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Determination of the characteristics of contemporary Turkish mosque and it's acoustical properties

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ABSTRACT

In the last 10 years in Turkey the number of a place of worship of the followers of the religion of Islam (mosque) has increased. Mosque, as a multi-functional place designed to be used technically for speech and music performances, is an active research area for experts of acoustics.
In this study, a section of a comprehensive study focused on speech intelligibility in mosques is presented. The aim is to determine Turkish mosque types which are commonly built since the year of 2000 and to evaluate of its acoustical properties. Mosques built since the year of 2000 in a city which has the average population of the Turkish urban areas, are selected to be analyzed for determining the specification of the sample mosque models' physical characteristics. Method used in this study is; collection of the determined mosques' properties; comparative analyze of the collected data; synthesizing the design of the sample mosque and obtaining the room acoustic parameters by using simulation techniques. Finally, acoustical parameters of sample mosque are compared with the acoustical parameters of mosques suggested in the literature. Also, by this research the base model of the contemporary Turkish mosque is provided using for future studies on mosque acoustics.

Keywords: Contemporary Turkish mosque; Mosque acoustics; Acoustical simulation

1. INTRODUCTION

Mosque is defined as a place of worship of the followers of the religion Islam. In Turkey among all religions Islam is the prominent one (1). Therefore, in Turkey among all religious buildings the Muslims' one is attracting more attention and is built more often. The number of mosques in the territory of Turkey has been increasing over the years. Especially in the last 10 years referred increase is becoming more prominent. While every year around 660 mosque is being built, since 2010 till now average annual number of mosque has increased to 1000. (URL1).

Speech and music events such as collective worshiping, listening the sermon and recitation of holy Quran are organized in these places. The rituals that take place in the mosque are: salah, sermon and Khutbah Sermon. Salah is the ritual of worshiping the god. In the Salah rituals that are used for music, the imam (sound source) standing in front of the mihrab (architectural element in a form of niche (20) located on the qibla wall), melodically recites the holy Quran; the congregation (the listener), being turned towards to the Qibla wall, is standing behind the Imam and is listening to the recital. Sermon and Khutbah sermon are rituals where religious speeches are made. In the sermonrituals that are used for speech, the imam is sitting on the chair over the pulpit (few step high platform raised from the ground (20)) making the religious speech; the congregation being in a row is sitting on the floor listening the preach. During the Khutbah Sermon the congregation being in a row is still sitting on the floor but imam, who is making the religious speech, is standing over the mimbar (a 'pavilion' in the form of a lodge covered with cones, placed over the top of the raised platform that is located behind the arched door and is reached by stairs *(20)*). Based on Islamic beliefs, in mosque women and men do not worship side by side. Therefore, in every mosque there is a special place arranged as women's worship

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area. Considering the characteristics of the rituals in the mosque, it can be said that the mosque is designed as a place for listening. Therefore, the intelligibility of speech and clarity of music in mosques are important issues and this condition shows the importance of acoustic comfort in the related places.

The mosques attract the attention of experts of acoustics due to their own architectural properties as well as their special acoustical properties. The physical properties of the mosque such as form, volume, floor height, surface characteristics, ceiling type, material properties and source receiver positions in rituals directly affect the acoustic comfort of the mosque (2-10, 14, 19). Therefore, in the mosque acoustics literature: the effect of different architectural elements (6, 21-22) and interior finishing materials (7, 10, 19) on acoustic comfort in the mosque were discussed. In addition, the studies on determination of the optimum acoustic values for the mosque still continue (6, 9-10). In order to determine the acoustics of the mosque, parameters such as Reverberation Time (RT) and Early Decay Time (EDT) are examined. The intelligibility of the speech is evaluated over the parameters Definition (D50) and Speech Transmission Index (STI); liveliness of music is evaluated over the parameters of Clarity (C80) (2-10, 14, 19). The acoustic defects such as focusing, caused by concave surfaces, and echo, caused by delayed reflections from reflective properties of interior finishing materials, are likely to occur in large and domed spaces such as mosques. Due to the negative effects on the acoustical comfort of the space, related defects must be predicted and prevented during the design phase of the mosque.

