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Effect of Variation in Audience Absorption on the Reverberation Characteristics of Mosque

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Abstract: The role of the mosque, as a multi-functional space, where different modes of activity are performed, has been established. The respective aural requirements of the space are defined, together with the corresponding acoustical characteristics of speech sounds. The role of audience absorption in the modification of the latter is highlighted and expressed in terms of some measurable acoustical performance descriptors.

Acoustical measurements, conducted in a typical medium-sized mosque, on an audience sample of a limited size, have been utilized to extrapolate values to simulate absorption of full audience capacity. This parameter, has been used to derive the two prime acoustical performance descriptors of reverberation time and signal level reduction for modes of activity. These, in turn, are employed to investigate the effect of absorption, due to audience, on the aural requirements of the space, namely sound audibility, speech intelligibility and "tajweed" comprehension, in the light of the relevant acoustical characteristics of speech.

Analyses of the results confirm the significance of audience absorption in modifying the acoustical nature of speech sounds. They assert variation of speech quality with activity mode, according to the magnitude of audience absorption. This variation is found to be beneficial as it enhances the aural requirements of the space.

Introduction

The mosque is, acoustically, a multi-functional space, in the sense that various worship activities are conducted inside. These comprise:

i) performing prayers individually or in a group, led by a leader (imam),

ii) attending to preaching being delivered on its own, or in conjuction with weekly Friday prayers,

iii) listening to, or reciting verses from the holy Quran, separately or during prayers.[1]

The acoustical performance of the mosque building, as a source-path-receiver system, is influenced by the relative position of both the speaker and members of the audience, while conducting any of these activities. It follows that two distinct modes of use can be identified, each being dependent on the postures of worshippers and their orientation in relation to the speaker. These modes are:

i) prayer mode, where all members of the audience, whether standing, bowing, prostrating or sitting, are aligned, in rows, parallel to the Qibla wall, with the imam at the front, facing away from the audience. Both are positioned on the same floor level.

ii) preaching mode, where the audience are seated, in rows, on the floor, while the imam is standing on an elevated platform (minbar) facing the audience.[1,2]

The full recognition of speech syllables is the most important requirement during preaching. On the other hand, the comprehension of "tajweed", which is a special emphasis on the pronunciation of vowels and some consonants in relation to others, is the one of significance during prayer. It is the full comprehension of such emphasis, in particular, that sets the very stingiest standards for the anticipated listening conditions in mosques. It is essential, therefore, that an aural environment conducive to the satisfactory fulfillment of these conditions, should be sought by mosque designers. The stipulations of such an environment can be translated into three basic aural requirements, which are:

i) sound audibility, where adequate loudness is to be received by all members of the audience. This is an essential requirements during both modes of worship,

ii) speech intelligibility, where all utterances should be clearly understood. This quality is especially important during preaching,

iii) "tajweed" comprehension, where all speech segments and suprasegmentals should be distinctly perceived by the listeners. This is a requisite for prayers.

These aural requirements are governed by respective acoustical characteristics of speech. In their turn, the latter are influenced by the amount and nature of sound absorption present. The investigation of these interrelated factors is the theme of this paper.

Acoustical Characteristics of Speech

Speech syllables are composed of articulated segments - vowels and consonants, which go to make utterances. Superimposed on the syllables are suprasegmentals which include variations in stress, length and pitch.[3,p.14] It is the relative value of pitch, length and degree of stress of an item that are significant for the recognition of an utterance.[3,p.15]

Moreover, Quranic recitation is characterized by such features as intonation of vowels, which is the pattern of pitch changes that occur in certain situations, and by the assimilation of some consonants, which is the change of one sound into another because of the influence of neighbouring sounds.[3,p.98]

The intelligibility of speech depends on recognition of consonants which, on the whole, posses low sonority (acoustically: intensity) but low pitch (acoustically: frequency).[3,p.221] By comparison, the comprehension of tajweed in Quranic recitation is mainly governed by the clarity of vowels, which, on the contrary, have high sonority, but low pitch.[3,p.221]

The presence of sound absorption furnished by the audience, which is relatively high and largely selective in frequency, as will be demonstrated experimentally, will, undoubtedly, influence the acoustical characteristics of speech, during both modes of worship, by reducing loudness and shortening reverberation time of articulated syllables. The extent of the detrimental, or otherwise beneficial effect of this, on speech intelligibility and comprehension of Quranic recitation, depends on the particular worship mode postures of the audience as can be, experimentally, investigated.

