COMPARISON OF THE ACOUSTICAL PROPERTIES OF AN ANCIENT AND A RECENT MOSQUE

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Karabiber, Zerhan; Erdogan, Sevda

Yýldýz Technical University, Faculty of Architecture
Barbaros Bulvarý, Beþiktaþ 80750
Istanbul
Turkey
Tel: + 90 212 259 70 70 ext: 22 55
Fax: + 90 212 261 05 49
e-mail: karabi@yildiz.edu.tr; sevder_er@hotmail.com

ABSTRACT

Regarding the work carried on the CAHRISMA Research Project, some differences among the measured and calculated values at the acoustical parameters of the ancient mosques are found. To explain this fact, different works are planned which one is the comparison of the acoustical properties of an ancient -Sokullu- and a recent -Sisli- mosque. These mosques are chosen due to the similarities of their volume, shape and finishing materials. Comparison of the measured and calculated values of the acoustical parameters showed that although there is no great difference between the spaces, acoustics of the Sokullu Mosque is better

INTRODUCTION

CAHRISMA (Conservation of the Acoustical Heritage by the Revival and Identification of the Sinan's Mosque's Acoustics) is a research project going on within the Fifth Framework of EC INCO-MED Research Projects (Contract no: ICA3-1999-00007). Main objectives of the CAHRISMA Project are identification, revival and conservation of the architectural heritage in a new way. The mentioned innovation of the project basically consists to upgrade the architectural heritage and conservation concepts by broadening them as to include the acoustical heritage. Objective and subjective evaluations and audio-visual reconstruction of Sinan's mosques (Sinan is a well known Turkish-Ottoman architect of 16th Century) and Byzantine Churches (Istanbul, 6th Century) in real-time 3D virtual environments are the basic approaches to reach the goals of the research. Virtual restoration, virtual conservation, determination of significant acoustical effects and improvement of the acoustical criteria for the architectural design of new mosques are the main results of the project [1].

Some differences among the measured and calculated values of the acoustical parameters are found at the mosques of Sinan, regarding the work carried on the CAHRISMA Research Project. To explain this fact, different works are planned, which one is the comparison of the acoustical properties of an ancient and a recent mosque. Sokullu Mosque (16th Century) and Sisli Mosque (20th Century) are chosen for this purpose due to the similarities of their volume, shape and finishing materials. Reverberation time and other room acoustical parameters are measured at the mosques and the results are compared. This paper presents the work and findings realised by the comparison of the acoustical parameters measured at these two spaces.

PROPERTIES OF THE MOSQUES

Sokullu Mosque, located in the historical peninsula of Istanbul, was built in Ottoman period at 1572 by well-known Turkish-Ottoman master architect Sinan. It has always been evaluated as one of Sinan's masterpieces. Being one of the smallest mosques of Sinan, the mosque has approximately a floor area of 290 m² and a volume of 5700 m³. It is covered with a hexagonal based dome of 13 m diameter, having a central plan (Fig. 1). Selected areas of the interior of the mosque are decorated with tiles.

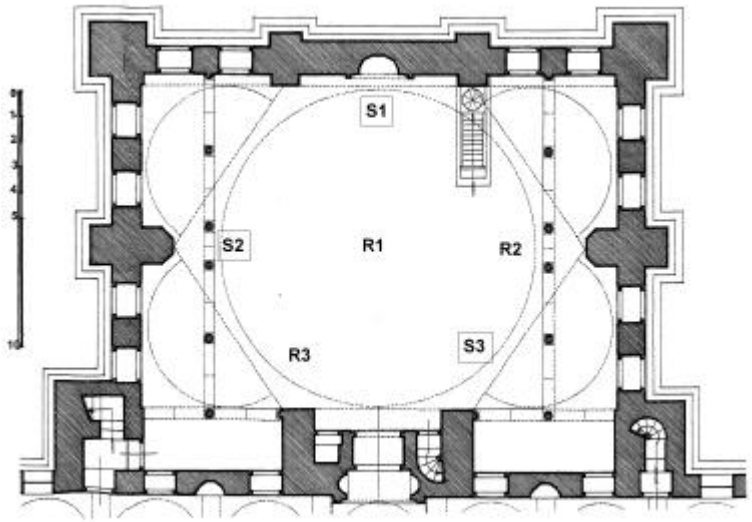


Figure 1. Plan of the Sokullu Mosque showing measurements' source (S) – receiver (R) positions.

