 2.15s to 2.35s at 1kHz. Furthermore, the receiver points at the right side of the mosque have long RT_{30} than those located at the left side.



(a) 500 Hz (b) 1000Hz (c) 2000Hz

Figure 5. RT for the 1:2 rectangular mosque geometry, when the mosque is assumed empty, a: at 500Hz, b: at 1kHz, and c: at 2kHz (Imam position).

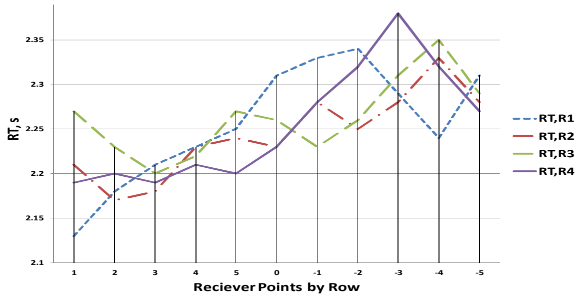
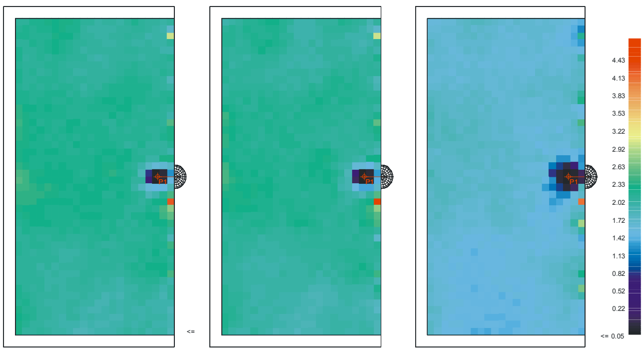


Figure 6. RT for the 1:2 rectangular mosque geometry at 1kHz as a function of worshippers rows (Imam position).

For our proposed mosques, EDT should be between 2.7s and 3.85s [9].Early decay time is measured keeping the same source and receiver positions where RT measurements are realised. Figures 7 and 8 demonstrate that the value of early decay time obtained by this type ranges from 1.8s to 2.2s. These values are near to RT values and are shorter than the optimum value, and for all receiver points.



(a) 500 Hz (b) 1000Hz (c) 2000Hz

Figure 7. EDT for the 1:2 rectangular mosque geometry when the mosque is assumed empty, a: at 500Hz, b: at 1kHz, and c: at 2kHz (Imam position).

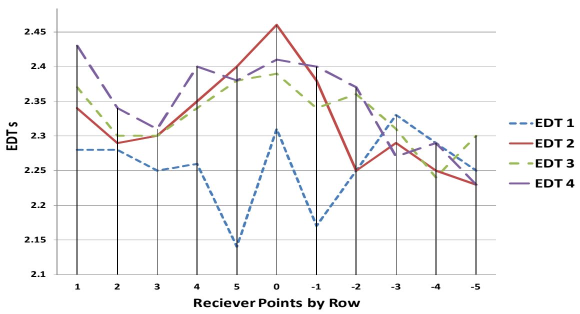


Figure 8. EDT for the 1:2 rectangular mosque geometry at 1kHz as a function of worshippers rows (Imam position).

Speech Transmission Index (STI) is directly related to speech. To ensure good speech intelligibility, the envelope of the signal should be preserved, allowing the various frequency bands to contribute to speech quality. Speech Transmission Index (STI) for the 1:2 rectangular mosque geometry as a function of worshippers rows is presented in figure 9. For the first activity mode, STI is around 0.40, which is considered poor. The best values have been found at locations just around the source or imam and at the 1st row.