Contemporary Turkish mosques are still being built with domed ceiling as it was being built in Ottoman period. However, the use of resonators in the cavity of dome appears only as the characteristic of the Ottoman period; nowaday, it has lost its practicality (4, 8). Since contemporary Turkish mosques are different from the old Ottoman mosques in terms of size and acoustic performance (in contemporary mosques resonators are not being applied in cavity of the domes; related mosque's designs are simpler and the diffusion effect of the finishing materials are lower than one's in old Ottoman mosque), the future studies on mosque acoustics will be led to attainment of more efficient results if focuses on contemporary mosque characteristics.

In this paper that is prepared as part of a comprehensive study on the given appoints, it is aimed to determine the acoustic conditions of mosque that presents the most commonly built mosque in Turkey being determined through the investigation/ compilation of physical properties of Turkish contemporary mosque, by using the simulation methods. All mosques being built since 2000 in Eskisehir, province which has the average population of the Turkish provinces, have been selected as a research area of this study. The physical properties (like size, shape, interior materials and capacity) of all mosques in Eskişehir province were investigated; characteristics of mosque to be built in 2019 were predicted over the obtained datas from examined mosques by using statistical methodes such as determination of average value and trend analysis; and in this way, Contemporary Turkish Mosque's common architectural (pulpit, mimbar, mihrab, women's worship area etc.) and material (floor, wall, ceiling, mimbar, pulpit, mihrab finishing material) properties were determined. According to these characteristics, sample mosque was modeled in digital environment and it was evaluated in terms of room acoustics using simulation method.

The aim of this study is to emphasize the importance of acoustic comfort in mosques and to determine how well the acoustic criteria proposed in the national and international literature for the mosques is provided in the modern Turkish mosques.

2. RESEARCH METHOD

2.1 Procedure for Determining the Characteristics of Contemporary Turkish Mosque

Total of 29 mosques built in Eskisehir province of Turkey since 2000 are selected as a research area to determine the Contemporary Turkish Mosque's characteristics. Information on the capacity and floor area of the mosques were obtained and confirmed on site. The physical characteristics of the mosque such as: the shape of the mosque, the interior finishing material, the location of the other architectural elements in the main room of the mosque (membar, mihrab, pulpit, women worship area, load-bearing system (columns, domes)) and the solid-void ratio on the wall were observed by visiting each selected mosque; and the data obtained from the observations were compiled. Physically separate spaces from the main area of the mosque, such as basement and entrance hall were excluded from detailed investigations. Therefore, detailed investigations focus on the main area of mosques. Schematic floor and section plan of each mosque, including the load-bearing system of it, is drawn and

the location/ size of the architectural elements such as doors, windows, stairs, etc. were marked. Physical properties of all mosques were compiled, tabulated, evaluated and as a result the common properties for the sample mosque were determined.

Statistical methods were used to determine the characteristics of the sample mosque. The physical properties such as the shape of the main area of mosque, the interior finishing material, the interior location of the architectural elements were determined as the most common properties of the examined mosque. Dimension and capacity characteristics were determined by analyzing the capacity and floor areas of the examined mosques according to the years through trend analysis, and were determined as the average capacity and floor area of the mosque to be built in 2019.

2.2 Procedure for Modeling and Simulation of the Sample Contemporary Turkish Mosque

ODEON 14 Auditorium acoustic simulation software was used for acoustic modelling of determined sample mosque. Modeling and simulation methods were based on the fallowing steps: acceptances and conditions in modeling; the source- receiver position taken according to the rituals in mosque; acoustic parameters to be used in evaluation, and model and simulation data evaluation.

Acceptances and conditions in modeling: Depending on the occupancy rate of the mosque, 3 different models are made: empty, 30% and 100% occupied (4). The background noise in the model is designed according to the NC25 curves proposed in the literature (5).

The source- receiver position taken according to the rituals in mosque: The mosque model is simulated according to 3 different rituals in the mosque and the source- receiver positions taken according to them: salah, sermon and khutbah sermon.

-Salah ritual: source point, being turned towards mihrab, being located in mihrab at distance of 1,5m from the wall, is having the elevation of 1,65m (5); receiver grid being turned towards Qibla wall is having elevation of 1,7 m (5)

-Sermon ritual: source point located at pulpit is having elevation of 1,8 m symbolizing the imam sitting on the chair (1,2m of height) over the 0,6 m high pulpit; receiver grid being turned towards Qibla wall is having elevation of 0,9m (5).

