International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:12, No:9, 2018

Assessment of the Occupancy's Effect on Speech Intelligibility in Al-Madinah Holy Mosque

Wasim Orfali, Hesham Tolba

***Abstract*—**This research investigates the acoustical characteristics of Al-Madinah Holy Mosque. Extensive field measurements were conducted in different locations of Al-Madinah Holy Mosque to characterize its acoustic characteristics. The acoustical characteristics are usually evaluated by the use of objective parameters in unoccupied rooms due to practical considerations. However, under normal conditions, the room occupancy can vary such characteristics due to the effect of the additional sound absorption present in the room or by the change in signal-to-noise ratio. Based on the acoustic measurements carried out in Al-Madinah Holy Mosque with and without occupancy, and the analysis of such measurements, the existence of acoustical deficiencies has been confirmed.

***Keywords*—**Worship sound, Al-Madinah Holy Mosque, mosque acoustics, speech intelligibility.

I. Introduction

PLACES of worship for Muslims (Mosques) are built mainly for speech and prayer activities. Henceforth, the acoustic comfort in mosques is very important because it allows having a good intelligibility of the delivered speech [1], [2]. Speech intelligibility is usually evaluated by the use of objective parameters. These measures include objective measures such as, sound pressure level (SPL), reverberation time (RT), Energy-Frequency Distribution (EFD), and subjective measures such as Mean Opinion Score (MOS) [3]. The aim of this work is to explore methods to evaluate, predict and preview the acoustical qualities in Al-Madinah Holy Mosque, the second holiest site in Islam (the first being the Masjid al-Haram in Mecca) [4], [5].

In this work, we explore the acoustic quality in Al-Madinah Holy Mosque by measuring the SPL in different positions inside and outside this mosque with and without occupancy, which can modify the speech intelligibility by the effect of the additional sound absorption present in the mosque or by the change in the signal-to-noise ratio [6]-[8]. The number of representative measurement positions were chosen in order to achieve an appropriate coverage of Al-Madinah Holy Mosque.

In addition to the measurement of the SPL values at numerous positions inside and outside the Holy Mosque, the Background Noise (BN) values were also computed and the effect of the occupancy of such a mosque on the difference between the SPL and the BN in all representative positions was also shown. Measurements were carried out using one of the acoustical measurement tools that functions according to the latest revision of standard IEC 60268-16:2011 [9], named NTi XL2 audio and acoustic analyzer [10].

W. Orfali is with the Department of Architectural Engineering, Taibah University, Al-Madinah, KSA (e-mail: orfaliwasim@hotmail.com).

H. Tolba is with the Department of Electrical Engineering, Alexandria University, Alexandria, Egypt (e-mail: htol65@hotmail.com).

II. Al-Madinah Holy Mosque

Al-Madinah Holy Mosque located in Al-Madinah Almunawarra in KSA is one of the first mosques that were built in Islam. In the year 622 EC, one year later after building Quba mosque in Al-Madinah Almunawarra, the Islamic prophet Mohammed built Al-Madinah Holy Mosque in the south of the city. This second mosque built in history is considered now as one of the largest mosques in the world [11]. This mosque was a very simple structure, a square enclosure of 30x35 meters, the mosque was built with palm trunks and mud walls. The location of the mosque was chosen to be close to the modest house of Prophet Mohamed, in which he was later buried along with two of his companions; Abu Bakr As-Saddiq and Omar Ibn AlKhattab [11]. Later in 629 AD, the mosque was doubled in size to accommodate the increasing number of Muslims. Subsequent Islamic leaders continued to enlarge and elaborate the Holy Mosque over the years. The current mosque is more than 100 times the size of the original building. As it stands today, the mosque has a rectangular plan on two floors with the Ottoman prayer hall projecting to the south. The main prayer hall occupies the entire first floor. The mosque enclosure can accommodate up to 1,000,000 worshippers.

