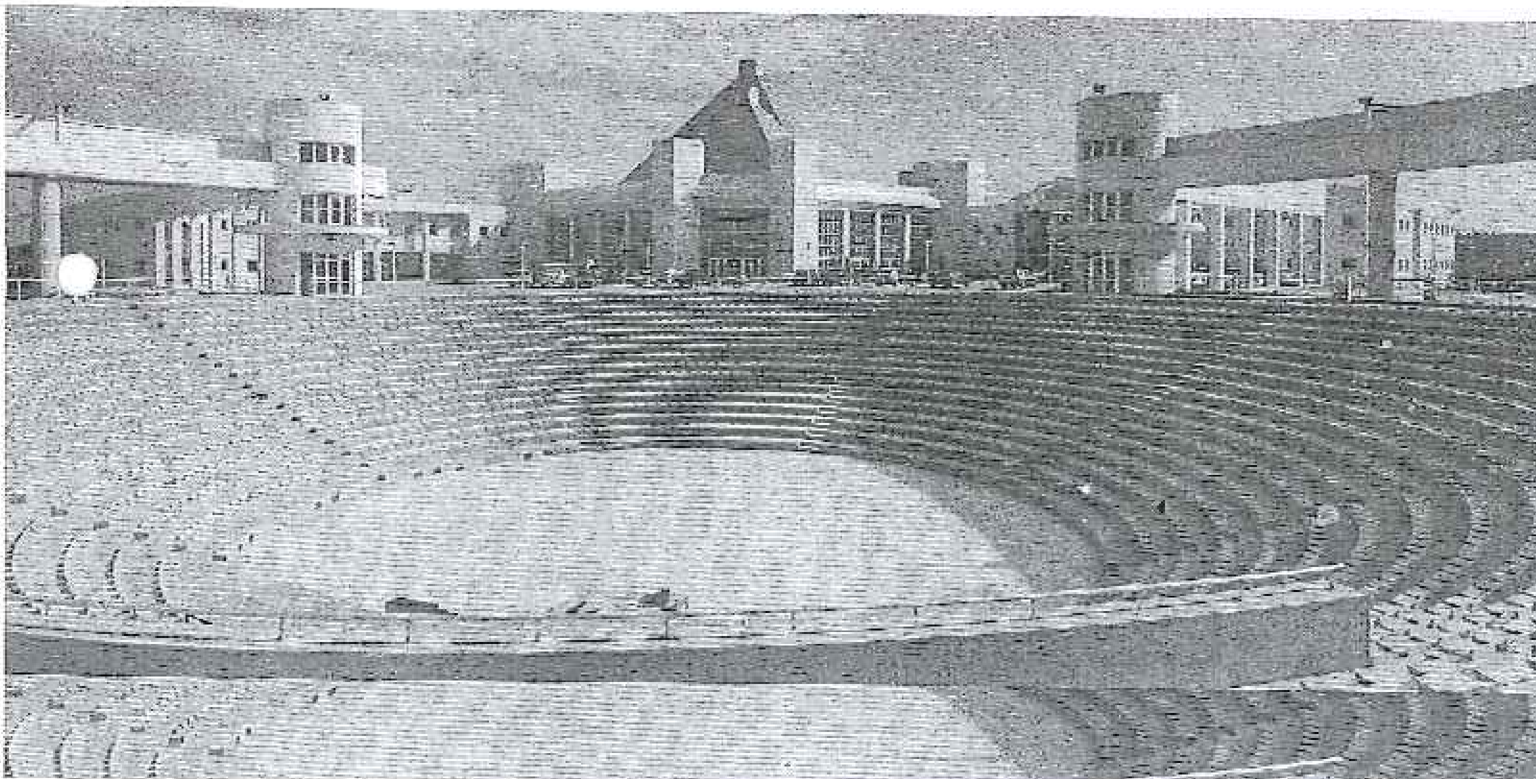
ISSN 1301-6121

# ARKİTEKT

MAYIS-HAZIRAN 2007 - SAYI:2007/03 - YIL:74 - 5,00 YTL - KKTC:7,00 YTL
MAY-JUNE 2007 - VOLUME:2007/03 - YEAR:74 - 5,00 YTL - KKTC:7,00 YTL





ARKİTEKT

The JOURNAL of ARCHITECTURE and DESIGN
İki ayda bir yayınlanan hakemli bir dergidir. It is a referred journal published bimonthly.



