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Research Method for Computer Modelling Study in Mosque Acoustic Design

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ABSTRACT

Having high quality of sound is an important feature in main prayer hall design and it is the basic element in mosques with variety of worship activities. These activities perform by audience and should provide good acoustical performance for them. Nowadays, architects have often focused on their problems and targets, which are to design a beautiful mosque. They often design forms with variety component such as column, dome, ceiling and others for designing architecture or structure without focusing on the acoustic problems that might cause after construction. This paper presents method of evaluation acoustic performance in main prayer hall and modelling it in a computer simulation process as using the computer modelling of room acoustics can be a useful tool in the design of acoustically main prayer halls in mosques for architectures.
KEY WORDS: Architectural Acoustic, Sound, Computer Model Study, Mosque, Main prayer hall.

1 INTRODUCTION

In the Islamic world, there are specific public spaces which are called Mosque. It is an English word that emanates from the Arabic word of 'masjid' (Utami, 2005). Every mosque has own acoustical requirements. Mosques are multi-function public halls with many worshipping activities that have different acoustical requirements. As in many other religions, worshippers sometimes need privacy spaces that they spend their times in it for feeling themselves in total harmony with the community. Acoustics is one of the main features for create these effects. There are three distinct acoustical requirements for mosques (Abdou, 2003; Karabiber, 1999; Kayili, 2002; Prodi & Marsilio, 2003; Utami, 2005).

- Audibility of the prayer orders of the Imam (prayer leader)
- Listening and understanding of the speech that the Imam say in the prayer or Khutba (lecturer)
- Listening to the performance of the musical version of the Holy Koran.

A high level of quality of sound is needed for all mentioned worship activities. To ensure good listening conditions acoustical needs must be considered in the design phase (Abdou, 2003). Therefore, for both speech and other sounds having high quality of sound is very important, especially important for holy tones that must be both wide and effective (Hamadah & Hamotida, 1998; Karabiber, 1999).

Acoustic is derived from the Greek word of akoustos, meaning of hearing and it is the science about the production, control, transmission, reception, and effects of sound (Suri, 1966). Physics and engineering, physiology and psychology, speech and singing, architecture, Environmental noise control and more are various branches in this science. One of the most important of these branches is architectural acoustic and it is necessary for understanding and optimizing of the sound environment in all types of rooms and buildings, including various places for work, residential living, education, worship and leisure.

The 20th century in the world of architectural acoustic is called to the Sabine century because Wallace Sabine in 1898 developed reverberation time for understanding of the behaviour of sound buildings (Suri, 1966). The most researchers in the field of architectural acoustic are developed methods and techniques for evaluate, predict and simulate sound qualities of small and big rooms. The most common methods and techniques are: Wave-based and Ray-based methods that acoustical researchers have developed in this field. During last 20 years acoustical simulation software and studies about them are developed. Ray base method is a common method that is used in the most of these software's. Simulation the propagation of the sound and study about distribution of sound are the main purpose of this software's in the room acoustic studies (Ozgur, Ozis, & Alpkocak, 2004).

2 Description of Sound process in the main prayer hall

Main prayer hall is a basic and important element in mosques that used for worship activities such as prayer public speaking, preaching, lecturing, and Quran recitations. All these activities are dependent on sound audibility and speech intelligibility (Abdou, 2002).

- Sound audibility means that sound receive to all audiences equally.
- Speech intelligibility means that sound should be clear for various positions of the listeners in the audience area.

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Both the speech signal-to-noise ratio and the acoustic characteristics of the space are effective parameters for having high quality of speech and sound in rooms. It can be influenced by the ambient Background Noise (BN) and the Reverberation Time (RT) (Abdou, 2002).

Having good audibility and intelligibility sound which receive to audience in main prayer hall will need good acoustical performance. Process of acoustical performance cause by a complex system of sound and this system engenders by composition of sources, directs and receivers. This system is very influenced by the relative positions of both the speaker and members of the audience. Sources divided into two main categories, desired sounds such as speech from speakers or lecturers and undesired sounds such as air-conditioning system. Directs are the distances between lecturer to listeners that can be straight-line or tortuous-line and audience area can be the receivers or listeners (people) which listen to speech of lecturer (See Figure 1).