After the foundation of the Kingdom of Saudi Arabia in 1932, the Mosque of the Prophet went through several major alterations. Successive expansions throughout history have made the Prophets Mosque the magnificent architectural masterpiece it is today. Today, Al-Madinah Holy Mosque is much bigger than the first mosque built by the Prophet. The mosque today has a rectangular design on two floors. Its main prayer hall occupies the entire first floor with the Ottoman prayer hall projecting to the south [11]. Today the mosque has a flat paved floor topped with 27 sliding domes on square bases. The roof is also used for prayer during peak times, and is accessible by stairs and escalators. The paved area around the mosque is equipped with umbrella tents and is also used for prayer. The courtyard inside the mosque is also shaded with umbrellas affixed to freestanding columns. The total area preserved for the worshippers inside the Holy Mosque is 384,000 m2, and outside the Holy mosque (the paved area) is 235,000 m2. Fig. 1 illustrates the exterior of the Holy Mosque, whereas Fig. 2 illustrates an inside view of the Mosque. For more details, see [4], [5].

III. Acoustic Parameters

The acoustic parameters that are used in order to characterize the acoustical environment precisely within mosques include: the Sound Pressure Level, the speech

Fig. 1 The Exterior of Al-Madinah Holy Mosque

Fig. 2 The Interior of Al-Madinah Holy Mosque

intelligibility of the delivered speech within the Holy Mosque, the analysis of its frequency response, the reverberation time and the mean opinion score. For more details about these parameters, see [3], [12], [13]. In this paper, we focus on the measurement of the Sound Pressure Level (SPL) within the Holy Mosque.

A. Sound Pressure Level (SPL)

The intensity of sound is a way to measure and describe the amplitude of a sound wave at a particular point. However, it is not the usual quantity used when describing the amplitude of a sound. Sound pressure is usually the most accessible parameter to measure in acoustics. Sound pressure is used as a measure of the amplitude of the sound wave because it is easier to measure, and because human ears are sensitive to pressure. This leads to the quantity defined as the sound pressure, which is defined as the root mean square (rms) pressure of a sound wave at a certain point [14]. The sound pressure level is usually expressed on a logarithmic scale. This scale is based on the ratio of the actual sound pressure to the notional threshold of hearing at 1 kHz of 20 μPa. That is, the sound pressure level (SPL) represented in dB is defined as:

$$SPL = 20 \log_{10} \left[\frac{P_{actual}}{P_{ref}} \right],$$

where P_{actual} is the actual pressure level (in Pa) and P_{ref} is the reference pressure level (20 μPa) [3].

The sound pressure level and sound intensity level are approximately equivalent in the case of free space propagation in which no interference effects were present. However, the ear is a pressure sensitive organ that divides the audio spectrum into a set of overlapping frequency bands whose bandwidth increases with frequency. Henceforth, the pressure amplitude of a sound wave does not directly relate to its perceived loudness. In order to achieve a measurement which truly relates to the perceived loudness of a sound, a frequency weighting should be used to compensate for for the variation of sensitivity as a function of frequency of the ear.

Such a compensation is usually performed using one of the Two frequency weightings: A- and C-weightings. The most appropriate one for low amplitude sounds is the "A-weighting" as it broadly compensates for the low level sensitivity versus frequency curve of the ear. On the other hand, the "C-weighting", is more suited to sound at higher absolute sound pressure levels and that is why it is more sensitive to low frequency components than the A-weighting. The sound levels measured using the A-weighting are often given the unit dB-A and levels using the C-weighting dB-C. In addition to this factor that must be considered when using a sound level meter, it is also necessary to average over at least one cycle, and preferably more, of the sound waveform. Thus, most sound level meters have slow and fast time response settings. The slow time response gives an estimate of the average sound level whereas the fast response tracks more rapid variations in the sound pressure level, as described in [14].

IV. Measurement System and Procedures

Sound Pressure Level (SPL) meters are the most basic sound measurement devices [15]. In this study, we will use the NTi XL2 acoustic measuring system and analyzer for the measurement and evaluation of room acoustics in order to evaluate the acoustical characteristics of Al-Madinah Holy Mosque. Such a tool forms a combination of a sound level meter, a comprehensive and powerful acoustic analyzer as well as a powerful audio analyzer. Its wide range of functions are tailored for challenging applications in sound installations and evacuation systems, live sound events, noise monitoring, building acoustics, occupational health and manufacturing quality control [10].