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# A TOUCHING PAST AND A DESPERATE FUTURE: HISTORY AND ACOUSTICS OF KOCATEPE MOSQUE

Semiha YILMAZER*
Zühre SÜ **

The leading mosque of capital Ankara with a congregation capacity of 15.000 was completed and opened for use following a three phased project competition. The project started at the beginning of 20th century and the building was inaugurated at the end of the first half of the century. In terms of the architectural style, with its four minarets and central dome, it is a synthesis: 16th century aesthetics of traditional Ottoman-style and the 20th century technology. Studies about acoustical quality of Sinan's Mosque are abundant (Erdem 1992; Karabiber and Erdoğan, 2004; Kayılı, 2002, Topaktaş, 2003; Üretmen 1991). Especially through usage of cavity resonators, earthenware water jug; Architect Sinan coped with the defects of sound in his well-known mosque. Kocatepe Mosque is very much inspired by Sinan's work. In this paper, as a first part of the acoustical analyzing, reverberation time (RT), which is the most important indicator of the acoustic characteristics, of the mosque is analyzed via computer-aided prediction. The results demonstrate Kocatepe Mosque to be in good condition for recital of musical version of Holy Koran, as it creates a ritual and tranquil acoustical atmosphere. However, the mosque is in inadequate condition for prayer mode in terms of intelligibility of the speech. This is basically verified by the abrupt jumps in low frequency results of reverberation time in the activity modes and the empty condition of the mosque. Although, the acoustics of the mosque is closest to the optimum conditions for speech and music in the fully-occupied condition, the ancient Mosques of Sinan are still unique of its kind and be a reference and model for the mosques to be built.

## INTRODUCTION

Mosque design necessitates abiding by different acoustical requirements. All the activities including prayer such as public speaking, preaching, lecturing, and Qur'an recitations performed in mosques are subject to speech audibility and intelligibility, which should be considered carefully at the design stage, in order to ensure good listening conditions.

Thus, intelligibility of both speech and sound are extremely important, especially for holy tones which must be both spacious and effective. The acoustical parameters governing speech audibility, intelligibility and spaciousness of sound that are commonly assessed for acoustical analysis of mosques are the reverberation time, sound pressure distribution and sound transmission index. In this paper, reverberation time of the Kocatepe Mosque will be analyzed via computer-aided prediction and its results will be discussed.

## HISTORY OF KOCATEPE MOSQUE

The idea of building Kocatepe Mosque dates back to 1940 with a project competition. The joint project of Vedat Dalokay and Nejat Tekelioğlu was accepted as applicable. According to the project, the complex would consist of a mosque for two thousand people, the main offices of the Presidency of Religious Affairs, a high Islamic institute, a library, an auditorium, a museum, a parking lot for two hundred cars, retail shops, a large kitchen, and a policlinic. Nevertheless, due to conflict between architects and the government, the mosque had not been built. With the same project, Dalokay joined another mosque competition held for Islamabad, Pakistan, in 1969, winning another first prize. Many conservative Muslims criticized the design at first for its non-conventional design and absence of the traditional arches and dome, but virtually all criticism was eventually silenced by the mosque's awe-inspiring scale, form, and setting against the Margalla Hills upon completion. Construction of the mosque began in 1976, and was funded by the government of Saudi Arabia. The mosque was completed in 1986, and used to house the International Islamic University (Figure 1)

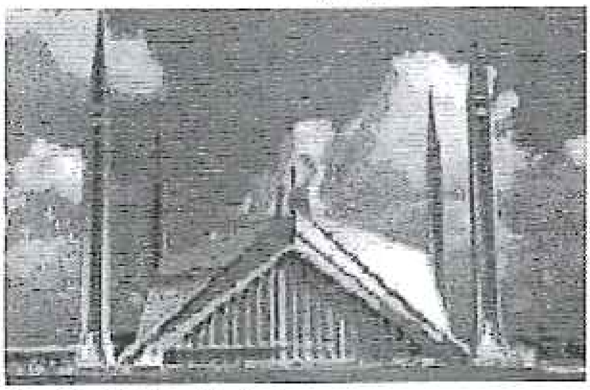

Figure 1. The Faisal Mosque, Islamabad

On the other hand, in Ankara, the second competition was held in 1957. Part of the project concerning the main offices of the Presidency of Religious Affairs was finished in 1964. A third competition was held in 1967 and Hüsrev Tayla and Fatih Uluengin's project was awarded. In 1987, following the completion of the building process, Kocatepe Mosque was inaugurated with a congregation capacity of 15.000.