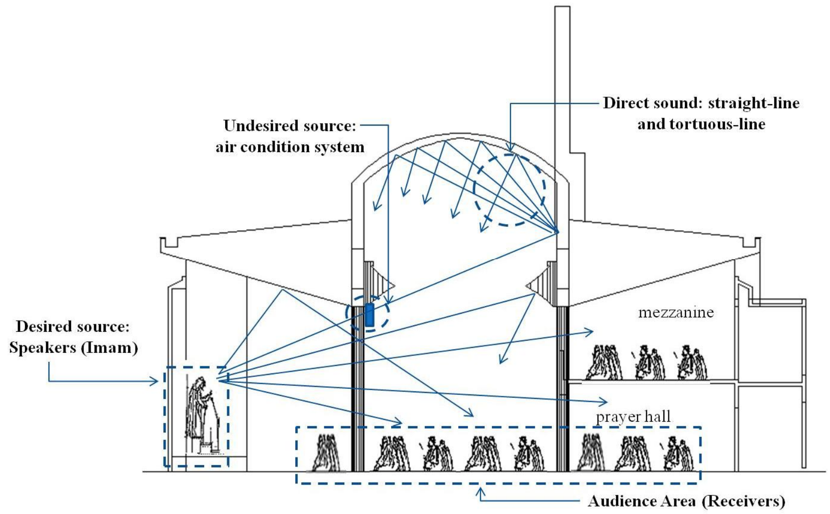

Figure 1: Basic components in system of acoustical performance in main prayer hall.

The study of mosque acoustics in the variety subjects such as acoustical characteristics, sound quality for speech audibility and intelligibility, and other acoustic criteria have been done in the last 50 years. Unfortunately, treatment of acoustic problems has been studied after finalizing the construction of mosques.

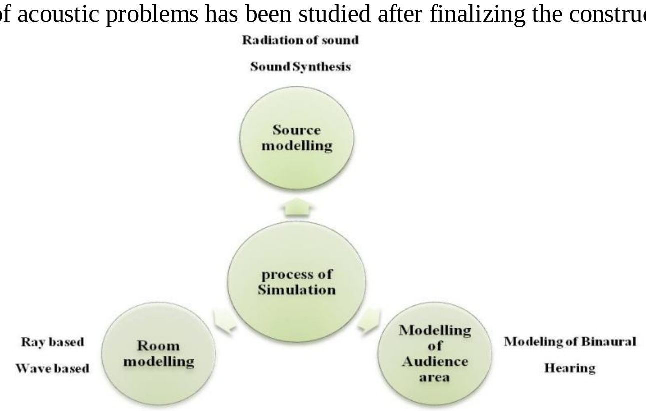

Figure 2: The process of acoustical simulation software for acoustical performance.

3 Description of Used Techniques in computer model study

The various techniques including wave based and ray based are used for evaluation of sound process in computer scale modelling study. In modelling of high frequency sound waves with large rooms bigger than 100 m3 volumes are used the ray based techniques and in modelling of low frequency sound with small size rooms smaller than 100 m3 volume are used waves based techniques that are successful for both techniques. In comparison of these two techniques wave based techniques are not preferred because of the cost of computation for large rooms in computers (Ozgur, et al., 2004). Both techniques have various sub-techniques for computer model study and Figure 3 illustrates various techniques used in ray base method.

