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Research article / Araştırma makalesi

Acoustic Evaluation of Worship Buildings: Gülbahar Hatun Mosque Case

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Abstract: The auditory perception of sound in the inner spaces of worship buildings has great importance in terms of ergonomics and it has different optimum properties depending on the function of the space. It is necessary to determine the acoustical properties of the spaces to resolve their acoustic problems. Within the scope of this study, Gülbahar Hatun Mosque in Trabzon was investigated acoustically. Evaluations were performed according to the objective parameters of sound like reverberation time (T30), Early Decay Time (EDT), Definition (D50), Clarity (C80), Speech Transmission Index (STI); and acoustical analysis of the current situation was made by using computer simulation technique. ODEON version 10.1 was used as a simulation program and the 3D model of the Mosque was prepared in SketchUp8. The evaluations were made according to the different occupancy rates of the mosque, taking into account the prayer and preaching activities.

İbadet Yapılarının Akustik Açıdan İncelenmesi: Gülbahar Hatun Camii Örneği

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Sesin nesnel parametreleri,
Cami,
Model,
Bilgisayar simülasyonu

Öz: İbadet yapılarının ana mekanlarında sesin işitsel algısı ergonomi açısından büyük önem taşımaktadır ve mekanın işlevine göre farklı optimum özellikler göstermektedir. Uygulanmış mekanların akustik açıdan optimum düzeye getirilebilmesi için ise öncelikle mevcut akustik koşullarının belirlenmesi gerekmektedir. Bu çalışma kapsamında Trabzon Gülbahar Hatun Camii'nin mevcut akustik özellikleri sesin nesnel parametreleri üzerinden incelenmiştir. Mevcut akustik koşulların belirlenmesinde ODEON version 10.1 simülasyon programı kullanılmış olup üç boyutlu modeller SketchUp8'de hazırlanmıştır. Değerlendirmelerde, reverberasyon süresi (T_{30}), erken gecikme süresi (EDT), belirginlik (D_{50}), netlik (C_{80}), konuşmanın anlaşılabilirlik indeksi (STI) nesnel parametreleri kullanılmıştır. Namaz ve vaaz faaliyetleri sırasında caminin farklı doluluk oranları değerlendirmelerde dikkate alınmıştır

1. Intoduction

In addition to functional and aesthetic approaches, the comfort conditions of the physical environment are of great importance in the interior design of the buildings. In order to provide physical comfort conditions; indicators such as temperature, humidity, wind (air flow) should be obtained at optimum levels. In addition to these, especially in places where sound auditory perception is important, special designs related to sound should also be carried out. Since sound-related (acoustic) designs in the spaces are becoming more complicated by the volumetric increase, the acoustics should be considered as part of the design, from the stage of the making general architectural design approach decisions to the detailing process. In this context, worship structures are acoustically important because of their functions and large volumes in general.

Acoustical research in places;

1. At the design stage; It is carried out either by computer simulation method, or by measurements on scaled physical models.

2. Existing places; It is carried out either by computer simulation method or by acoustical measurements in places.

Acoustical studies about mosques are generally getting made; in the form of evaluation of the current situation, in order to make solutions to obtain optimum conditions; or in the form of acoustical comparison of changes in the form or material, etc.

Abdou (2003) in his study, examined the acoustic properties of the existing modern mosques in Saudi Arabia by making measurements in 21 sample mosques of different sizes and architectural features. Acoustic measurements were obtained with background noise for the operation of the air conditioning unit and the ventilators when they did and did not work. The effect of air conditioning unit, ceiling fans and sound reinforcement systems on the objective parameters of sound has been evaluated in the study. Gül and Çalışkan (2013) examined the acoustic properties of Ahmet Hamdi Akseki Mosque, which was built as the biggest neo-classical mosque project in Ankara in recent years, through the computer simulation program (ODEON v.11.23). Within the scope of the study, the objective parameters of the sound, including the reverberation time, the speech transmission index and the A-weighted sound levels, were evaluated for situations of the full and partially occupancy, where the sound reinforcement system of the mosque was on and off. The results showed that the main worship area is suitable for a mosque. Kavraz and Ilban (2016) examined the acoustic properties of Bulancak Sarayburnu Mosque through the computer simulation program (ODEON v.10). In the study where they included the objective parameters as reverberation time, early decay time, definition, clarity and sound transmission index in the scope of the evaluation, they offered material changes for wall and dome surfaces of the main worship place. Odabası, Gül & Çalışkan (2011), performed acoustic measurements to determine the acoustic properties and have achieved the objective parameter values of the Doğramacızade of Ali Pasha Mosque that considered as the first technological mosque in Turkey. They evaluated the A-weighted sound levels, clarity, early decay time, intelligibility of the sound, and reverberation times. The determined objective parameter values of the sound were compared with the results obtained with the Odeon program at the design stage of the building. As a result of the comparison, it was seen that the difference between the results obtained from measurement and simulation was negligible and found that the numerical acoustic simulation is a reliable evaluation tool. Abbreviations should be defined at first mention and used consistently thereafter.