Sisli Mosque located in Istanbul is a twentieth century mosque. Its construction was completed at 1949. It was built according to Arch. Prof. Vasfi Egeli's projects being based on the Turkish-Ottoman Architecture principles. Square form planned mosque having approximately 332 m² floor area and 4750 m³ volume, is covered with a central dome of an 11,40 m diameter decorated with flanking windows and three sideways half domes (Fig 2).

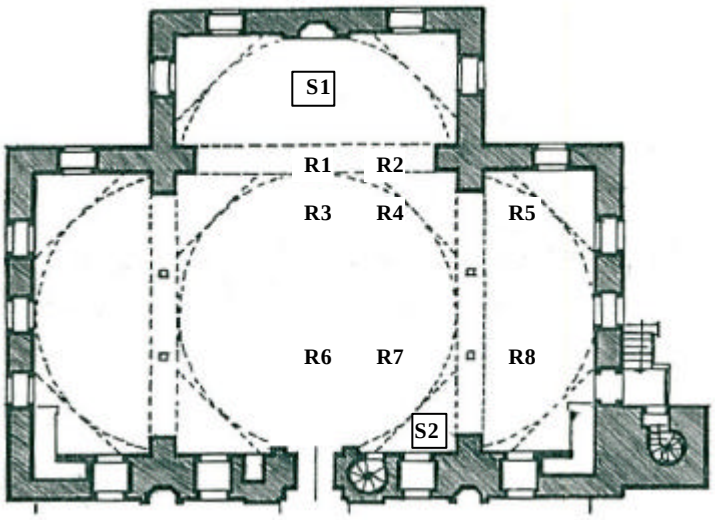


Figure 2. Plan of the Sisli Mosque showing measurements' source (S) – receiver (R) positions.

The sound absorption properties of the materials used in the mosques are almost similar. Both have thick carpets on the floor and acoustically reflective surfaces like tiles, marble, plaster and lime stone on the walls and domes. The audience capacities of Sokullu and Sisli Mosques are respectively 600 and 640 people approximately (both of the mosques have balconies).

MEASUREMENTS

There are three distinct acoustical requirements for mosques; to hear the namaz orders of the Imam, to understand the sermon of the preacher and to listen or to join to the recital of the musical versions of the Holy Koran. Thus, intelligibility of speech and a high sound quality for musical sounds are paramount [2]. Therefore Reverberation Time (RT) and other room acoustical parameters such as Early Decay Time, Clarity, Definition and Speech Transmission Index are measured at both of the mosques. For this purpose 01 dB Symphonie System dBBATI32 is utilised. Measurements are made in different source and receiver positions in unoccupied state. Source (S) and receiver (R) positions, chosen to realise an appropriate coverage in the rooms, are given at Figure 1 for Sokullu Mosque and at Figure 2 for Sisli Mosque. At least three measurements have been realised consecutively in each of the positions in order to be in accordance with ISO 3382 1997 (E). Table 1 gives the average results of the RT measurements for three source (hs: 1.50m) and three receiver positions at Sokullu Mosque and Table 2 gives the average results of the RT measurements for two source and eight receiver points at Sisli Mosque. In both of the mosques two receiver heights are used (hr: 0,80m and hr': 1,50m) to cover the characteristic usage of the mosques, where people sometimes sit on the floor and sometimes stand still during the ceremony.

Table 1.Measured octave band Reverberation Times at different measurements points (Sokullu)

Receiver Points	**Reverberation Time (s)**					
	Frequency band (Hz)					
	125	**250**	**500**	**1000**	**2000**	**4000**
S1R1	3,58	3,86	3,28	2,77	2,24	1,55
S1R2	3,55	3,70	3,39	2,75	2,17	1,55
S1R3	3,81	3,90	3,36	2,68	2,28	1,52
S2R1	3,90	3,88	3,52	2,73	2,15	1,49
S2R2	3,88	3,84	3,43	2,76	2,12	1,39
S2R3	3,45	3,50	3,22	2,70	2,06	1,53
S3R1	3,82	3,74	3,41	2,71	2,14	1,58
S3R2	3,86	3,66	3,61	2,72	2,13	1,50
S3R3	3,51	3,66	3,42	2,72	2,21	1,49
Average	**3,71**	**3,75**	**3,40**	**2,73**	**2,17**	**1,51**

Table 2. Measured octave band Reverberation Times at different measurements points (Sisli)