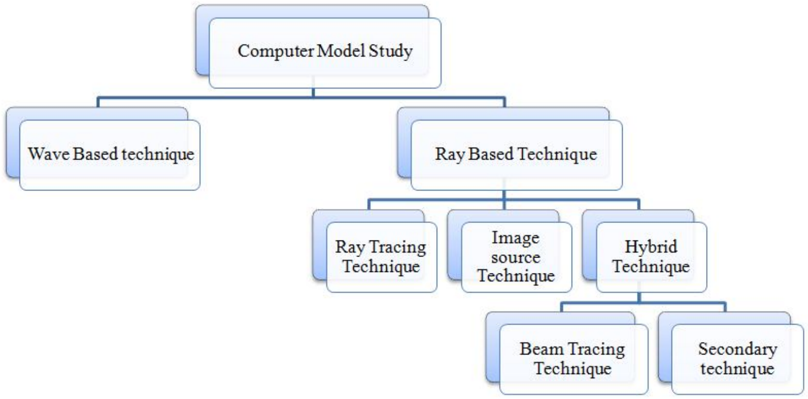

Figure 3: Used techniques in modelling of room in computer scale model study

3.1 Ray Tracing Technique

Ray-tracing technique is the first and well-known technique for convenient design of room acoustic in computer scale modelling study. The development of room acoustical ray tracing technique is started approximately forty years ago. It is suited to research and study distribution of high-frequency sound waves and their reflections from large surfaces. As can be seen in Figure 4, a large number of sound rays are used for acoustical performance in this technique which are derived from sound source and are emitted in various directions. The particles are traced around the room until loose own energy according to the absorption coefficient of the surface's material at each reflection. Rays of sound reflect when they hits a surface and according to geometrical optics a new direction of ray determine until a set of rays arrive at audience area (Krokstad, Strom, & Sorsdal, 1968; Rindel, 2000; Utami, 2005).

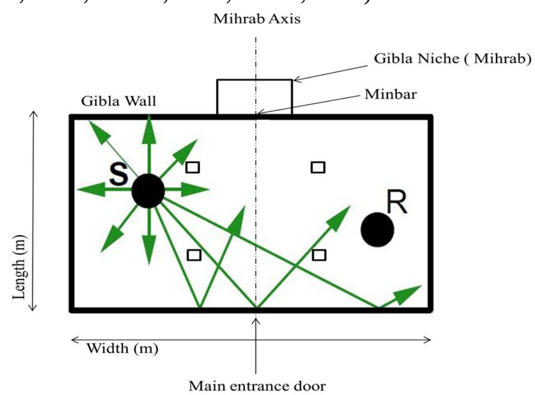

Figure 4: Distribution of sound in ray tracing technique

The distribution of rays on the audience area surface and analyzing them in appropriate intervals of the time delay is the main outcome of this technique. Hence, this is a qualitative presentation of the sound distribution in space and time. The direction of incidence of each ray can be indicated for a closer analysis. It is necessary to introduce receiver surfaces or volumes for detection of the sound rays if need to obtaining quantitative results. Therefore, energy-reflectogram can be calculated and used for guess of some room acoustic parameters (Rindel, 2010).

3.2 Image Source Technique

The principle of the image Source is based on a specular reflection that by mirroring the source in the plane of the reflecting surface can be constructed (See Figure 5). Specular reflection paths are computed up to any order by recursive generation of virtual sources (Funkhouser, et al., 2004). In general, the order of reflection encounter the number of surfaces a reflection (Utami, 2005). It is easy to construct image sources in a rectangular shape room to a certain order of reflection, and from this it can be deduced (Allen & Berkley, 1979; Rindel, 2000, 2010).

Using image source Techniques in room acoustical study are limited just for rectangular rooms or in such samples where low order reflections are enough such as designs of loudspeaker systems in non-reverberant enclosures (Allen & Berkley, 1979; Borish, 1984; Rindel, 2000).

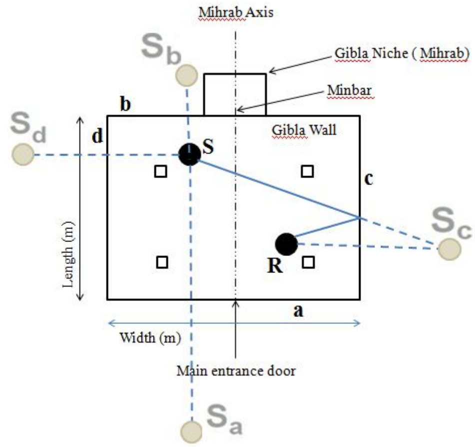

Figure 5: Distribution of sound in image source technique

3.3 Hybrid Technique

The advantages and the best features of ray tracing and image sources techniques are combined and developed to design a new technique that is called hybrid technique (Howarth & Lam, 2000; G. Naylor, 1992; G. M. Naylor, 1993; Rindel, 2000). In this technique, the rays create image sources and secondary sources on the walls for early reflections and late reflections, respectively (Rindel, 2000). Therefore, a secondary source has proven to be efficient at choosing the early and late reflections in hybrid technique (Utami, 2005). Having a professional way to find image sources by tracing sound rays from the source and noting the surfaces that they hit is the important idea of the combined technique. In this way, each path is related with a particular sequence of valid image sources, which are identified by backtracking the path of a sound particle, then testing it to determine whether it gives a contribution at the chosen receiver position. The energy impulse response can be formed by adding the contributions of all image sources and using the energy reflection coefficients of the room boundaries involved when the valid images have been found (Utami, 2005).Thus, modern computer scale model studies can create reliable results with only modest calculation times.