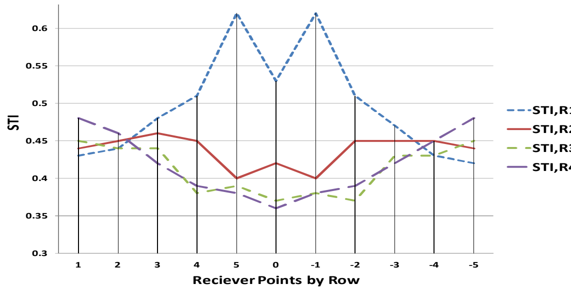
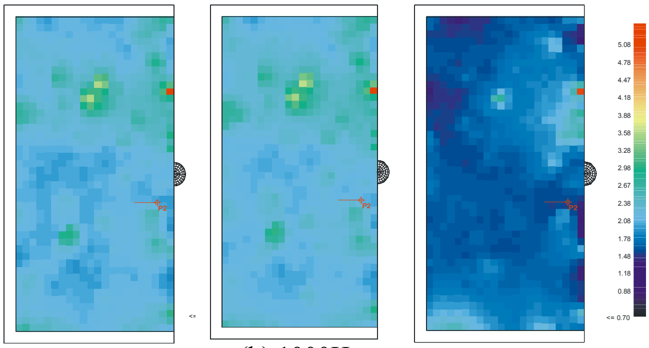


Figure 9. STI for the 1:2 rectangular mosque geometry as a function of worshippers' rows (Imam position).

Secondly we discuss the results obtained by the 2nd scenario (Khatib Position). For the khatib position, figure 10 shows the reverberation times as contour maps for 3 frequencies and in figure 11 presents the results obtained at 1kHz and as a function of worshipper's rows. We found that all receiver points have approximately the same RT's values at 1kHz and near to the optimum values.



(a) 500 Hz (b) 1000Hz (c) 2000Hz

Figure 10. RT for the 1:2 rectangular mosque geometry at; a: at 500Hz, b: at 1kHz, and c: at 2kHz (Khatib position).

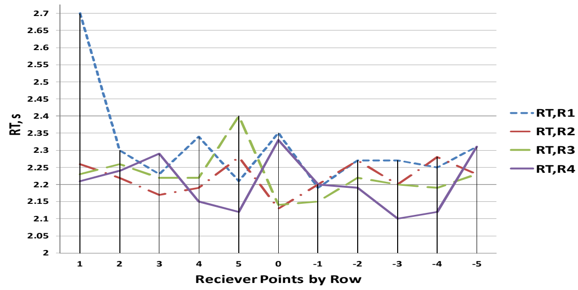
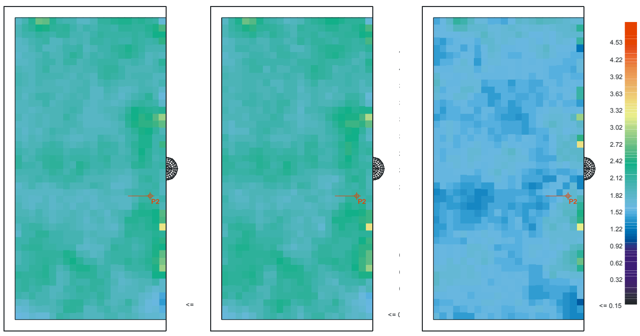


Figure 11. RT for the 1:2 rectangular mosque geometry at 1kHz as a function of worshippers rows (Khatib position).

Figures 12 and 13 demonstrate that the value of early decay time obtained at khatib position ranges from 2.1s to 2.5s. This value is near to the optimum value. This is due to the effect of marble walls at receiver points.



(a) 500 Hz (b) 1000Hz (c) 2000Hz

Figure 12. EDT for the 1:2 rectangular mosque geometry; a: at 500Hz, b: at 1kHz, and c: at 2kHz (Khatib position).

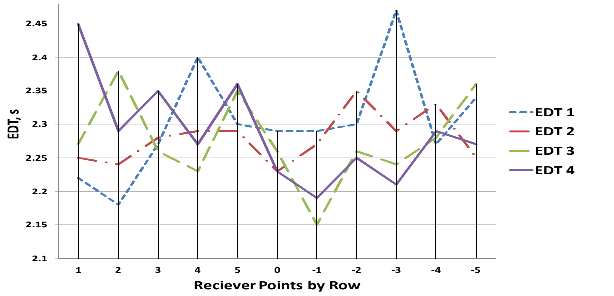


Figure 13. EDT for the 1:2 rectangular mosque geometry at 1kHz as a function of worshippers rows (Khatib position).