Receiver Points (for S1-S2)	**Reverberation Time (s)**					
	Frequency band (Hz)					
	125	**250**	**500**	**1000**	**2000**	**4000**
R1	5,14	4,92	4,24	2,80	1,92	1,37
R2	5,16	4,95	4,60	2,80	1,93	1,38
R3	5,20	5,05	4,86	3,19	2,06	1,36
R4	5,43	5,14	4,82	3,14	2,04	1,40
R5	5,55	5,22	4,80	3,05	2,10	1,50
R6	4,61	4,47	4,09	3,17	2,23	1,48
R7	5,24	4,85	4,41	3,27	2,08	1,47
R8	5,49	5,29	4,94	3,00	2,12	1,51
Average	**5,23**	**4,99**	**4,60**	**3,05**	**2,06**	**1,43**

Early Decay Time (EDT), Clarity (C_{80}), Definition (D_{50}), Speech Transmission Index (STI) and Rapid Speed Transmission Index (RASTI) are measured keeping the same source and receiver positions where RT measurements are realised. Table 3 and Table 4 show the octave band average values for Sokullu and Sisli Mosques respectively.

Table 3 Early Decay Time, Clarity, Definition, Speech Transmission Index and Rapid Speech Transmission Index measured at Sokullu Mosque.

f (Hz)	EDT (s)	Clarity (dB)	Definition %	STI	RASTI
125	3,22	-2,10	34,90		
250	3,24	-4,45	21,63		
500	3,08	-3,18	29,53		
1000	2,44	-0,35	41,23	**0,51**	**0,48**
2000	1,87	0,48	42,80		
4000	1,26	2,55	54,03		
Average	**2,52**	**-1,18**	**37,35**		

Table 4. Early Decay Time, Clarity, Definition, Speech Transmission Index and Rapid Speech Transmission Index measured at Sisli Mosque.

f (Hz)	EDT (s)	Clarity (dB)	Definition %	STI	RASTI
125	1,93	-1,54	37,15		
250	2,85	-5,58	20,13		
500	3,42	-6,48	16,96		
1000	2,64	-2,05	34,19	**0,50**	**0,46**
2000	2,00	-0,90	36,16		
4000	1,08	1,51	46,65		
Average	**2,32**	**-2,51**	**31,87**		

COMPARISONS AND EVALUATION

The comparison of the average reverberation times of Sokullu and Sisli Mosques is presented in Figure 3.

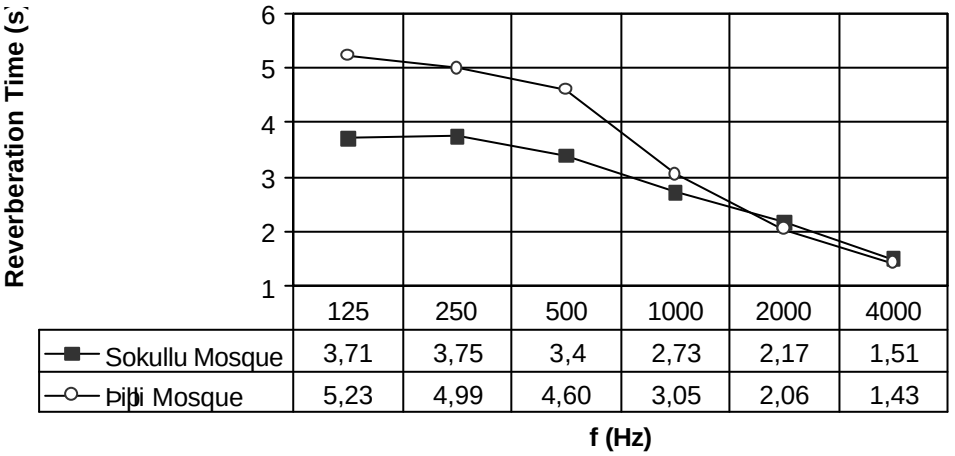
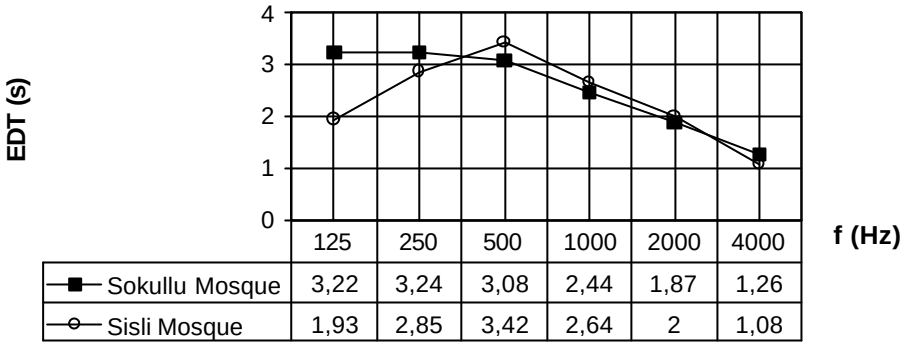


Figure 3. Comparison of Sisli and Sokullu Mosques' Reverberation Time (RT) averages.