## ARCHITECTURAL FEATURES OF KOCATEPE MOSQUE

Commanding the hill of Kocatepe, the mosque is a modern city landmark. The architectural style of the mosque is a combination of traditional Ottoman-style according to the16th century aesthetics with the 20th century technology (see Figure 2). With its four minarets, the mosque resembles Selimiye and with its central dome and half domes it is inspired from Sultan Ahmet Mosque of Mehmet Aga, from the school of Sinan the Architect.

The main mosque has an estimated volume of 68696 $m^2$ and 4288 $m^2$ floor area. Its dimensions are 64x67 m, with 48.5 m height and it is covered with a dome with a diameter of 25.5 m. There are four smaller half domes surrounding the central dome. These half domes are enlarged with 12 domes. The main dome rests on 4 large pillars (elephant feet) each with a diameter of 3 meters. Different than the earlier mosques, the diameters of the elephant feet are reduced to 3 meters in Kocatepe Mosque with the latest technology of the time. The mosque has become more spacious inside the mosque and partition of the congregation has been prevented. The main part of the mosque (harim) is surrounded by galleries in "U" form. The galleries are built in two-story forms, which are quite different from the classical Istanbul mosques. As a result, more space is gained and a special view is added to the harim.

The mosque as a whole is built by reinforced concrete framework system and the outer sides were covered with artificial stone. The dome, the half domes and the minarets are built of gross concrete. The mosque is surrounded by a court like a plateau. The remaining parts of the complex, taking advantage of the slope of the ground, were hidden under the court. The auditorium and the administration offices are placed on a level below the plateau on which the mosque rests. There is a three-story car park under the west court of the mosque and a three-story supermarket of 15.000 $m^2$ under the courtyard with arches. Although the mosque itself reflects the classical Ottoman

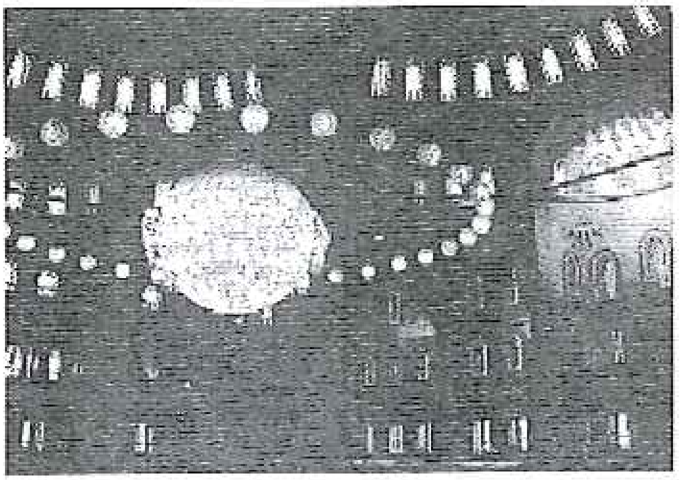

Figure 2. Interior and exterior views from Kocatepe Mosque, Ankara,

architecture, the auditorium, car park, supermarket, administration offices display contemporary architecture (Türkiye Diyanet Vakfı, 2002).

## MEASURING METHOD

The technological developments of recent years have affected the field of architectural acoustics by means of measurement techniques. The previous methods of scale models and hand calculations left their place to the more practical and realistic method of computer simulations. The simulation technique is used both for the acoustical calculations of the completed buildings and is assessing and modifying the acoustical characteristics of a place in the phase of design.