In this study, acoustic characteristics of Trabzon Gülbahar Hatun Mosque will be determined by computer simulation method. The results of the objective parameters of the sound will be evaluated and the causes of the current acoustic performance will be evaluated. In addition, the results of the mosque will be introduced into the scientific literature for further scientific studies.

2. Materials and Methods

In this study, current acoustic conditions of Gülbahar Hatun Mosque in Trabzon were investigated by computer simulation method. ODEON version 10.1 Computer Simulation Program is used for this purpose. The three-dimensional model used in the simulation program was prepared in SketchUp8. The acoustic evaluations for the current situation were made with the objective parameters of the sound. Objective parameters evaluated in the study are reverberation time (T30), early fall time (EDT), definition (D50), clarity (C80), and the sound transmission index (STI). The accepted optimum levels of objective parameters used in the evaluation are; for T30, 1.75-2.13 sec (Kayılı, 2005), (Abdülrahimov, 2006) for EDT 1.9 to 2.32 sec (Gade, 1989), for D50 30% to 70% (ISO, 2009) and for C80 -4 dB +4 dB (Beranek, 1996) intervals. For the STI parameter is used the table, where the STI numerical values are categorized with the subjective equivalent of each category (Table 1)

Table 1. STI Classification of value ranges (Steeneken and Houtgast, 2002)

Quality	STI value
Bad	0 - 0,32
Weak	0,32 - 0,45
Enough	0,45 - 0,60
Good	0,60 - 0,75
Excellent	0,75 - 1

Gülbahar Hatun Mosque, also known as Hatuniye Mosque, is located on the south side of Atapark in the Gülbahar Hatun neighborhood of Trabzon. It was built by the Ottoman Sultan Yavuz Sultan Selim in 1514 on behalf of his mother Gülbahar Hatun and as a mosque of a complex containing a mosque, a tomb, a bath, a school, an imaret and a madrasa (PDTCT, 2019). At present, only mosque and tomb are remaining and other structures within the complex have been demolished in the historical process (Figure 1).

Figure 1. The Gülbahar Hatun Mosque.

The volume of the mosque, which is built with masonry construction, consists of a main worship hall covered with a dome and a couple of zaviye rooms covered with small domes on both sides. The mosque does not have a women's section. The walls of the mosque, which is covered with plaster, are also covered with wood up to 80 cm height from floor and the pulpit is built as marble. The window gaps and the main entrance door are surrounded with stone frames and the marble windowsills are covered with carpet (Figure 2) (Table 2).