Speech Transmission Index for the 1:2 rectangular mosque geometry as a function of worshippers rows and at the Khatib position is presented in figure 14. For the 2nd activity mode, we found that STI is around 0.40, which is considered poor. Increasing the distance from the source the decreasing the STI values. The best values have been found at locations just around the source or khatib and at the 1st row where we obtained the max. value, STI equal to 0.60.

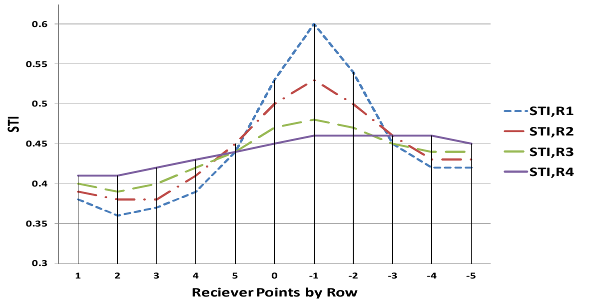
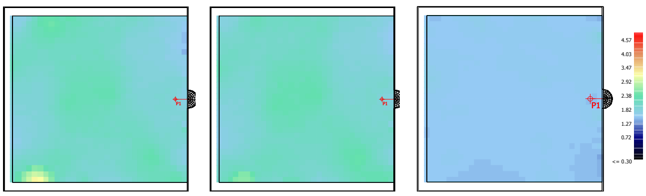


Figure 14. STI for the 1:2 rectangular mosque geometry as a function of worshippers rows (Khatib position).

3.2 Square form

For the 1st scenario, as shown in figure 15 presents reverberation time obtained by 49 receiver points for the square mosque form and at several frequencies.



(a) 500 Hz (b) 1000Hz (c) 2000Hz

Figure 15. RT for the square mosque geometry; a: at 500Hz, b: at 1kHz, and c: at 2kHz (Imam position).

Taking into account the functions realized in mosques and the optimum levels for mosques of these size (which are between 0,6 and 1,9 seconds, it can be said that all receiver points have the optimum RT's value, especially at low frequencies. Furthermore, at 1kHz, RT's values range from 1.82 to 1.90s. All receiver points located at two sides of the mosque have longer RT's than those located at the centre, see figure 16, this is due to the source location.

Figures 17 and 18 demonstrate that the value of early decay time obtained by this type and at the Imam position is better than those obtained by the rectangle where the RT average is approximately 2.95s.

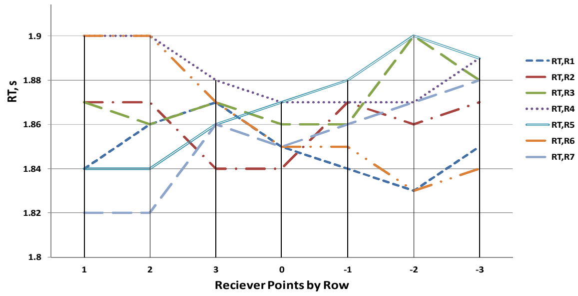
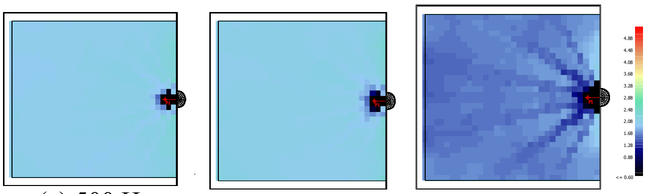


Figure 16. RT for the square mosque geometry at 1kHz as a function of worshippers rows (Imam position).



(a) 500 Hz (b) 1000Hz (c) 2000Hz

Figure 17. EDT for the square mosque geometry; a: at 500Hz, b: at 1kHz, and c: at 2kHz (Imam position).