The computer simulations of Kocatepe Mosque are performed for different activities using ODEON 6.05 software package. The calculation method of the software is based on prediction algorithms including image-source method and ray tracing, which allows reliable predictions in modest calculation times. Beside the geometrical approach, the statistical properties of the room's geometry and absorption are also proven to be efficient in the ODEON Room Acoustics Program (Naylor 1993).

For the simulation to be started, a 3D Model of Kocatepe Mosque is obtained using a CAD Software. The model is imported to the ODEON Room Acoustics Program. The 3D display of the model can be seen in Figure 3. 2 omni-directional point sources and a receiver are specified for each activity pattern.

Figure 4 and figure 5 illustrate the locations of the receiver and the sources, where Source 1 is indicating the source at mihrab and Source 2 is indicating the source at minbar. The sources, which are at the mihrab and minbar are activated according to the activity.

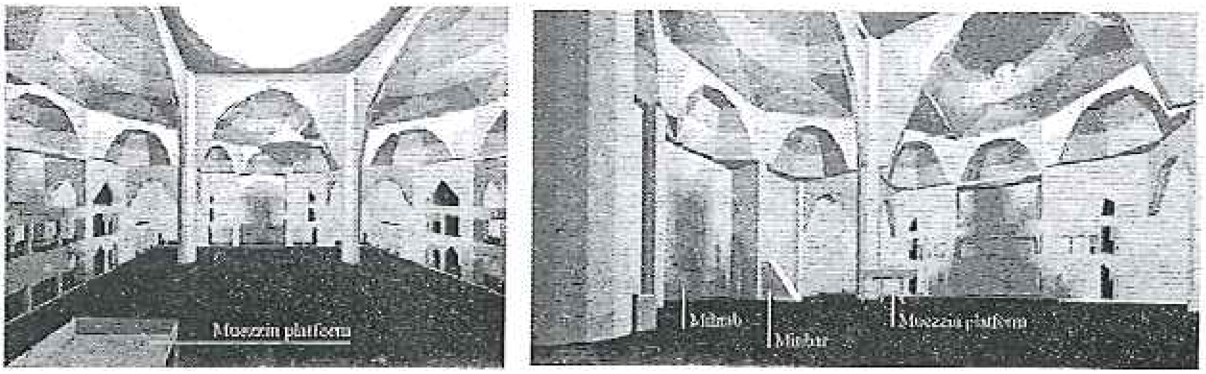


Figure 3. 3D display of the mosque

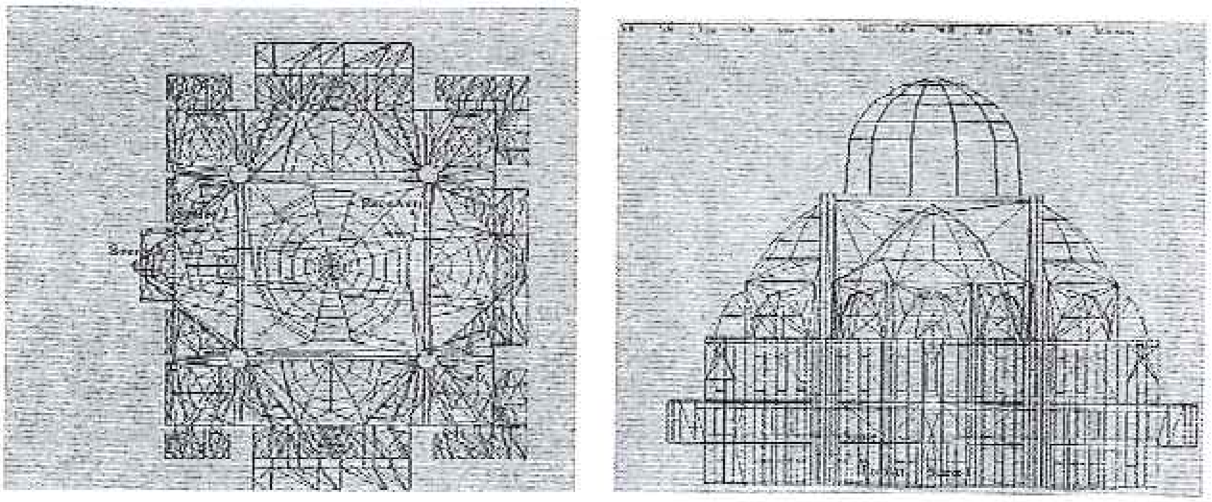

Figure 4. Plan and elevation view of the source and receiver locations

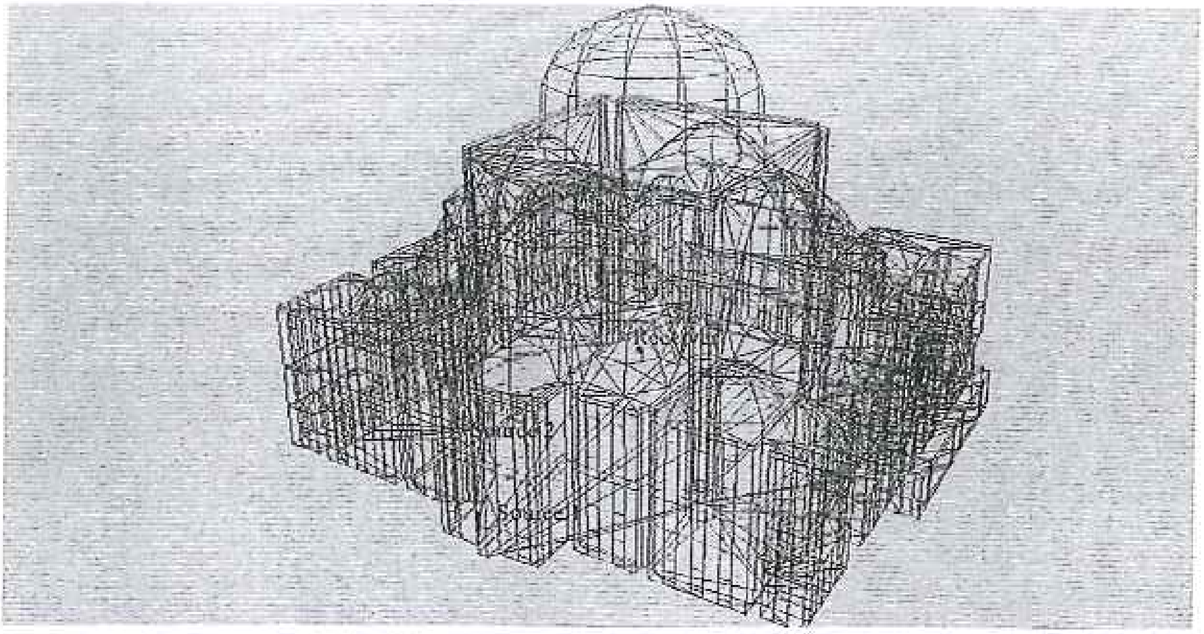

Figure 5. 3D view of the source and receiver locations

Different materials at different sections of the mosque, which have been detailed previously having different sound absorption coefficients are assigned using the material library of ODEON software (Table 1). After fixing the calculation parameters, the selected receiver surfaces are divided into grids considering that 0.96 $m^2$ area per prayer will be provided (Abdou, 2003). The maps and the cumulative distribution graphs of calculated parameters are obtained for these surfaces in order to get the results of different acoustical parameters and their distribution throughout the mosque.

The process is repeated for different activities performed in Kocatepe Mosque. The unoccupied mosque is assessed for the reverberation time. The first activity mode is the prayer mode when the source is 'imam' at mihrab facing towards mihrab. The mosque is assumed to host a 1/3 fullness considering the daily prayers. The second mode is preaching mode and the recital of the musical versions of the Holy Koran. The source is "imam" at minbar facing to the worshippers. The mosque is assumed to be fully occupied considering the Friday prayers listening to Friday Speech, besides the religious days and festivals. The receiver surfaces for both activity modes are defined at 0.80 m height as seating level. For the two different activity modes music and speech related parameters are analyzed including reverberation time (RT).