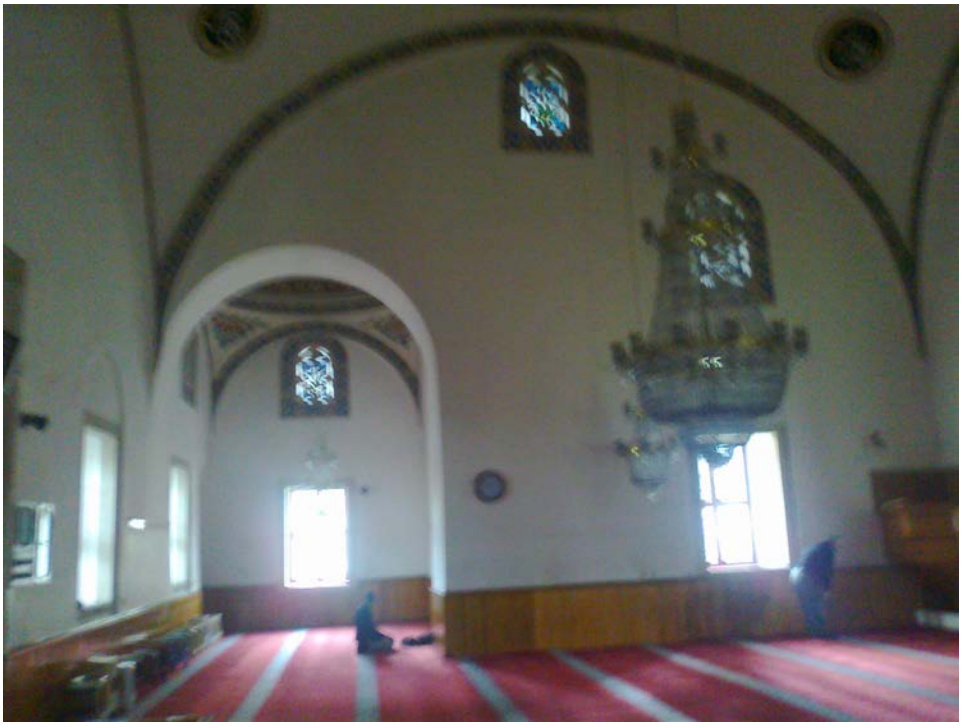

Figure 2. The interier view of the Gülbahar Hatun Mosque.

Table 2. Inner surfaces and covering materials of the Mosque

	No	Surface	Material	ODEON Code	Sound Absorbtion Coefficients 125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Floor surfaces	1	Floor covering	Carpet	7005	0.08	0.24	0.57	0.69	0.71	0.73
	2	Worshipers	Human	11050	0.15	0.23	0.56	0.78	0.88	0.89
Wall surfaces	3	Wall surfaces	Plaster	4002	0.02	0.02	0.02	0.02	0.02	0.02
	4	Windows	Glass	10003	0.16	0.24	0.56	0.69	0.81	0.78
	5	Door and Wall bottoms	Wood	Abdulrahimov, 2005	0.1	0.1	0.1	0.08	0.08	0.09
	6	Stone (around the door)	Stone	Kavraz, 2014	0.06	0.13	0.17	0.2	0.2	0.24
	7	Mihrap	Marble	2001	0.01	0.01	0.01	0.01	0.02	0.02
Ceiling surfaces	8	Dome	Plaster	4002	0.02	0.02	0.02	0.02	0.02	0.02
Other surfaces	9	Rostrum	Wood	Abdulrahimov, 2005	0.1	0.1	0.1	0.08	0.08	0.09
	10	Pulpit	Plaster	4002	0.02	0.02	0.02	0.02	0.02	0.02

Within the scope of the study, a three-dimensional model was prepared in SketchUp8 (Figure 3). ODEON version 10.1 For the model transferred to the Computer Simulation Program, the sound source and receiver positions and all necessary other assignments were carried out. After the necessary settings the program were run and the results of the objective parameters of the sound were obtained.

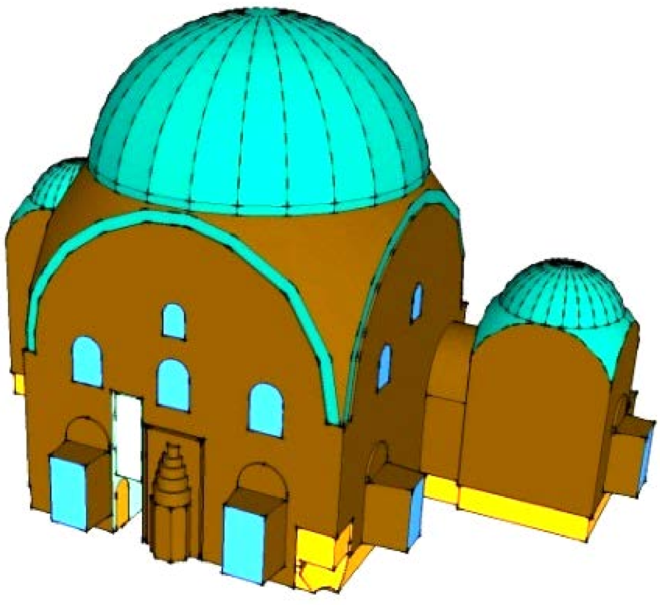

Figure 3. The model of Gülbahar Hatun Mosque's praying hall.