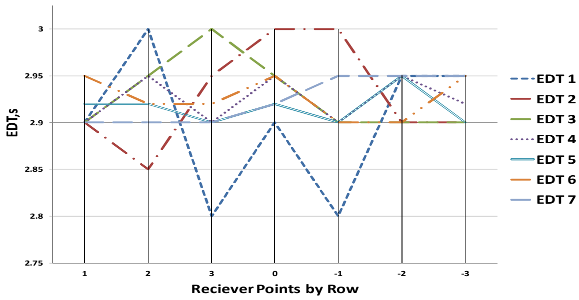


Figure 18. EDT for the square mosque geometry at 1kHz as a function of worshippers rows (Imam position).

Speech Transmission Index for the square mosque geometry as a function of worshippers rows and at the Imam position is presented in figure19. We found that STI values range between 0.65 and 0.75, which is considered good. The best values have been found at locations just around the source or imam and at the 1st row.

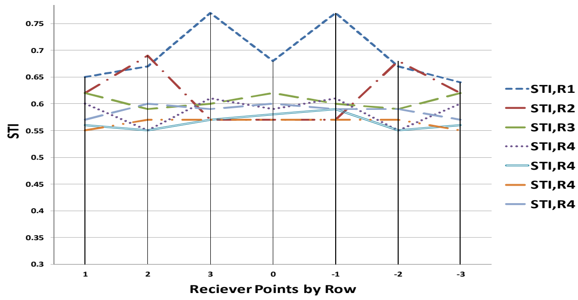
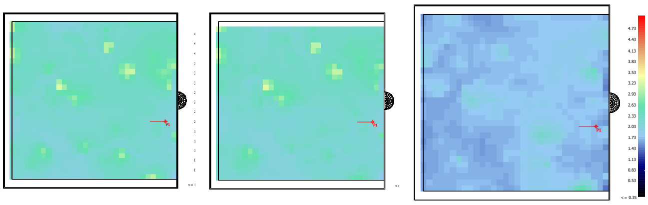


Figure 19. STI for the square mosque geometry as a function of worshippers rows (Imam position).

In the Second Step, we have been discussing the results obtained by the khatib position. Figure 20 demonstrates the reverberation times as contour maps at 500,1000, and 2000Hz. RT values as a function of worshipper's rows at 1kHz are presented in figure 21. We found that the 3rd row has the best value, where we can obtain RT equal to 1.90s. Generally, RT values at 1kHz range from 1.70s to 2.40s.



(a) 500 Hz (b) 1000Hz (c) 2000Hz

Figure 20. RT for the square mosque geometry; a: at 500Hz, b: at 1kHz, and c: at 2kHz (Khatib position).

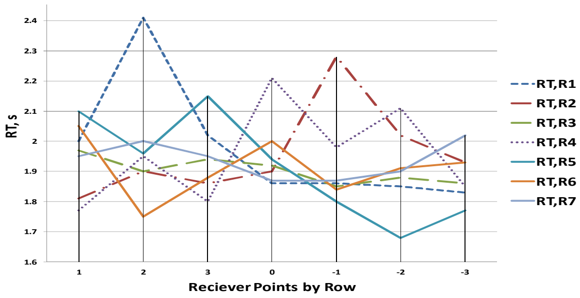
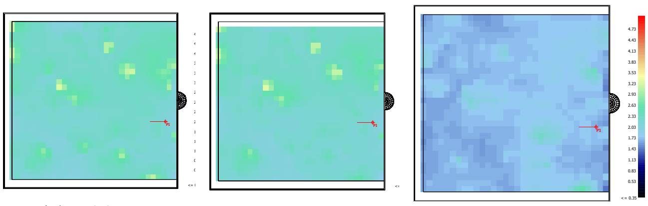


Figure 21. RT for the square mosque geometry at 1kHz as a function of worshippers rows (Khatib position).

As it is shown in figures 22 and 23, all points have approximately the same RT value, approximately 3.0s. At 1kHz, Rt values range from 2.8s to 3.2s. These values are acceptable for the mosque volume.



(a) 500 Hz (b) 1000Hz (c) 2000Hz

Figure 22. EDT for the square mosque geometry; a: at 500Hz, b: at 1kHz, and c: at 2kHz (Khatib position).