-Khutbah sermon ritual: source point located at mimbar is turned towards congregation and it has elevation of 3,2 m symbolizing the imam standing on the feet (1,65m of height) over the 1,55 m high mimbar; receiver grid is having elevation of 0,9m (5)

Acoustic parameters to be used in evaluation: RT, EDT, D50, C80 and STI parameters were investigated in order to determine acoustic conditions in the room (2-4). Grid calculation was used in simulation of acoustic codition. Grid size was determined as 1,2*1,2m, symbolizing the distance between rows of congregation during the rituals.

Model and simulation data evaluation: The evaluation of the general acoustic condition of the sample mosque model was done according to the simulation data obtained for each mosque ritual and occupancy cases. The results obtained were evaluated by being compared to the optimum values proposed in literature.

2.3 Optimum acoustic conditions/properties for Sample Contemporary Turkish Mosque

In this section optimum values of acoustic parameters (RT, EDT, D50, C80 and STI) proposed in literature of determination of the optimum acoustic condition in mosque, were compiled and arranged according to the physical and architectural features of Sample Contemporary Turkish Mosque determined within the scope of this study (Table 1).

Table 1- Optimum acoustic values for mosque

PARAMETER	VALUE *(Reff.)*	PARAMETER	VALUE *(Reff.)*	
RT	1,1- 1,7 s	STI	<0.3: bad;	0.6-0.75: good;
EDT	+/- 10% RT *(4, 15)*		0.3-0.45: poor;	0.75-1.0: excellent
D50	0.3-0.7 *(5, 13-14)*		0.45-0.6: fair;	*(16)*
(500-1000 Hz)			*(16)*	
C80	-1 to +3 *(4, 17)*			

For all relevant parameters, except for -RT (EDT, D50, C80 and STI) the proposed values for mosques in the literature are considered as optimum. The optimum value range of RT was determined by considering the proposed values for mosques in the literature, as well as the proposed values for spaces that accommodate the events similar to mosque's ones.

The optimum RT values for the mosques, based on the literature, have been evaluated according to the architectural features of the sample mosque (see 3.1 Architectural Properties Section). According to this; For the sample mosque with a volume of 4000 m3, the optimum RT value at medium frequencies according to different sources is 2.1 s (6); 2,4- 2,9 (9) and 1,35s (10). The values which are quite different from each other are compared with the RT values suggested in the literature for the places that accommodate speech and music events similar to the mosques' one. According to this;

-For the speech, the optimum RT values of the Catholic and Protestant church proposed in the literature were examined and it was seen that related value has been proposed as: 1.1 s-1.5 s for the Catholic Church (11); 1.35 s for the Protestant Church (12).

-For the music, the optimum RT values of choral music being proposed in the literature were examined and it was seen that related value has been proposed as 1.7 s (18).

This obtained data, in case of RT value of sample mosque being among the range of 1.1s and 1.7s for speech and music performances, has been evaluated as appropriate for providing optimum conditions. In addition, it is seen that 1.35s (10) suggested by Orfali for the optimum RT value of the mosque has value being among the respective range.

According to the foundings in literature, in this study it was assigned that the optimum RT value of the sample mosque for all frequencies should be between 1.1s and 1.7s. and in the middle frequencies should be 1.35 s.

3. SAMPLE CONTEMPORARY TURKISH MOSQUE MODEL PROPERTIES

3.1 Architectural Properties

Contemporary Turkish Mosque Model's characteristic determination was done respectively as followes: determination of volume, floor area and capacity; determination of plan and ceiling types; determination of location of women worship area, mihrab, pulpit and mimbar and determination of interior finishing materials.

Volume, floor area and capacity: As a result of the compilation of the physical characteristics of the Contemporary Eskişehir Mosques the capacity and floor area of a mosque to be built in 2019 were calculated using statistical trend analysis, to have a capacity of 1164 person and floor area of 647 m2 (Figure 1).