The activity scenarios in the mosques were created according to two different source point positions (prayer mode and preaching mode), three different occupancy rates (empty, 50% and 100%) and two different positions of the worshipers (sitting position and standing position). Source 1 is located on the imam's position in time of the praying. Source 2 is located on the imam's position in time of the preaching. In both positions sources are located 150 cm high from the floor level (from the step level of the stair for the source2) (Figure 4)

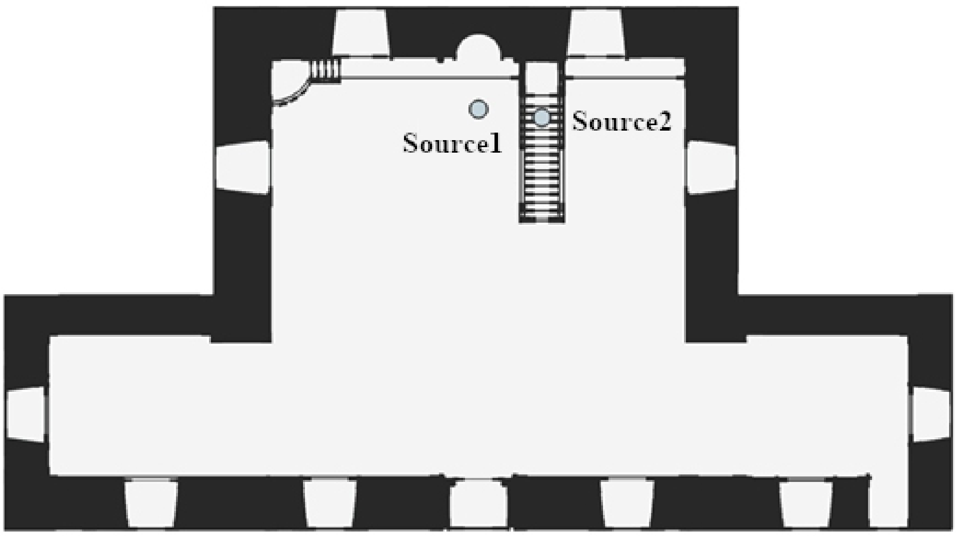

Figure 4. Sound source positions.

The grid function of ODEON 10.1 is used for receiver locations. The main prayer hall of the mosque is divided into 50 cm X 50 cm squares and a receiving point is defined at the center of each square. The objective parameter values of the sound were obtained as the means of the values obtained for each receiver point.

The examination of the obtained values of the objective parameters was compared by changing the occupancy proportion and the location of the sound source positions.
Scenarios are organized in 3 graphs. The cases of comparison of objective parameter results of sound according to occupancy proportions and abbreviated expressions used in the graph;

a. The source 1 is active, the worshipers are in the sitting position, different occupancy ratios;
- In the prayer mode, when the mosque is empty - 1 (empty),
- In the Prayer mode, the worshipers are kneeling, the occupancy ratio is 50% - 1 (K) (50%),
- In prayer mode the worshipers are kneeling, occupancy ratio is 100% - 1 (K) (100%),

b. The source 1 is active, worshipers in standing position, different occupancy ratios;
- in the prayer mode, worshipers are standing, occupancy ratio is 50% - 1 (S) (50%),
- In prayer mode, worshipers standing, occupancy ratio is 100% - 1 (S) (100%),

c. The source number 2 is active, worshipers in sitting position, different occupancy ratios
- In preaching mode, the mosque is empty - 2 (empty),
- In the preaching mode, the worshipers are sitting, the occupancy ratio is 50% - 2 (O) (50%),
- In the preaching mode, the worshipers are sitting, the occupancy ratio is 100% - 2 (O) (100%).

In the graphs; O: worshipers are in the sitting position, A: worshipers are in the standing position, 1: The source 1 is active and prayer mode 2: The source 1 is active and prayer mode

3. Results

The results of the objective parameters of T30, EDT, D50 and C80 obtained from the performed simulations for the purpose of acoustically evaluating the Gülbahar Hatun Mosque were compared for different scenario situations; with each other and with the optimum values. The comparison of the results of the objective parameters with the optimum values is based on the mean of the values in the middle frequencies.

3.1. Analysis of T30 results for Gülbahar Hatun Mosque

Figure 5 shows the mean T30 values for Gülbahar Hatun Mosque according to the occupancy ratios. The optimum T30 value for the volume of Gülbahar Hatun Mosque is in the range of 1.75 - 2.13 sec (Kayılı, 2005), (Abdülrahimov, 2006). At medium frequencies, T30 values were obtained in the optimum level range near the upper limit at 100% occupancy. In empty and 50% occupancy situations, T30 values were obtained above the upper limit of the optimum range. At medium and high frequencies, the values were closer to each other but differences between the values at low frequencies are increased.

Due to the high variation in the values of sound absorption coefficients in octave band frequency ranges on carpet and fabric surfaces, T30 values which are very high at low frequencies were obtained low at middle and high frequencies.