V. Experiments and Results

A representative number of listener positions was selected for measurement in order to achieve a proper coverage of the mosque floor area. The number of measurement positions are chosen in order to achieve an appropriate coverage in Al-Madinah Holy Mosque. Microphone positions are placed at least half a wavelength apart, i,.e., a minimum distance of around 2 meter for the usual frequency range. The distance from any microphone position to the nearest reflecting surface, including the floor, is at least a quarter of a wavelength, i.e., normally around 1 mt. No microphone position is too close to any source in order to avoid too strong influence from the direct sound. Measurements were acquired using the M2230 microphone mounted on an adjustable microphone holder fixed to a tripod, maintained 0.85 m above the floor representing the location of a listeners ear in a standing position. Measurements were carried out with the mosque occupied and unoccupied.

In our experiments the representative positions for measurements were apart by a distance that exceeds 20 meters. Actually, the structure of the Holy Mosque and the symmetry of its building, as well as the distribution of the speakers inside and outside the Holy Mosque facilitates the choice of the number of the representative points chosen (at which measurements have been conducted) and reduces their number. In fact the structure of the building divides the area of the Holy mosque into similar areas that are almost isolated with their own speakers as shown in Fig. 3.

It was necessary to measure the Holy Mosque background noise (BN) and subsequently determine the noise criterion rating. The octave-band sound pressure level SPL of ambient BN was measured at each selected measurement location using the same calibrated 1/2" condenser microphone maintained at 0.85 m above the floor.

The results regarding the sound pressure levels for the Background Noise (BN) inside Al-Madinah Holy Mosque at one of the representative positions at which measurement were taken, with low and high occupancies are illustrated in Fig. 4 (a). It is clear from this figure that the BN levels - although the large numbers of worshippers is not highly affected by the occupancy factor of worshippers inside the Mosque. This is due to the large area of such a mosque in addition to its high ceiling.

We repeated the above-mentioned experiments to measure the preacher SPL inside and outside the Holy Mosque. The octave-band sound pressure level (SPL) of the preacher was measured at each selected measurement location using the same calibrated 1/2" condenser microphone maintained at 0.85 m above the floor. The SPLs values obtained through measurements at one of the representative positions inside the Holy Mosque with low and high occupancies are illustrated in Fig. 4 (b). It is clear from this figure that the SPLs also are not much affected by the occupancy factor of worshippers inside the Mosque for the same above mentioned reason. However, we noted that the BN level increased with the high occupancy by few decibels (up to 12 dB at 500 Hz) due to cocktail parties (noise produced by side-talks of worshippers), whereas the SPL decreased with the high occupancy by about 8.2 dB at 500 Hz due to the expected reduction of reverberation and echo during full/high occupancy.

We noted also from the obtained measurements that the difference between the SPL and BN at some positions is higher with low occupancy compared to the difference between these values at high occupancy at some positions. This comparison is illustrated in Fig. 4 (c) at a selected position inside the Holy Mosque, with low occupancy, whereas Fig. 4 (d) illustrates such a comparison at the same selected position at high occupancy. That is, the occupancy of the whorshippers affect the difference between the SPL and BN inside the Holy Mosque. This should be taken into consideration and adjustments should be done to the distribution of sound inside the mosque for a uniform sound distribution within the mosque.

VI. Conclusions and Future Work

In this work we are studying the acoustical behavior in Al-Madinah Holy Mosque. This is conducted by evaluating