Table 1. Sound absorption coefficients of different materials used in Kocatepe Mosque

| MATERIAL | 63 Hz | 125 Hz | 250 Hz | 500 Hz | 1 kHz | 2 kHz | 4 kHz | 8 kHz | Scatering Factor |
|---|---|---|---|---|---|---|---|---|---|
| Smooth concrete | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.05 | 0.05 | 0,1 |
| Marble | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0,2 |
| Solid wood panel | 0.15 | 0.15 | 0.10 | 0.06 | 0.08 | 0.10 | 0.05 | 0.05 | 0,1 |
| Double glazing | 0.02 | 0.02 | 0.06 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0,1 |
| Solid wooden door | 0.14 | 0.14 | 0.10 | 0.06 | 0.08 | 0.10 | 0.10 | 0.10 | 0,1 |
| Prayers-1/1 per $m^2$ | 0.55 | 0.55 | 0.86 | 0.83 | 0.87 | 0.90 | 0.87 | 0.87 | 0,5 |
| Prayers-1/3 per $m^2$ | 0.10 | 0.10 | 0.21 | 0.41 | 0.65 | 0.75 | 0.71 | 0.71 | 0,5 |
| Ceramic tiles | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0,3 |
| Carpet on concrete | 0.02 | 0.02 | 0.06 | 0.14 | 0.37 | 0.60 | 0.65 | 0.65 | 0,1 |
| Chandelier | 0.35 | 0.35 | 0.25 | 0.18 | 0.12 | 0.07 | 0.04 | 0.04 | 0,2 |
| Lime plaster | 0.04 | 0.04 | 0.05 | 0.04 | 0.08 | 0.04 | 0.06 | 0.06 | 0,1 |

## REVERBERATION TIME

Reverberation time is the time required for a sound source that is loud enough to decay to inaudibility. For liturgical purposes (orchestra, chorus, or organ) the optimum range for reverberation time is given as 3.0 to 3.5 s for spaces larger than 10000 $m^2$ (Egan, 1994). The reverberation time formula is proposed by Sabine as;

T = (0,163 V) / A in seconds,

Where,

A = the equivalent sound absorption area in $m^2$ ( = $\sum S^2 av$ )
$\sum S^2 av = S1^2 1 + S2^2 2 + \ldots + Sn^2 n$
V = the volume in m_
S = the surface area in m_
- = sound absorption coefficient (Sabine, 1994).

The first analysis is made for the unoccupied mosque. RTunocc is found as 7.48 s at mid frequencies. This is much above the optimum level even for liturgical purposes (Egan,1994). The long sound decay at low frequencies can be detrimental for speech intelligibility. For good speech intelligibility, RT values at low octave-band frequencies should remain flat down to 100 Hz. An increase, at low frequencies, RT values around 10%-20% would still be acceptable to yield a natural sound impression. However, in the case of Kocatepe, the increase is around 50% for the empty condition of the mosque. On the other hand, the bass ratio, which is the average RT at low frequencies to mid frequencies, is 1.54 in Kocatepe Mosque. The optimum range for music performances is given as 1.2 to 1.25 (Kuttruft, 1991). Thus, the value implies over-warm space rich in bass sound, which is affective in the sense of spatial impression but detrimental in terms of speech intelligibility.

For the first activity mode, i.e. the prayer mode in 1/3 fullness, the global estimation results show that the mosque has an RT1/3occ of 4.35 s. at mid frequencies and for the second activity mode that is the preacher-recital mode in 3/3 fullness RT3/3occ is found as 3.19 s. at mid frequencies (Figure 6). Distribution maps illustrate that the 90 % of the receiver surfaces have RT1/3 occ of 6.2 s and RT3/3 occ 2.81 to 3.89 s. (see appendix).