The ease software is one of the most room acoustical simulation software that is developed by a hybrid technique (source/ray tracing model) called “CAESAR” (Vorländer, 1989) and it is included from the application of simulating installations of professional architectural acoustic and sound reinforcement systems (Ahnert & Feistel, 1991). It was developed approximately 15 years ago by German acoustical engineers. It can be used for various designs because it is a professional architectural and engineering acoustical analysis software tool, for example to decide the greatest design of room, the perfect location of sound sources and speakers or to figure out the best location to put acoustical materials in a room.

Main function of EASE software is included (Xing, 2009) simulation of the reverberation time and clarity of seven different frequency of sound between 125Hz and 8000Hz, speech intelligibility, direct sound field distribution and reverberation distribution, consonant loss ratio, and ray diagram analysis (Xing, 2009).

4 The Process of Computer Model Study in main prayer hall of mosques

As can be seen in Figure 2, the process of acoustic simulation software for illustrated acoustical performance in Figure 1 are included three main parts; the first part is source conception which is about how the sound is propagated. Second part is the modelling method of room which is the most important part of the sound simulation software and is also important for the correct acoustical parameters with designing of geometry, reflectors and absorbers for correcting direct sounds. The third part is modelling of different positions of receivers for indicate simulation results (Ozgur, et al., 2004).

4.1 MODELLING OF SOURCE

Two important characteristic of sound sources that are depended on frequency of sound are sound power and directivity. For modelling of sound source in computer simulation is needed to having source position including high of sound source and place of it and the direction of sound distribution for ray tracing (Krokstad, et al., 1968; Vian & Maercke, 1986). With choosing direction of sound, the directivity can be modelled by start energies of the particles or variation of the density of particles, as displayed in Figure 6 in an area of the unit sphere.

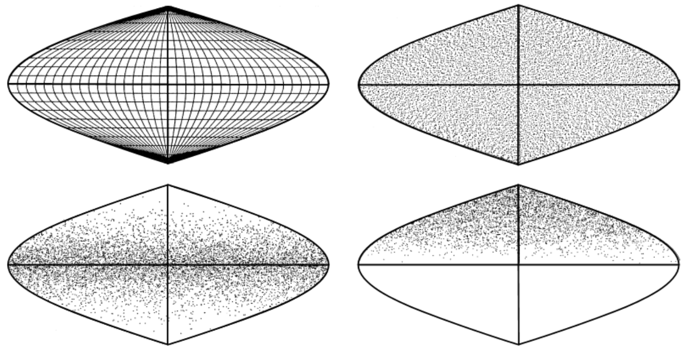

Figure. 6: Top right: Uniform distribution. Top left: spherical and regular grid with various ray sources. Bottom right: Focus of rays at the North Pole. Bottom left: Focus of rays at the equator.

In main prayer hall, source of sound is a person who is called imam and normally is a man raised voice. The leader or imam stands in front of audience, near the mihrab. Generally, all of mosque designs are based on the position of the mihrab, which is planned in direction of the Qibla. It is an Omni-directional source that propagates sound equally in all directions; thus, visual representation of it appears as a sphere. As can be seen in Figure 7 all common sounds (music, speech, and noise) are more complex because they contain sound energy over wider ranges of the human audible spectrum 20 to 20000 Hz for young people with normal healthy ears and convenient range of frequency for testing and measurement is between 125 to 4000 Hz that according to the Figure 8, this range for male voice is 125 to 2000 Hz.