Effect of Audience Absorption on Speech

In mosque buildings, generally little absorption is provided by the building fabric, except for the carpeted floor. On the other hand, the absorption due to the audience, as will be experimentally verified in this paper, is substantial. It is also selective in nature, as it is more biased towards the high range of the audio-frequency spectrum. Accordingly, its effect on different speech syllables will be unbalanced, depending on their spectral composition. Previous work on mosque acoustics, as reported in literature, has confined experimental measurements to unoccupied mosques, due to the practical difficulty in taking measurements with audience present. [1,4,5] This difficulty is overcome in this study

by taking measurements on a sample of worshippers and, then, extrapolating the results for a theoretically full capacity audience.

Since performing prayer and listening to preaching dictate different body postures and relative speaker - listener orientations, it is expected that the amount of sound absorption, furnished by the audience, will vary. This variation can be attributed to differences in the angle of incidence of sound, "thickness" of the absorbing material (the audience) and exposed surface area to incident sound rays.

This study focuses on investigating the effect of this variation in absorption, in magnitude and frequency, due to change of worship mode postures, on the acoustical characteristics of mosques.

The results of measurements are compared with the ideal aural requirements for both worship activities. Conclusions are drawn on the degree of satisfaction of such requirements under actual practices.

Acoustical Performance Descriptors

The worship aural requirements in the mosque can be expressed in terms of some measurable acoustical performance descriptors, based on established procedures for assessment of buildings of similar nature. These are derived from the determination through measurement of the absorption per member of audience for the two alternative modes of worship. For practical considerations, such measurements are conducted on a sample of audience, and the results are then extrapolated for full capacity audience of the mosque.

The reverberation chamber method is used for measurements, and the Sabine Formula employed for computation of absorption per person, as a function of frequency, by. [6,p.133]

$$\alpha_{(person)} = \frac{0.16\,V}{N}\left[\frac{1}{RT_{(with\ sample)}} - \frac{1}{RT_{(unoccupied)}}\right] \text{ m}^2 \text{ sabin} \quad \ldots\ldots (1)$$

Where:

α : absorption per person (m^2 - sabin)

V : volume of mosque in cu m

N : number of persons in measurement sample

$RT_{(with\ sample)}$: reverberation time with audience sample present (sec)

$RT_{(unoccupied)}$: reverberation time with mosque unoccupied (sec)

This coefficient is used to compute two performance descriptors that affect the segments and suprasegmentals of speech utterances during both modes of worship. The two descriptors are:

i) Reverberation time, as a function of frequency, for full audience capacity, for both modes of worship, is also calculated using Sabine Formula. This governs the decay rates of syllables and thus affects intelligibility. It is compared with reverberation time for unoccupied of mosque to highlight the changes in the decay rates of speech syllables.

ii) $SR = 10 \log \frac{A_{(total)}}{A_{(unoccupied)}}$ dB .....(2)

Where:

SR: is the signal level reduction, as a function of frequency, as a result of added audience absorption in the space.

$A_{(tot)}$: total absorption, in m^2 sabins, as a result of the presence of full audience

$A_{(unoccupied)}$: Absorption due only to the building fabric of the unoccupied mosque.

This is compared with normalized signal level, and attenuation in signal level highlighted. This will affect audibility of speech during both worship modes.

Experimental Measurements

The Study Model

Acoustical measurements were conducted in a typical medium-sized mosque, with a floor area of 500 sq. m., an average height of 6 m and a total volume of approximately 3000 cu m. The estimated full audience capacity was 400 persons. The floor area per person, necessary to accommodate a single worshipper, was taken as 0.8m x 1.2 m.[8,p.9] The building had hard plastered internal finishes on walls and ceiling, but a carpeted floor. The glazed fenestrations constituted less than 10% of the perimeter surface area.

The study sample comprised 40 persons, dressed in light summer clothing, arranged for measurement purposes, according to patterns typically adopted during preaching and prayer modes consecutively, along the spacing norms quoted above.

Instrumentation

The measuring equipment, used, comprised:

- A B&K building acoustic analyzer (type 4418)
- A B&K sound source (type 4224)
- A 1/2 inch B&K condenser microphone (type 4134)

Measurement Procedure

Two different set-ups were established for conducting measurements. They were chosen to simulate the two alternative actual worship modes practiced in the space. The reverberation time was thus measured, as a function of frequency, at 1/3 Octave bands from 100 to 8000 Hz. The measurement procedure was as follows:

During Preaching Mode

The sound source was located at the speaker's position at an elevation of 2.7 m above the floor, simulating a speaker standing on the minber. The microphone was positioned at a height of 0.7 m from the floor, representing a seated person. Measurements were taken for the two alternative cases of the unoccupied space, and in the presence of the study sample, where the microphone was placed in the middle of the sample. To randomize the results, readings were taken at five different locations, for the sample, across the space floor area, and the results averaged out.[9]

During Prayer Mode

The sound source was located at the imam's position close to, and facing the mihrab - a nitch in the Qibla wall, at an elevation of 1.5 m. The microphone was positioned at similar height, in the middle of the study sample, representing a standing audience. Readings were carried out, in an analogous manner, for the two cases on an unoccupied space and with the sample present, also at five different locations, where similar averaging was made on the results.