RT1/3occ is much better than RTunocc but still

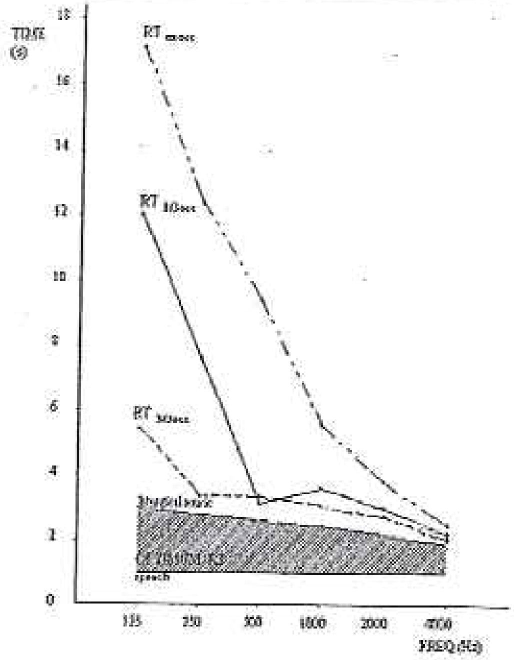


Figure 6. Calculated values for RTunocc and RT1/3occ and RT3/3occ for frequencies from 125 to 4000 Hz, shaded area: optimum RT (Egan, 1994).

higher than the optimum range. It is especially detrimental for the intelligibility of speech, which should not be greater than 1.0 s (Kuttruuf, 1991). This is not satisfactory in terms of both music and speech purposes. A positive point to mention is that the sound field is nearly even. The higher values of RT1/3occ are observed at upper galleries, which might be depending, both upon the distance of these receiver surfaces to the source and the huge volume of the mosque. There is a small amount of echo spots underneath the dome. . This may be found satisfactory, considering the dimensions of the dome. RT3/3occ is in the optimum range considering the recitals of the musical version of the Holy Koran. But, it is still detrimental for the intelligibility of speech when the preaching mode is considered. The number of worshippers attending Friday prayer greatly affects the total sound absorption inside the mosque. Therefore, the length of the reverberation time becomes more controlled. RT3/3occ is satisfactory in terms liturgical music underneath the main and secondary domes. There are almost no echo spots underneath the domes, despite the huge concave surface above. This depends on the dimensions of the domes and heights of their centers from the floor. Especially the main dome, when considered and completed as a sphere is much above the receiver surfaces. Therefore, none of the receiver surfaces is

Table 2. Reverberation times depending on frequency for different activity patterns in Kocatepe Mosque

| | 63 HZ (S) | 125 HZ (S) | 250 HZ (S) | 500 HZ (S) | 1000 HZ (S) | 2000 HZ (S) | 4000 HZ (S) | 8000 HZ (S) |
|---|---|---|---|---|---|---|---|---|
| Source at Mihrab | 12.11 | 11.99 | 7.65 | 5.11 | 3.60 | 2.99 | 2.21 | 1.12 |
| Source at Minbar | 5.33 | 5.45 | 3.38 | 3.35 | 3.04 | 2.74 | 2.03 | 1.06 |

within this problematic focusing volume.

## CONCLUSION

One of the criteria in the mosque is to provide optimum reverberation times. The results demonstrate that, Kocatepe Mosque to be in good condition for recital of the musical version of Holy Koran, as it creates a ritual and tranquil acoustical atmosphere. However, the mosque is inadequate condition for prayer mode in terms of intelligibility of speech. This is basically verified by the abrupt jumps in low frequency results of reverberation time in the most of the activity patterns and the empty condition of the mosque (Table 3, 4). On the other hand, the sound reinforcement system would increase the direct sound level at listening positions and yield a better intelligibility.

Excessive reverberations may be encountered when the walls and the ceiling of an auditorium are covered with highly reflective material that would cause degradation of the speech articulation especially when the case has a concave surface.

The two basic differences of Kocatepe Mosque, when it is compared with some ancient mosques of similar volume, are the excessive reverberation in empty condition and a much higher bass ratio. However, a flat distribution of reverberation on frequency is important in intelligibility of speech regardless of the volume. So, the sound absorption should be balanced

for different frequencies (Table 3). This bass balance is obtained in ancient mosques by special acoustical treatments. Some studies on ancient mosques show that there are differently dimensioned jugs buried in domes to absorb sounds. These are an ancient version of Helmholts resonators. The bottles with narrow necks can produce or absorb sounds with a frequency proportional to the width of the neck (Karabiber, 2005). These cavity resonators are used in most of the Sinan's Mosques including Sultan Ahmet Mosque, Suleymaniye Mosque, Selimiye Mosque, Sehzade Mehmet Mosque (Kayılı, 2002). The ancient Mosques of Sinan are still unique of its kind and be a reference and model for the mosques to be built.