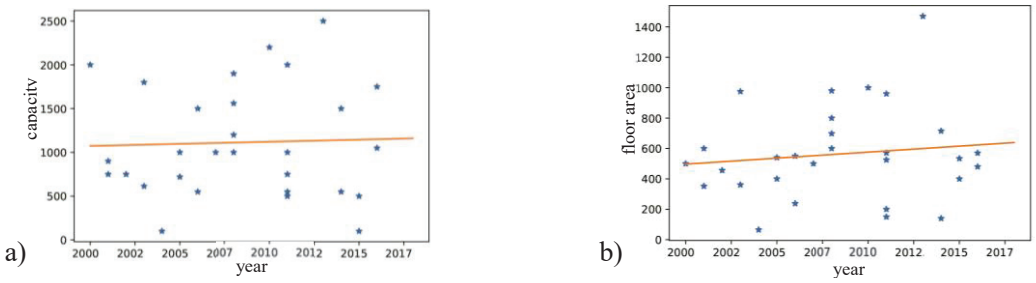

Figure 1- Trend analysis; related to its own building year mosque's a)capacity tendency; b)area tendency

The volume of the mosque is calculated as $8m^3$ per person. When the basement floor and main entrance area in the mosque have been removed from the total mosque volume, the volume of the main space of the mosque was calculated as 4000 m3.

Plan and ceiling type: According to the data obtained, the main space of the mosque has 5 different plan types: square (%21); narrow edge rectangle (%18); wide edge rectangle (%25); "T" shaped (%21) and different polygon shaped (%14). Ceiling type is made in 3 different ways: hip roof (%14); flat roof (%4) and domed roof (%82). According to the results, it was determined that the main area of mosque modeled in this study is a wide edge rectangular floor plan with domed ceiling. According to the number of domes being built in examined wide edge rectangular floor plan mosques the number of domes to be designed in model is determined: 1 main and 11 small domes over the main

area of mosque (Figure 2).

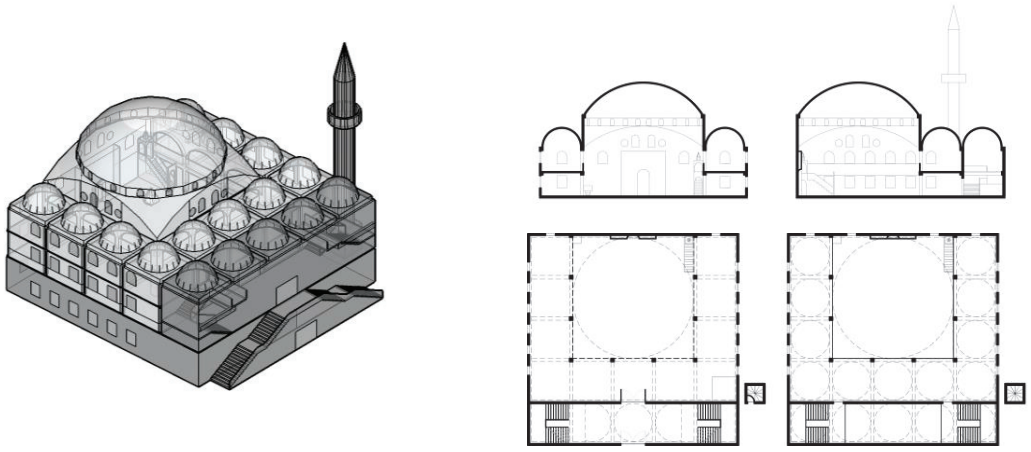

Figure 2- Determined mosque floor plan, section plan and 3D view

Location of women's worship area: In the sample mosques examined, it was seen that the women's worship area is located inside the main area of the mosque in two different places: on the back side of the ground floor of the mosque (%7) or over the mezzanine floor (%93). Also it is seen that the mezzanine floor inside the mosque is designed in two different shapes: leaning only on the back wall- "I" shaped (%30) and leaning on the back and side walls- "U" shaped (%70). In model mosque women's worship area has been located according to the results of the examination, over the "U" shaped mezzanine floor.

Location of Mihrab, Pulpit and Mimbar: For the acoustic performance of mosque the location of source (imam) during the salah, sermon or khutbah sermon is of the great importance. Therefore, the locations of mihrab, pulpit and mimbar have been determinated on site. All three are always leaning on the front wall, Qibla wall. Mihrab is always placed in the middle of the Qibla wall in a form of niche. But location of the mimbar and pulpit differs from mosque to mosque. In refer to mihrab, pulpit is always placed on the right side of it, and the mimbar is always placed on the other side. From the examination it has been seen that both pulpit and mimbar are placed in two different place: leaning on the side wall or aligned to the inner side of the women's worship place being placed over mezzanine floor. It is seen that in %64 of case both of them are placed to be aligned to the inner side of the mezzanine floor.