Laboratory testing for sound transmission loss and sound absorption of typical building components and material falls in this range																													
25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	6000	7300	8000	10000	12500	16000	20000
	31.5			63			125			250			500			1000			2000			4000			8000			16000	

Figure. 7: Audible frequency range divided into standard octave and 1/3 octave bands, which are convenient for measurement and analysis. Laboratory test standards for the acoustical performance of many building components extend from bands centered at 125 Hz to those at 4000 Hz (Cavanaugh, 1988)

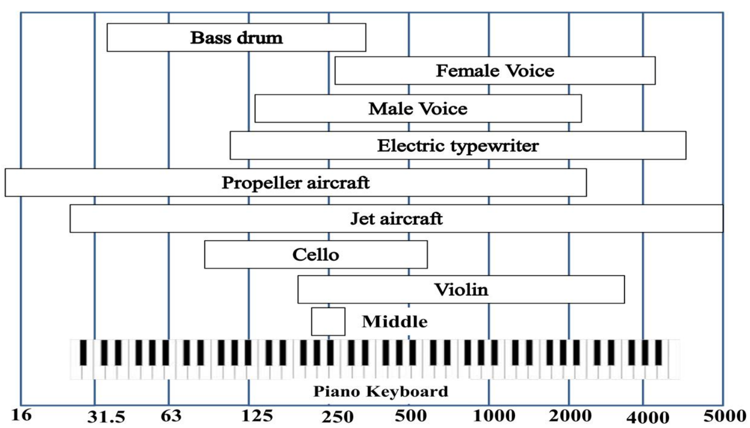

Figure 8: Comparison of frequency for some common sounds with a piano keyboard (Cavanaugh, 1988)

4.2 Modelling of main prayer hall

The room geometry must be designed as the 3D model objects in the computer simulation software to apply the algorithm described in program. These models can be including small details such as openings and voids or smaller geometric features with material features of them, so complexity of the model can be very high.

Room geometric information divided into two main groups: Geometry data and Surfaces data that should be include the acoustic characterization of room.

- Geometry data will be including volume, dimension (W, L and H) of plan and section, openings such as windows, doors, voids and more.
- Material data will be including type of material and Diffusion Coefficient which will define absorption and scattering of surfaces.

Both of data have to transfer in simulation software for making 3D model of the main prayer hall. Figure 9 illustrates a very simply shape of 3D model's main prayer hall and the chosen room geometry of it.

The acoustic characterization of surfaces in main prayer hall is based on absorption and scattering of waves by materials of surfaces.

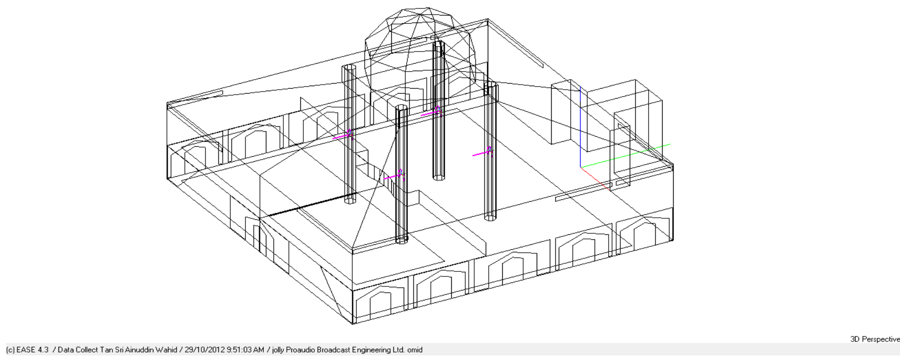

Figure 9: 3D model of main prayer hall.

4.3 Modelling of Audience area

Prayer, public speaking, preaching, lecturing, and Qur'an recitations are worshipping activities that perform in the distinct audience area inside main prayer hall and need to high quality of sound for having good speech audibility and intelligibility (Frishman & Kuban, 2002; Orfali, 2007; Utami, 2005). These activities are divided into two different modes: prayer mode (Figure 10.a) or preaching mode (Figure 10.b). Prayer mode divided into two different groups that are called group prayer and individual prayer. Group prayer is performed in four various positions that are included standing, bowing, prostrating, or sitting behind the Imam, in front of the qibla wall, on the same floor level, in rows parallel to the Qibla wall and distances around 1.2 m between each line. Individual prayer is the same of group prayer, but performed individually. In preaching mode, activities are in a group and the worshippers are sitting on the floor in random parallel to the Qibla' wall, while the imam is standing on minbar facing the listeners.