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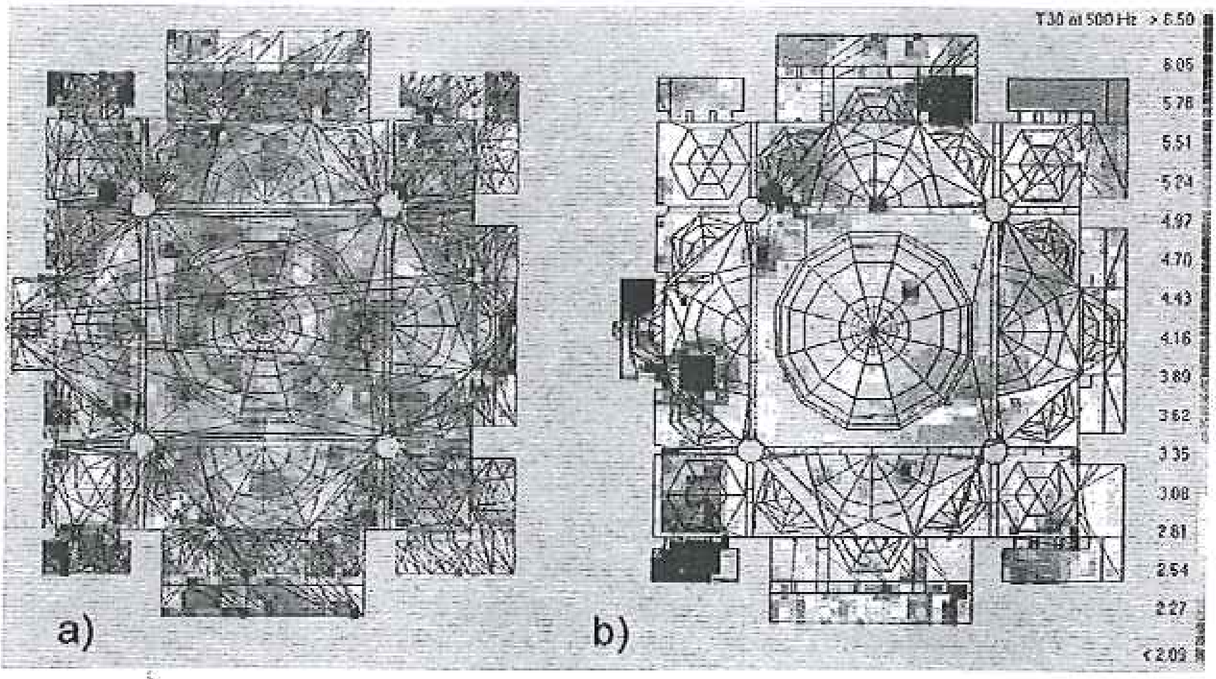
Table 3. Reverberation times depending on frequency for the empty conditions of mosques.

| | Volume (m3) | 125 Hz(s) | 250 Hz(s) | 500 Hz(s) | 1000 Hz(s) | 2000 Hz(s) | 4000 Hz(s) |
|---|---|---|---|---|---|---|---|
| Suleymaniye Mosque (Topaktas, 2003) | 85.300 | 9.88 | 8.78 | 8.43 | 6.15 | 4.35 | 2.62 |
| Kocatepe Mosque | 68.696 | 17.10 | 12.40 | 9.43 | 5.54 | 3.78 | 2.50 |
| Mosque in Saudi Arabia (Abdou, 2003) | 23.390 | 2.91 | 2.74 | 2.85 | 2.47 | 1.91 | 1.56 |
| Sokullu Mehmet Pasa Mosque (Karabiber and Erdoğan,2002) | 5.700 | 3.71 | 3.75 | 3.46 | 2.73 | 2.17 | 1.51 |
| Cenabi Ahmet Pasa Mosque (Topaktas, 2003) | 2.900 | 4.93 | 4.4 | 3.6 | 3.51 | 2.52 | 1.52 |

## APPENDIX




a)Reverberation time distribution maps for 500 Hz source at mihrab, b)Reverberation time distribution maps for 500 Hz source at minbar.

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Receiving: December 2006
Acceptance: April 2007