Interior finishing materials: Interior materials of examined mosques has been listed, the most commonly used indoor finishing materials were brought forward and identified as the interior finishing material of the mosque to be modelled. (Table 2).

Table 2: Interior finishing materials of the Contemporary Turkish Mosque

Architectural Element	Floor	Wall			Ceiling	Mihrab	Mimbar	Pulpit	Women's worship area			
		Side and Back Wall		Front Wall					Floor	Side and Back Wall		Front Wall
Material	Carpet	Plaster+ 1m heigh timber on struts		Tile covering %50 of wall and the rest of it is plasterd	Plaster	Tile	Tile	Tile	Carpet	Plaster+ 1m heigh timber on struts		Tile covering %50 of wall and the rest of it is plasterd

3.2 Acoustic Features

The simulated acoustic values, for all ritual and occupancy cases in mosque, are presented in following tables.

Table 3- **RT** values simulated for all ritual cases in empty, 30% ve 100% occupied mosque

frequence	63	125	250	500	1000	2000	4000	8000
empty	2,62	2,66	3,15	2,78	1,78	1,33	1,08	0,70
30% occupancy	2,07	2,09	2,12	1,62	1,17	1,05	0,92	0,63
100% occupancy	1,52	1,53	1,36	1,02	0,93	0,95	0,83	0,52
Proposed RT_{opt}	1,1-1,7							

Table 4- **EDT** values simulated for all ritual cases in empty, 30% ve 100% occupied mosque

frequence	63	125	250	500	1000	2000	4000	8000
empty	2,69	2,73	3,21	2,82	1,82	1,27	0,98	0,69
30% occupancy	2,17	2,23	2,19	1,51	1,08	0,79	0,71	0,56
100% occupancy	1,46	1,48	1,29	0,88	0,81	0,69	0,67	0,53
Proposed EDT	+/- 10% RT							

Table 5- **D50** values simulated for Salah, Sermon and Khutbah Sermon rituals in empty, 30% ve 100% occupied mosque

frequence		63	125	250	500	1000	2000	4000	8000
Salah	empty	0,29	0,29	0,27	0,31	0,37	0,50	0,56	0,68
	30% occupancy	0,36	0,35	0,39	0,52	0,54	0,62	0,66	0,74
	100% occupancy	0,45	0,44	0,50	0,64	0,61	0,65	0,66	0,73
Sermon	empty	0,25	0,25	0,22	0,25	0,33	0,46	0,52	0,64
	30% occupancy	0,29	0,27	0,30	0,42	0,47	0,54	0,58	0,68
	100% occupancy	0,42	0,42	0,46	0,57	0,58	0,63	0,64	0,72
Khutbah Sermon	empty	0,27	0,26	0,23	0,28	0,36	0,47	0,55	0,68
	30% occupancy	0,31	0,30	0,31	0,43	0,46	0,51	0,56	0,66
	100% occupancy	0,32	0,32	0,37	0,53	0,55	0,58	0,61	0,71
Proposed D50		0.3-0.7							

Table 6- **STI** values simulated for Salah, Sermon and Khutbah Sermon rituals in empty, 30% ve 100% occupied mosque

Occupancy	Salah	Sermon	Khutbah Sermon
empty	0,49	0,44	0,46
30% occupied	0,53	0,46	0,49
100% occupied	0,54	0,52	0,45
Quality Score	<0.3: bad; 0.3-0.45: poor; 0.45-0.6: fair; 0.6-0.75: good; 0.75-1.0: excellent		

Table 7- **C80** values simulated for Salah, Sermon and Khutbah Sermon rituals in empty, 30% ve 100% occupied mosque

frequence		63	125	250	500	1000	2000	4000	8000
Salah	empty	-2,30	-2,40	-3,10	-2,00	0,00	3,00	4,60	7,80
	30% occupancy	-0,70	-1,00	-0,20	2,60	3,60	5,70	6,70	9,60
	100% occupancy	1,4	1,1	2,4	5,5	5,5	6,6	7,1	9,6
Sermon	empty	-3,1	-3,1	-3,9	-3,1	-0,8	1,8	3,3	6,3
	30% occupancy	-2,1	-2,5	-1,8	0,8	2,4	3,9	4,8	7,6
	100% occupancy	1,1	1,0	2,1	4,2	4,2	5,6	6,6	9,3
Khutbah Sermon	empty	-2,6	-2,8	-3,6	-2,6	-0,3	2,1	3,8	7,0
	30% occupancy	-1,6	-1,6	-1,5	1,1	2,1	3,1	4,1	7,0
	100% occupancy	-0,1	-0,1	0,8	3,8	4,5	5,1	5,8	8,5
Proposed C80		-1 to +3							