There was a decrease in T30 values as the occupancy increased. The effect of the occupancy ratio, which is more obvious in low frequencies, is reduced at medium and high frequencies. The highest T30 values in the middle frequencies were obtained with 2,34 sec in the preaching mode where the mosque was empty and the lowest T30 value was 1.92 sec in the preaching mode with 100% occupancy ratio and worshippers are standing.

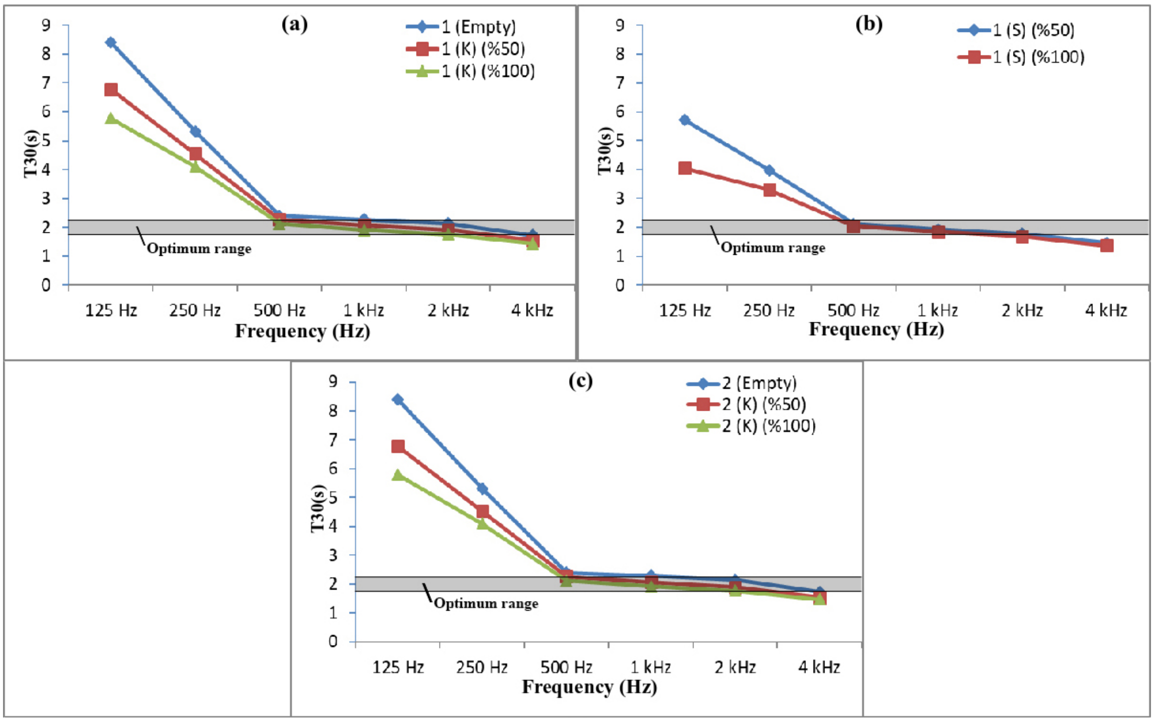

Figure 5. Mean T30 values of Gülbahar Hatun Mosque according to occupancy ratios.

3.2. Analysis of EDT results for Gülbahar Hatun Mosque

The graphs of EDT values obtained for Gülbahar Hatun Mosque according to occupancy ratios are given in Figure 6. The optimum EDT for the volume of Gülbahar Hatun Mosque is in the range of 1.92 - 2.32 s (Gade, 1989).

When the EDT results were examined, the values were obtained extremely low at low frequencies, and slightly above the optimum upper limit at medium and high frequencies. In general, EDT values were obtained equal to T30 values or above the T30 values with small differences. This shows that the reverberation is proportionally diminished within the mosque. EDT values decreased with increasing occupancy ratio. The highest EDT value in the middle frequencies was 2.34 sec, when the mosque was empty, in the preaching mode; and the lowest EDT value was 1.85 sec in the prayer mode within 100% occupancy, worshipers are standing.