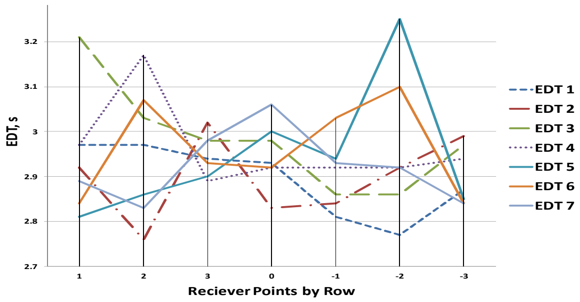


Figure 23. EDT for the square mosque geometry at 1kHz as a function of worshippers rows (Khatib position).

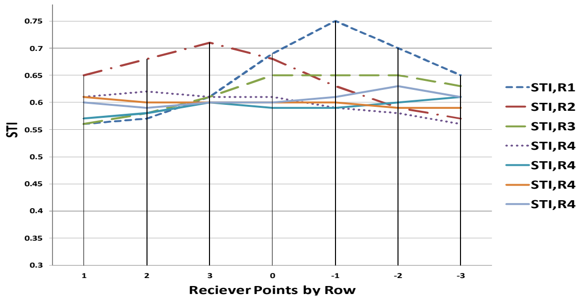


Figure 24. STI for the square mosque geometry as a function of worshippers rows (Khatib position).

For this scenario at katib position, we found that STI values are around 0.65, which is considered good. The best values have been found at locations just around the source or khatib and at the 1st row where we obtained the max value, 0.75, as shown in figure 24.

4 Conclusion

Sound fields of two simple mosque geometries were tested. Reverberation time, early decay time, speech transmission index were measured. The square mosque showed the merits of uniform spatial distribution of RT, EDT, and STI over the front rows in the case of Imam position. Furthermore, almost of rows have acceptable levels of RT, EDT, and STI while the "Friday" speech or Khatib position. The 1:2 rectangle mosque geometry negatively impacted sound fields in the front rows at all source positions. The investigation carried out in this study is expected to help architects to understand better the effect of early architectural design decisions pertaining to the space and form of the mosque on its acoustics.

References

[1] Z. G Karabiber, "Acoustical problems in mosques: A case study on the three mosques in Istanbul". *Forum Acusticum, Berlin*, CDROM, 4 pgs. (1999).

[2] Z.K Yuksel, C. Binan, R. Unver, "A research project in the intersection of architectural conservation and virtual reality: CAHRISMA". *In 19th International Symposium CIPA*. Antalya, Turkey: Technical University of Istanbul. (2003).

[3] P. Fausti, R. Pompoli, N. Prodi, "Comparing the acoustics of mosques and Byzantine churches". *19th International Symposium CIPA*. Antalya, Turkey: Technical University of Istanbul. (2003).

[4] Z. Karabiber, S. Erdogan, "Comparison of the acoustical properties of an ancient and a recent mosque". *Forum Acusticum*, Spanish Acoustical Society (SEA), Seville, Spain (2002).

[5] M. A. Kayili, "Da geleneksel akustik sistemler ve Mimar Sinan uygulamalar", (Anatolian traditional acoustic works and works done by Sinan the Architect). 6th National Acoustical Congress TAKDER, 26-28 October (233-238). Antalya, Turkey (2002).

[6] I.L Topaktas, "Acoustical properties of classical Ottoman mosques: Simulation and measurements". PhD thesis, *Department of Architecture, Middle East Technical University*, Ankara. (2003).

[7] M. Kayili, "Acoustic Solutions in Classic Ottoman Architecture", *Foundation for Science Technology and Civilization*; Manchester, England September 2007.

[8] A.A. Abdou, "Measurement of acoustical characteristics of mosques in Saudi Arabia" *The Journal of Acoustical Society of America*, 113(3), 1505-1517. (2003).

[9] D. Templeton, "Acoustics in the Built Environment: Advice for the Design Team". Oxford: Butterworth(1993).