Results: Analyses And Discussions

Results are compiled from measurements on reverberation time, as a function of frequency, of the mosque space, with and without the study sample, for the two alternative worship modes of preaching and prayer. (Table 1) summarizes the results.

The permutation of these measurement configurations entails substantial data which has, so, been reduced using statistical and graphical techniques to yield information on sound absorption per member of audience. This is shown graphically in (Fig. 1). for the two alternative modes. Such values have been extrapolated to give total absorption of an assumed full audience capacity. The histogram in (Fig. 2). compares this absorption due to audience, for the two alternative modes, as percentage of total absorption in the mosque space.

The full audience absorption has, consequently, been utilized to extract two significant acoustical performance descriptors of the space, namely its reverberation time and signal level reduction for the two alternative modes of worship. (Fig. 3). Hold comparison of four spectra of reverberation time of the space with full audience, to that of the unoccupied space, for the two alternative modes. On the other hand, (Fig. 4). compares the signal level reduction, in speech intensity, introduced by full audience absorption for the two alternative cases as computed by Equation.(2)

The implications of these acoustical performance descriptors on the space aural requirement are discussed here:

Table 1: Measurements of reverberation time as a function of frequency for the two alternative worship modes with mosque unoccupied and with audience sample present.

	Preaching Mode		Prayer Mode			Preaching Mode		Prayer Mode	
f (Hz)	RT (sec.) (Unoccup.)	RT (sec) (with sample)	RT (sec) (unoccup.)	RT (sec) (with Sample)	f (Hz)	RT (sec) (Unoccup.)	RT (sec) (with sample)	RT (sec) (unoccup.)	RT (sec) (with Sample)
100	3.28	3.40	3.18	2.46	1000	2.00	1.94	2.06	1.56
125	3.62	3.66	3.46	2.90	1250	2.24	1.90	1.86	1.48
160	3.90	3.20	3.40	2.96	1600	1.90	1.80	1.88	1.42
200	3.82	2.90	3.50	2.42	2000	2.06	1.70	1.82	1.40
250	3.24	3.06	3.14	2.46	2500	1.86	1.68	2.02	1.48
315	3.06	2.94	3.44	2.34	3150	1.96	1.38	1.82	1.46
400	3.14	2.36	2.96	2.20	4000	1.90	1.30	1.72	1.28
500	2.96	2.46	2.36	2.24	5000	1.58	1.20	1.68	1.12
630	2.54	2.20	2.18	2.08	6300	1.24	1.06	1.46	0.92
800	2.48	1.94	2.30	2.14	8000	1.00	0.74	1.06	0.70

Audience Absorption

The absorption per person, as revealed by (Fig. 1), indicates, on the whole, higher values for the prayer than preaching mode. Generally, both variables tend to rise with frequency. The absorption of full audience displayed by the histogram in (Fig. 2), follows the same trend demonstrating the substantiality of the proportion of this component, for both modes, in relation to the total absorption of the space.

Reverberation Time

The reverberation time spectra, shown in (Fig. 3), confirm the marked effect of audience presence on shortening the reverberation time on the whole. They also reveal that values for the prayer mode are generally shorter than those for the preaching mode, especially in lower range of the audio frequency spectrum.