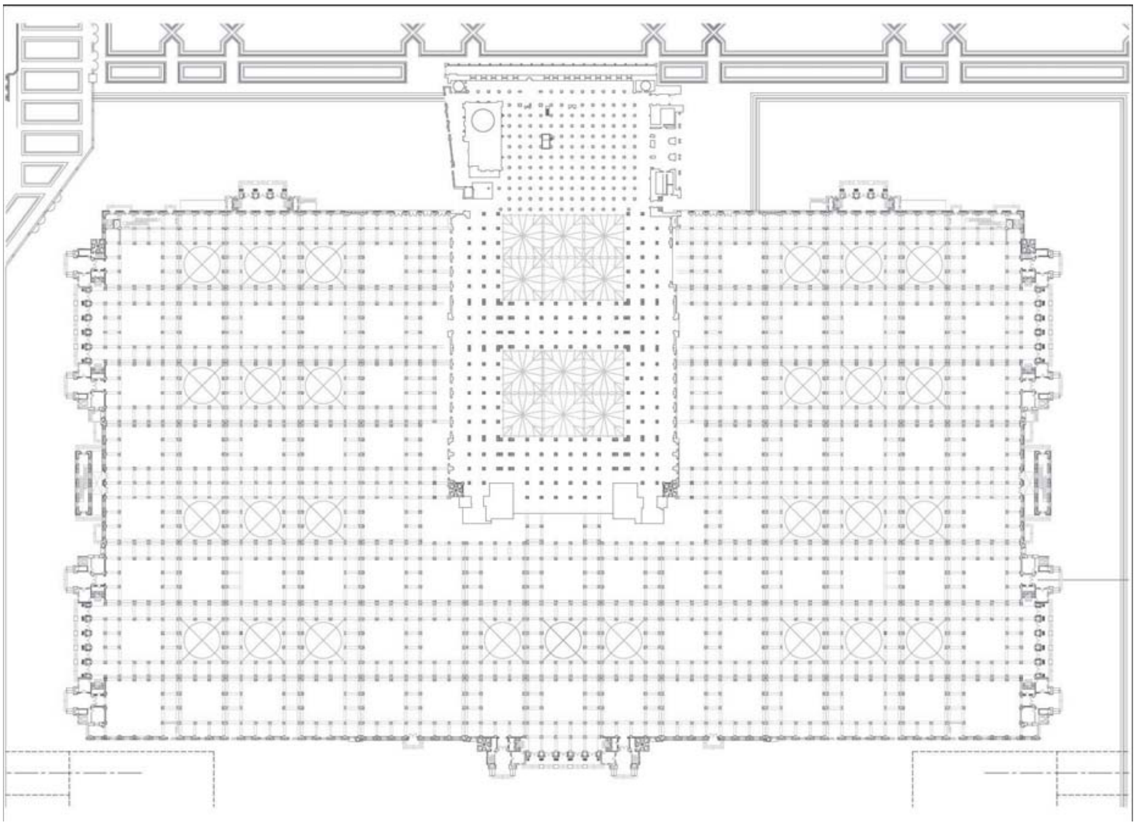
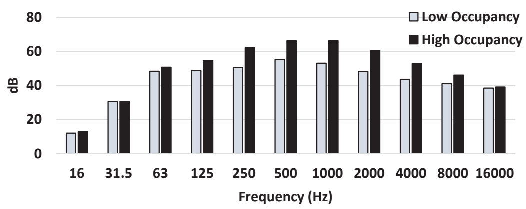
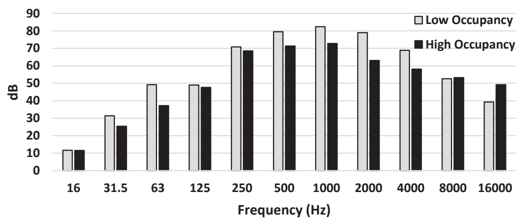


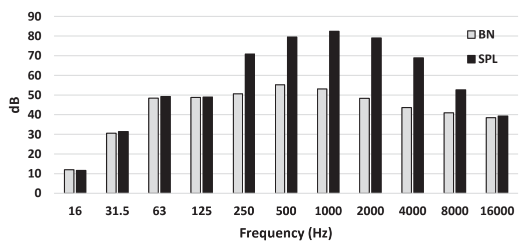
Fig. 3 Plan of Al-Madinah Holy Mosque showing a geometric configuration of the prayer hall



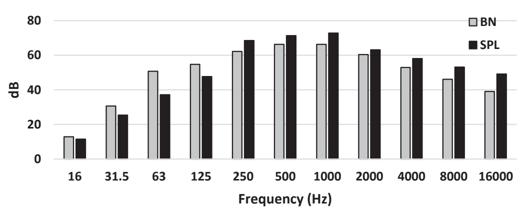
(a) BN level at one of the representative positions inside Al-Madinah Holy Mosque with low and high occupancies