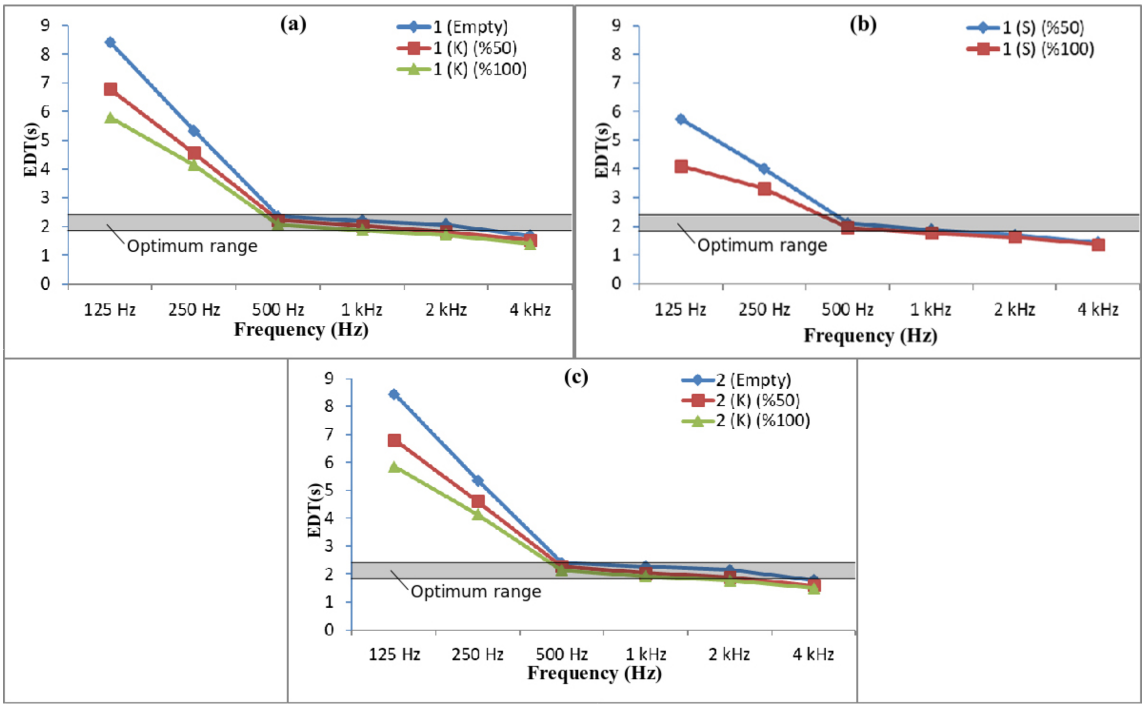

Figure 6. Mean EDT values of Gülbahar Hatun Mosque according to occupancy ratios.

3.3. Analysis of D50 results for Gülbahar Hatun Mosque

The mean D50 values of Gülbahar Hatun Mosque according to occupancy ratios are shown in Figure 7. The optimum level for parameter D50 is 30% - 70% range (ISO, 2009). When the D50 values were examined, it was found that they were slightly above the lower limit of the optimum range, in the middle frequencies. The D50 parameter values have increased with the increase of the occupancy ratio. The lowest D50 value in the mid-frequencies was 30% in the prayer mode, mosque was empty; the highest D50 value was obtained 35% in the preaching mode, occupancy of the mosque is 100%, worshipers are sitting position.