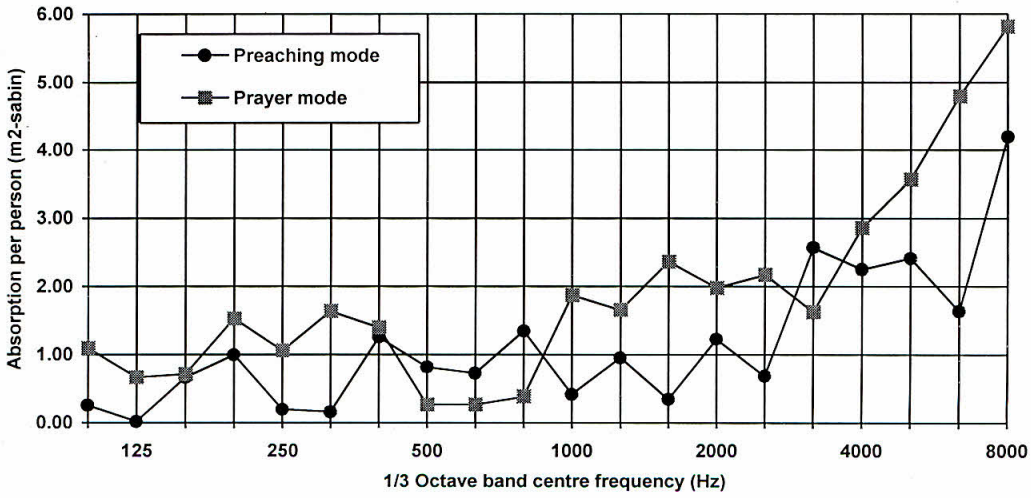

Fig. 1: Computed absorption per person for two alternative worship modes.

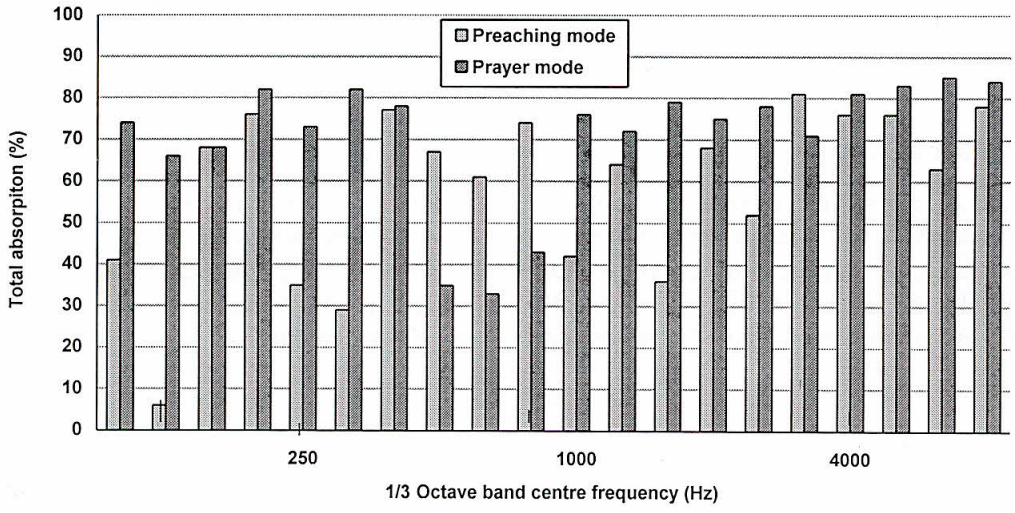

Fig. 2: Absorption due to audience for the two alternative worship modes as percentage of the total absorption in the space.

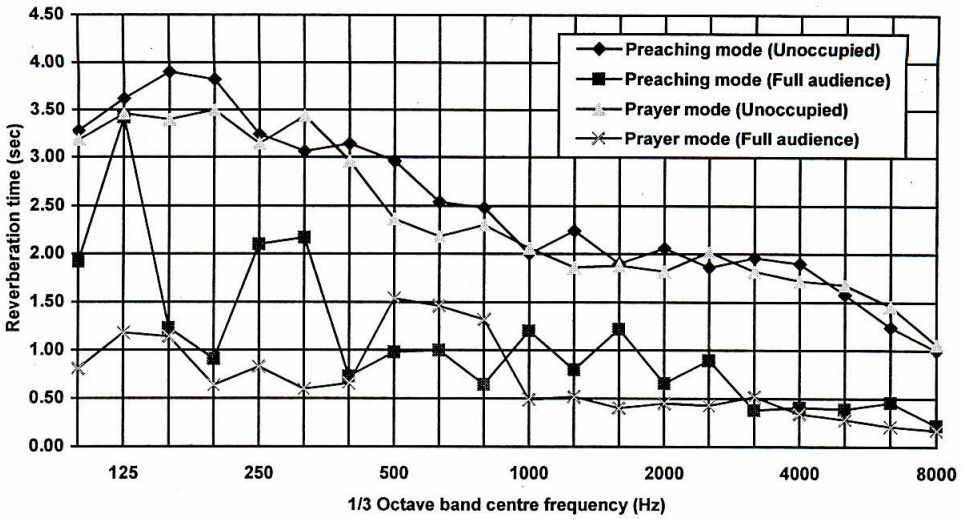

Fig. 3: Comparison of reverberation time spectra for two alternative modes for unoccupied space and with full audience.

The small discrepancy between the curves, for the two cases of the unoccupied condition, is probably due to the different relative positions of source and receiver.