(b) SPL at one of the representative positions inside Al-Madinah Holy Mosque with low and high occupancies



(c) Comparisons of SPL and BN values at one of the representative positions inside Al-Madinah Holy Mosque with low occupancy



(d) Comparisons of SPL and BN values at one of the representative positions inside Al-Madinah Holy Mosque with high occupancy

Fig. 4 Sound pressure and background noise levels measured inside Al-Madinah Holy Mosque at one of the representative positions, with low and high occupancies the performance of the acoustic system in Al-Madinah Holy Mosque in terms of the measurements of the acoustic parameters in different positions in Al-Madinah Holy Mosque with and without occupancy. We show through this study that the speech intelligibility in the mosque can be increased or decreased due to its occupancy (i.e., the effects of the additional sound absorption present in Al-Madinah Holy Mosque or by the change in S/N ratio. This is accomplished through the measurements of the previously mentioned acoustic parameters that could be used to evaluate the intelligibility of speech in Al-Madinah Holy Mosque. Analysis of the carried measurements showed that the effect of the occupancy does not affect much the BN values. The difference between the SPL at low occupancy and high occupancy found to be 5 dB or less. Based on the analysis of the above mentioned measurements, we noted that the occupancy affects both the SPL and the signal-to-noise-ratio inside the Holy Mosque. We noted also the existence of acoustical deficiencies represented in the variation of the SPL across the different locations inside the Mosque. We are currently continuing the efforts towards the computation of the whole set of these parameters for the completion of this study.

Acknowledgment

Thanks to Engineers A. Faqeeh, K. Alnasser and A. Jamal Al-leil for their assistance in providing us with the measurements within the course of this research.

References

[1] J. Douglas, *Sound of Worships: A Handbook of Acoustics and Sound System design for the Church*. Elsevier, 2011.
[2] A. Abdou, “Measurement of acoustical characteristics of mosques in saudi arabia,” *Journal of Acoustical Society of America, JASA*, vol. 113(3), pp. 1505–1517, 2003.
[3] T. D. R. (Ed.), *Springer handbook of Acoustics*. New York: Springer Science+Business Media, LLC, 2007.
[4] H. Alazhari, *The History of al-Masjid al-Nabawi & the virtue of visiting it*. Islamic Centre Leicester, 2014.
[5] A. S. A. I. Syed, *Architectural Conservation in Islam: Case Study of the Prophet’s Mosque*. Penerbit UTM, 2005.
[6] J. Bradley, “Measuring and predicting the effect of an audience,” 124^{th} Acoustical Society of America meeting, New Orleans, 1992.
[7] H. Arau, “Variation of the reverberation time of places of public assembly with audience size,” *Building Acoustics*, vol. 4(2), pp. 87–97, 1997.
[8] M. Hodgson, “Experimental investigation of the acoustical characteristics of university classrooms,” *Journal of Acoustical Society of America, JASA*, vol. 106(4), pp. 1810–1819, 1999.
[9] International Standard Organization: Acoustics ISO 9613-2 Attenuation of sound during propagation outdoors. part 2: General method of calculation, 1996.
[10] NTi audio - XL2 handheld audio and acoustic analyzer operating manual manual, NTi Audio, Switzerland, 2015.
[11] https://www.islamicity.org/6305/the-introduction-of-the-prophets-mosque-in-madinah/.
[12] W. C. Sabine, *Collected Papers on Acoustics*. New York, NY: Dover Publications, reprinted, 1964.
[13] D. Templeton, P. Sacre, P. Mapp, and D. Saunders, *Acoustics in the Built Environment*. Butterworth-Heinemann Ltd. 122.: Oxford, 1993.
[14] D. M. Howard and J. Angus, *Acoustics and Psychoacoustics*. 225 Wildwood Avenue, Woburn, MA 01801-2041: Focal Press, 2001.
[15] Speech intelligibility - A JBL professional technical note, Technical Notes Volume 1, Number 26, 2000.