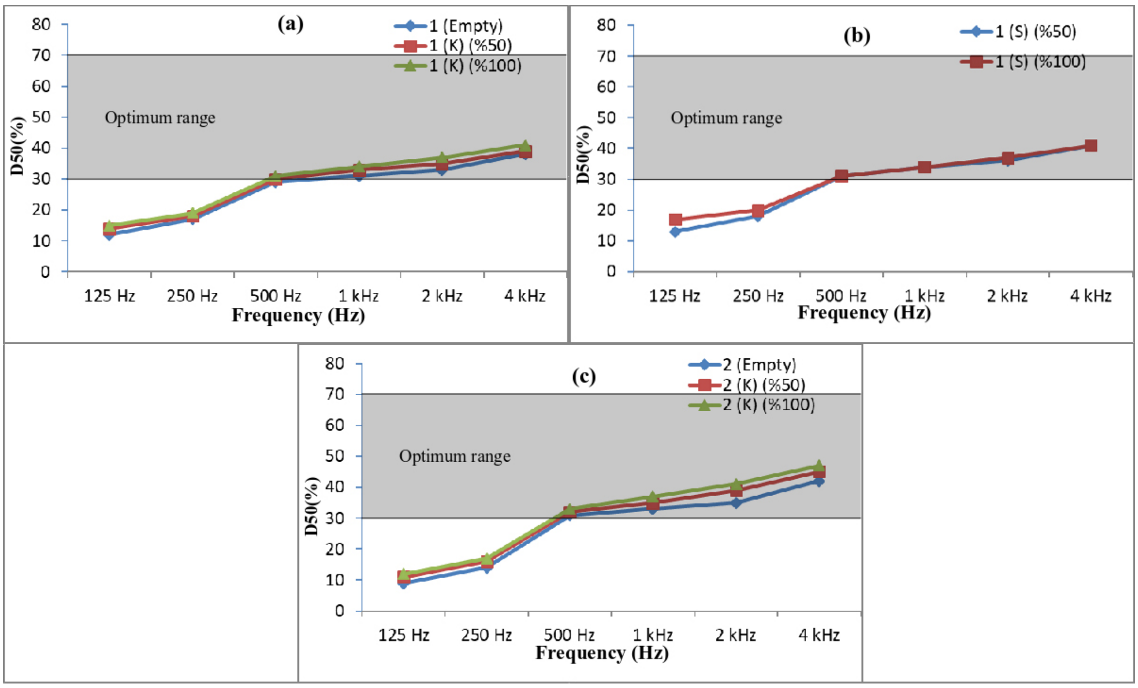

Figure 7. Mean D50 values of Gülbahar Hatun Mosque according to occupancy ratios.

3.4. Analysis of C80 results for Gülbahar Hatun Mosque

The values of C80 results of Gülbahar Hatun Mosque according to occupancy ratios are shown in Figure 8. The optimum values for parameter C80 are -4 dB +4 dB interval (Beranek, 1996). When the mean C80 values are examined according to the occupancy ratio, it is seen that the values are at optimum levels in all cases at medium frequencies. With the increase of the occupancy ratio, C80 values are increasing. The highest C80 values were -1.1 dB obtained in the preaching mode where the mosque is full and the worshipers were in the sitting position; and the lowest C80 values were -2.5 dB, obtained in the prayer mode and mosque was empty.

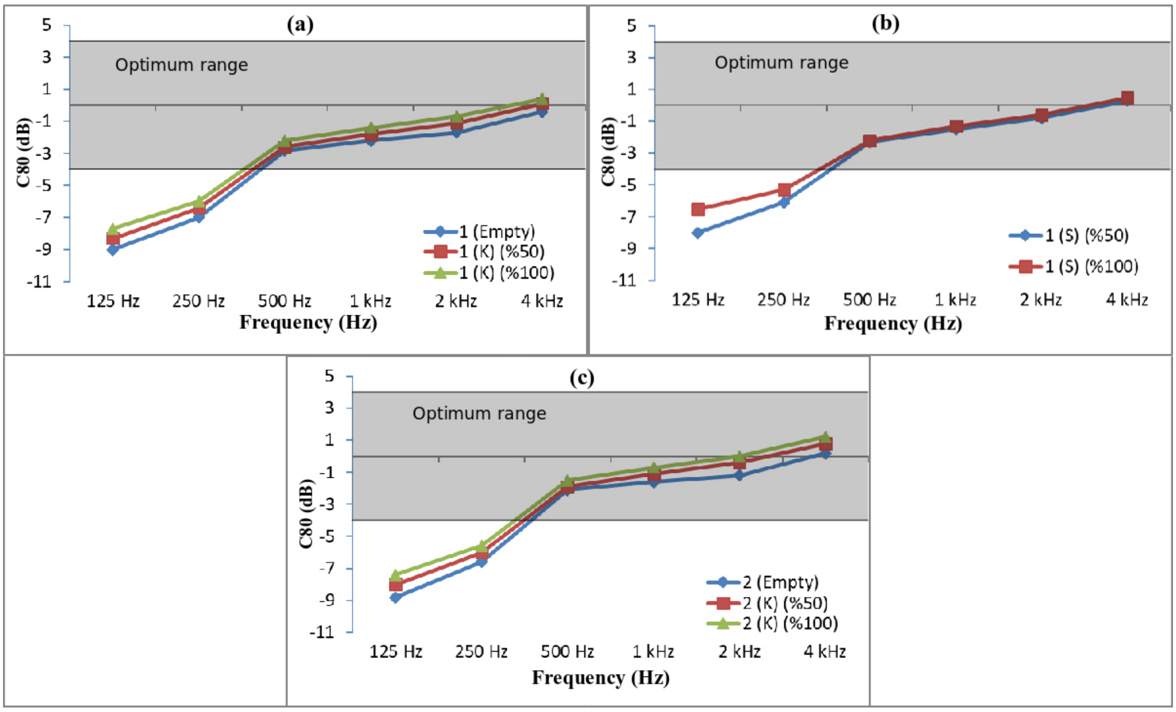

Figure 8. Mean C80 values of Gülbahar Hatun Mosque according to occupancy ratios.