It may, thus, be expected that sounds uttered during prayer, which, being of low frequency content, as previously hinted, will have, relatively, high decay rates. This will provide clarity of vowels and suprasegmentals and will, therefore, enhance comprehension of tajweed in Quranic recitation.

By contrast, preaching sounds, with high frequency content, will suffer less, due to their relatively low decay rate in the high frequency range, and, accordingly, speech intelligibility will be preserved.

Signal Level Reduction

The effect of audience absorption on intensity of sounds is shown in (Fig. 4), as attenuation in the signal level, with reference to a normalized level, for the two alternative modes. Here, high intensity, low frequency, utterances, in the prayer mode, suffer relatively, more attenuation, but with little effect on their, already, high audibility. On the other hand, low intensity, high frequency utterances in the preaching mode are less attenuated, thus preserving their limited audibility.

Conclusions

The foregoing study reveals that absorption furnished by the audience, in mosque buildings, is considerable, and has a large bearing on the fulfillment of aural requirements of the space during the two alternative worship modes of preaching and prayer.

The effects of such absorption are investigated, through monitoring the change in reverberation time and reduction of signal level, and noting their implications on the aural requirements of sound audibility, speech intelligibility and tajweed comprehension. These effects, on the whole, are found to be beneficial, as the presence of audience absorption enhances the values of these aural requirements, according to the acoustical characteristics of speech during each mode of worship.

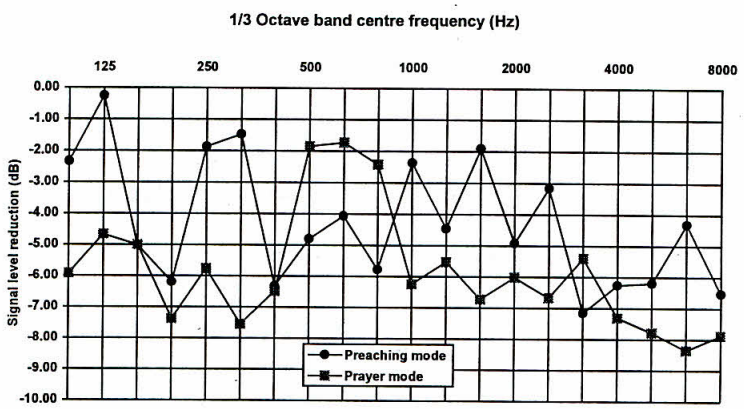

Fig. 4: Attenuation due to full audience in signal level for two alternative worship modes.

The investigation was made possible by employing an extrapolation technique from measurements, on an audience sample of a limited size, in a typical medium sized mosque.

The oddity in audience absorption in the mid-frequency range, by being contrary to the general pattern for both parameters under investigation, lacks explanation and can thus be the area of further work.

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تأثير تنوع إمتصاص الصوت بواسطة الجمهور على خصائص التردد (الذبذبة الصوتية) في المسجد

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ملخص البحث: إنّ دور المسجد كفراغ متعدد الوظائف يقوم المسلمون فيه بنشاطات متنوعه أَصبح واضحاً. ولقد حددّت المتطلبات السمعيّة لهذا الفراغ والمرتبطة بالخصائص الصوتيّة لمختلف أصوات الحديث. وإن دور إمتصاص الجمهور مع تنوع تواجدهم داخل الفراغ تم إبراز دوره والتعبير عنه بمصطلحات أو موصِفات قياس النشاط الصوتي.

إنّ القياسات الصوتيّة التي تم الحصول عليها من مسجد مكرر متوسط الحجم على عيّنة محددة من الجمهور استخدمت لاستخلاص قيم لرفع قدرة إمتصاص الأصوات في المسجد الممتلئ بالمستخدمين. وقد أستخدم هذا المحدّد لإستنتاج موصفتي إنتاج رئيسيتين لوقت التردد ولخفض مستوى الإشارة لأنواع مختلفة من الأنشطة والتي استخدمت بدورها للتحرّي عن تأثير إمتصاص الجمهور للأصوات من أجل تحديد المتطلبات السمعيّة للفراغ، أو على الخصوص: سماع الصوت، فهم الحديث، فهم لغة القرآن المجوّدة، وعلى ضوء المعلومات المرتبطه بخصائص علم الصوتيات.

وإن تحليل النتائج تؤكد أهميّة إمتصاص الجمهور للأصوات في تعديل الطبيعة الصوتيه لصوت الكلام (الحديث). وهذه تؤكد مدى جودة أنواع الحديث الناجم من حالة النشاط المرتبطة بقيم إمتصاص الصوت لدى الجمهور الّتي وجد لها فائدة لتحسين قدرة الفراغ السمعيّة.