Since RT and EDT values do not depend on source position, related values simulated from sample mosque model were presented only according to different occupany statuses (empty, %30 and %100 occupancy) of mosque (Table 3 and Table 4). Values simulated for other parameters (D50, STI, C80) were presented according to all ritual and occupancy cases in mosque (Table 5, Table 6 and Table 7).

4. EVALUATION OF THE RESEARCH RESULTS

In order to provide acoustic comfort conditions in mosques, the reverberation time should be provided between the recommended optimum values and it should be determined whether the sound distribution in the space is appropriate. Therefore, in the evaluation of simulated Turkish Contemporary Mosque Model, firstly RT and EDT values were examined.

It is seen that in empty mosque RT values are not among the optimum value range. However, it is seen that in %30 occupied and 100% occupied mosque RT values are close to requested ones. The reasons for long RT are related to wideness of volume of mosque, domed mosque ceiling and the reflectivity of interior finishing material. Due to the size and height of the dome, the focusing defect in the sample mosque has been eliminated, but due to its reflective properties, it sends long and very late reflections to the main area of mosque, causing acoustic defects such as echo and masking. However, as long as the mosque beside the intelligibility of speech, has to support clarity and liveliness of the Quran reciting, the long reflection time is beneficial in this sense.

Early Decay Time is directly linked to RT and changes with RT changes. The EDT values of the simulated mosque remain within the limits of +/- 10%. Therefore, it is seen that the sound is uniformly distributed in the modelled mosque for all cases of occupancy.

In the simulated mosque it is also seen that parameters over speech intelligibility D50 and STI have values that satisfy expectations: D50 suits the proposed optimum range and STI is characterized as “fair”. It is observed that as the number of people in the mosque increased, the D50 and STI values also increase. The reason for this is the increase in the total absorption of the space due to changes of occupancy rate in mosque.

In the case of music liveliness described by C80 parameter it is seen that it does not provide the desired comfort. According to the occupancy rate of the mosque, the best values of C80 are obtained for Salah ritual when the mosque is %30 occupied. In the relevant case, the C80 parameter is found to suit the proposed optimum value range at low and medium frequencies. Considering the fact that in the mosque the speaker / performer is always a man and male voice nature is to be low- pitched sound, the situation explaned above may be considered as suitable for the performance of the music. In empty or %100 occupied mosque for Salah ritual and in all occupancy statuses of Sermon and Khutbah Sermon, during music performance disturbing situation occurs, the sound gets dry and enrichment of sound gets prevented.

5. CONCLUSIONS

According to the datas compiled from contemporary Turkish mosque examination and the results obtained from of simulated sample mosque model having average characteristics of examined mosques, it was revealed that acoustic comfort conditions were not taken into consideration during the design phase. Although the contemporary mosques have been unconsciously designed in the meaning of acoustic, the simulated values (RT, EDT, D50, STI, C80) of the mosque's occupancy rate of %30 and %100 are approaching the proposed optimum values. If it is considered that actual occupancy of the mosque is fully occupied during the Sermon and Khutbah Sermon, than the general acoustic comfort of the simulated mosque can be characterized as comfortable. However, depending on the interior planning and furnishing, there are acoustic shadow defect occurred in mosque; therefore, this comfort issue should be questioned for the whole space. Furthermore, among of all rituals in mosque Salah is the most performed one and importance of lively reciting Quran during this ritual is of great importance. Therefore, it is important to C80 values be among proposed optimum range. According to the results of this study it is seen that C80 vlues are not among the proposed optimum values for C80. Sound reflective domed ceiling inside the mosque causes echo and masking defect that is found to be one of the main reason for the C80 value not being as it s required.

Finally, it is expected to the model of the Turkish contemporary mosque determined in this study, be used in further studies on mosque acoustics and in detailed researches on the clarity of music and speech intelligibility in mosque.

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