There are no optimum values for RT's of the mosques in the literature. However, taking into consideration the functions realised in mosques and the optimum levels for churches of these size (which are between 1,7 and 2,8 seconds [3], [4], [5]), it can be said that both of the mosques have long RT's, especially at low frequencies. On the other hand, although the volume of Sokullu (5700 m³) is bigger than that of Sisli (4750 m³), its RT is shorter, again for low frequencies. At high frequencies RT's of the mosques are almost the same.

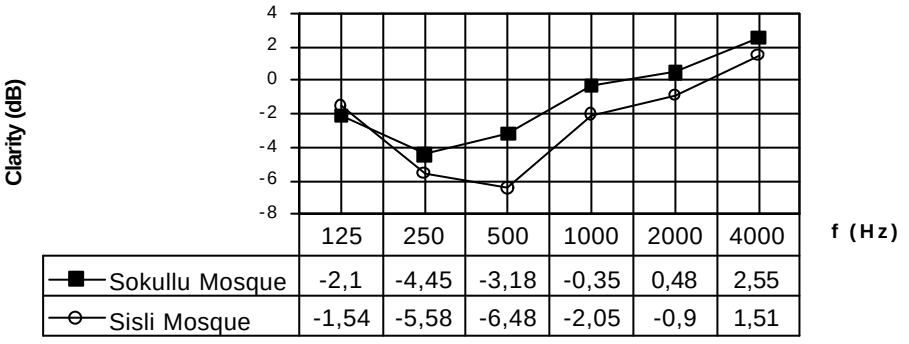
Figures 4, 5 and 6 illustrate comparatively Sokullu and Sisli Mosques' average values of EDT, C_{80} and D_{50} respectively.



	125	250	500	1000	2000	4000
Sokullu Mosque	3,22	3,24	3,08	2,44	1,87	1,26
Sisli Mosque	1,93	2,85	3,42	2,64	2	1,08

Figure 4. Comparison of Sokullu and Sisli Mosques' Early Decay Time (EDT) averages.

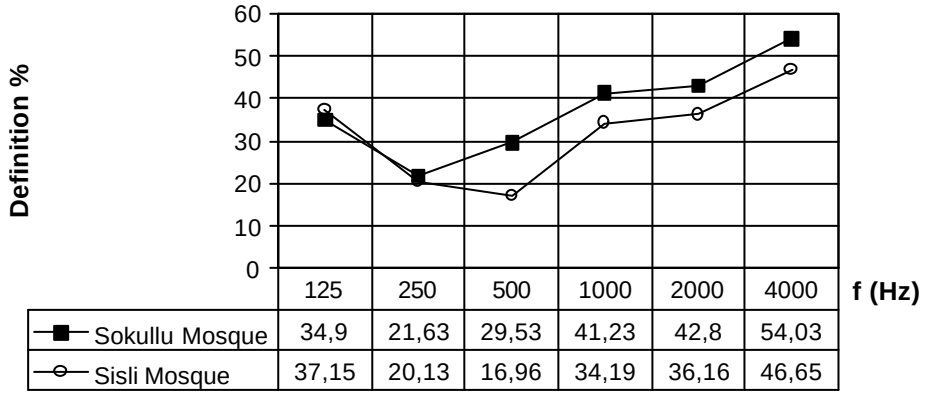
The EDT's of the two mosques differ from each other at low frequencies, but this time contrary to RT's, Sisli Mosque's EDT's at low frequencies are shorter than those of Sokullu Mosque's. The shape of the Sokullu Mosque's EDT curve is similar to its RT curve, whereas that of Sisli, especially at 125, 250 and 500 Hz shows a great difference.



	125	250	500	1000	2000	4000
Sokullu Mosque	-2,1	-4,45	-3,18	-0,35	0,48	2,55
Sisli Mosque	-1,54	-5,58	-6,48	-2,05	-0,9	1,51

Figure 5. Comparison of Sokullu and Sisli Mosques' Clarity parameter (C_{80}) averages.