3.5. Analysis of STI Results for Gülbahar Hatun Mosque

The STI values obtained for Gülbahar Hatun Mosque are given in Table 3. STI values of 0.45 and above were considered to be optimal.

When the results are examined, it is seen that the values are at the lower limit of the optimum range. In cases where the mosque was empty, STI decreased to 0.42 due to increased reverberation time and increased to 0.48 with the increase in occupancy.

Table 3. Gülbahar Hatun Mosque mean STI values

Mode	STI Value
1 (Empty)	0,44
1 (K) (%50)	0,48
1 (K) (%100)	0,47
1 (S) (%50)	0,45
1 (S) (%100)	0,45
2 (Empty)	0,45
2 (K) (%50)	0,44
2 (K) (%100)	0,42

4. Discussion and Conclusion

Optimum values were obtained for all D50 and C80 parameters. In the STI parameter, the results are slightly over the lower limit of the “good” category in prayer mode. In preaching mode, the value fell below the lower limit and came to the weak category. However, this situation is negligible in terms of acoustic performance since there are very small differences between values. Although the reverberation time is at optimum level, for D50 and STI parameters that related to the intelligibility of speech, optimum levels are gained at the lowest limit. This situation is thought to be caused by the zawiyahs located on both sides of the mosque. The additional volumes formed by the zawiyahs increase the reverberation time, but this increase decreases the D50 and STI values due to the late reflections. The increase in fullness in the mosque increased the absorption, as expected, decreased T30 and EDT parameters; The values of D50, C80 and STI parameters are increased.

In results it can be said that Gülbahar Hatun Mosque, thanks to its enough volume per person and its geometry, have good acoustic performance

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References

Abdou, A. A. (2003). Measurement of acoustical characteristics of mosques in Saudi Arabia. *Journal of the Acoustic Society of America*;113 (3): 1505-1517

Abdülrahimov, R., (2006) *Salonların Akustiği ve Tasarımı*; Trabzon.

Beranek, L. (1996) *Concert and Opera Halls: How They Sound.* New York, USA: Acoustical Society of America

Gade, A. C. (1989) Acoustical Survey of Eleven European Concert Halls, *The Acoustics Laboratory, Technical University of Denmark*, Report no:44.

Gül, Z. G, Çalışkan, M., (2013). *Acoustical Design of Turkish Religious Affairs Mosque* Paper presented at Proceedings of Meetings on Acoustics, Montreal

ISO, (2009) Acoustics – Measurement of rooms acoustic parameters – Part 1:Performance spaces, BS EN ISO-3382-1.

Kavraz, M. (2014). The acoustic characteristics of the Çarsi Mosque in Trabzon, Turkey, *Indoor and Built Environment*, 1-9.

Kavraz, M., İlban, B., (2016) *Bulancak Sarayburnu Camii'nin Akustik Açıdan Değerlendirilmesi,* Paper presented at Çağımızda Cami Mimarisinde Arayışlar Uluslararası Sempozyumu, Giresun

Kayılı, M., (2005). Acoustic Solutions in Classic Ottoman Architecture, *Foundation for Science Technology and Civilisation*, Publication ID: 4087.

Odabaş, E, Gül, Z. S., Çalışkan, M., (2011) *Doğramacızade Ali Paşa Camii'nin Akustik Ölçümlerle Değerlendirilmesi*, paper presented at 9.Ulusal Akustik Kongresi, Ankara

PDTCT. (2019) Provincial Directorate of Tourism and Culture of Trabzon, The Gülbahar Hatun Mosque. http://www.trabzonkulturturizm.gov.tr/TR,57661/camiler.html Access date: 09.02.2019

Steeneken, H. J. M., & Houtgast, T., (2002). Basics of the STI Measuring method. in Houtgast, T., Steeneken, H., Ahnert, W., Braida, L., Drullman, R., Festen, J., Jacob, K., Mapp, P., McManus, S., Payton, K., Plomp, R., Verhave, J., Wijngaarden, S. V., (Eds), *Past, Present and Future of the Speech Transmission Index* (pp. 13–44). Soesterberg, The Netherlands: TNO Human Factors.