Clarity values of the mosques mostly differ one from the other at mid frequencies. Clarity in Sokullu Mosque, is better then Sisli Mosque.



	125	250	500	1000	2000	4000
Sokullu Mosque	34,9	21,63	29,53	41,23	42,8	54,03
Sisli Mosque	37,15	20,13	16,96	34,19	36,16	46,65

Figure 6. Comparison of Sokullu and Sisli Mosques' Definition (D_{50}) parameter averages.

Mosques' Definition values are rather close to each other at low frequencies; at higher frequencies the differences get bigger. Definition in Sokullu is better than in Sisli.

Average values (125-4000 Hz) of the measured acoustical parameters for Sokullu and Sisli Mosques are given at Table 5.

Table 5. Average values (125-4000 Hz) of the measured acoustical parameters in Sokullu and Sisli Mosques.

Mosques	**RT (s)**	**EDT (s)**	***C*80 (dB)**	***D*50 %**	**STI**	**RASTI**
Sokullu Mosque	2,90	2,52	-1,18	37,35	0,51	0,48
Sisli Mosque	3,56	2,32	-2,51	31,87	0,50	0,46

The reverberation time is the parameter that shows the greatest difference in Table 5. Other parameters have rather close values for both of the spaces. Although the RT of Sisli Mosque is longer, its EDT is shorter than that of Sokullu Mosque. This can be interpreted as the presence of a less uniform sound field in Sisli Mosque. In general the optimum values of the EDT are given as ±10% of the RT [3]. The average values are not within these limits at neither of the mosques, however the EDT of Sokullu is much more closer to the optimum. Moreover, octave band values show better accordance with RT's in Sokullu Mosque (See Fig. 3 and Fig. 4).

Several sources give different values for the optimum values of $C_{80,}$ which is in fact a parameter to suit music use. As the musical sounds in mosques are choral, the average C_{80} values can be interpreted as suitable taking into consideration the values given in literature [3], [6]. On the other hand differences upon octave band frequencies are more evident in Sisli Mosque, demonstrating poor spectral conditions than Sokullu (See Fig. 5).

D_{50} is mostly regarded as a parameter related with speech and higher values are expected for a better intelligibility. D_{50} values of the mosques can be interpreted as poor, but again Sokullu Mosque's values are better than those of Sisli Mosque's, regarding spectral distribution (See Fig. 6). The STI and RASTI values which are other parameters related with intelligibility, are between 0,46 and 0,51, showing the subjective scale of "Fair" (0,45 - 0,60), for both of the mosques reinforcing the values held for $D_{50.}$

CONCLUSION

This study held to compare the acoustical properties of an ancient an a recent mosque showed that the 16th century mosque Sokullu, has slightly better acoustics then the 20th Century mosque, Sisli. For both of the mosques, the values of the measured parameters are in general not within the limits of the optimum values, however Sokullu Mosque's findings show less spectral differences and are closer to the optimum values. On the other hand, it should be mentioned that values taken into consideration as optimum, are not the values especially determined for mosques. Some of the early results of CAHRISMA Project give signs that Sokullu Mosque's acoustical environment is subjectively accepted as optimum for the mosques of its size. On the other hand, more work is required to explain the reason of the differences between these two similar space.

BIBLIOGRAHICAL REFERENCES

[1] Karabiber, Z., "A New Approach to an Ancient Subject: CAHRISMA Project", 7th International Congress on Sound and Vibration, Garmisch-Partekirchen, Germany, 4-7 July 2000, Proceedings pp 1661-1668.

[2] Karabiber, Z., "Acoustical Problems in Mosques: A Case Study on the Three Mosques in Istanbul", Forum Acusticum, Berlin 99, 15-19 March 1999, 4 pages on CD ROM.

[3] Templeton, D., Sacre, P., Mapp, P., Saunders, D., Acoustics in the Built Environment, Butterworth Architecture, 1993.

[4] Maekawa, Z., Lord, P., Environmental and Architectural Acoustics, EFN SPON, 1994.

[5] Everest, F.A., The Master Handbook of Acoustics, Fourth Edition, McGraw-Hill, 2000.

[6] Lynge, C., Odeon Room Acoustics Program, Version 4,21, Industrial, Auditorium and Combined Editions, Technical University of Denmark, 2000.