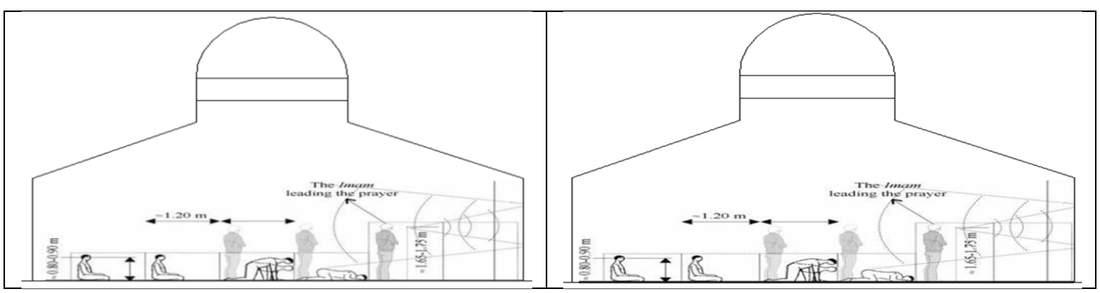

Figure 10: Worship activities in audience area of main prayer hall including: a) Prayer mode activity b) preaching mode activity

According to the figure 10, worship activities should be model in two horizontal and vertical levels. Worshippers perform various prayers in main prayer hall and it requires useful capacity of the audience area in horizontal level that is defined by the floor area. This is approximately: 0.80 x 1.2 = 0.96 m2.

Table1: Description of the audience area models in main prayer hall acoustic design.

Type of Mode	Position	Level of ears (Vertical Level)	Area of one audience (Horizontal Level)
Prayer mode	Prostrating	20-25 [cm]	80*120 [cm2]
Prayer mode	Bowing	110-120 [cm]	80*120 [cm2]
Prayer mode	Standing	165-175 [cm]	80*120 [cm2]
Preaching Mode	Sitting	80-90 [cm]	80*120 [cm2]

Conclusions

Mosques are suitable places for the acoustic design. Every mosque has own acoustical requirements and according to the volume, form, shape of mosques and function of sound and speech in it, different acoustical requirements are defined for various worshipping activities. Identifying and solving acoustic problems such as speech intelligibility should be done at the early in the design process before construction of mosque, as the cost of solving acoustic problems is very expensive after construction. Today, the computer aided architectures have been developing day by day and the architectures are solved acoustic problems by acoustical software in fast and strong. EASE software that is used a hybrid technique for evaluation of acoustical performance, is one of the best software between architecture and engineers. Evaluation of speech audibility and intelligibility in the mosques can be analyzed in the design process by computer simulation study and by this software for two worship activities. The design and testing of an architecture problem in real life costs too much money but for designing and testing of it in actual situation of the computers is very cheaper and faster.

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REFERENCES

Abdou, A. A. (2002). Assessment of the Acoustical Performance of Mosques Employing Impulse response technique. *: submitted to Journal of REVIEW 2002*, 47.

Abdou, A. A. (2003). Measurement of acostical characteristics of mosques in Saudi Arabia. *Acoustical Society of America, 113(3)*, pp 1505-1517.

Ahnert, W., & Feistel, R. (1991). *Binaural Auralization from a sound system simulation program.* Paper presented at the 91st Audio Engineering Society Convention, Berlin, Germany.

Allen, J. B., & Berkley, D. A. (1979). Image method for efficiently simulating small-room acoustics. *J. Acoust. Soc. Am, 65*(4), 943-950.

Borish, J. (1984). Extension of the image model to arbitrary polyhedra. *The Journal of the Acoustical Society of America, 75*, 1827.

Cavanaugh, W. J. (1988). Acoustics–General Principles in Encyclopaedia of Architecture: design, Engineering & Construction, Joseph A. Wilkes, Ed: John Wiley & Sons.

Frishman, M., & Kuban, D. (2002). *THE MOSQUE HISTORY, ARCHITECTURE DEVOLPMENT & REGONAL DIVERSITY*. London: Thames & Hudson Ltd.,.

Funkhouser, T., Tsingos, N., Carlbom, I., Elko, G., Sondhi, M., West, J. E., et al. (2004). A beam tracing method for interactive architectural acoustics. *The Journal of the Acoustical Society of America, 115*, 739.

Hamadah, H. A., & Hamotida, H. M. (1998). Assessment of speech intelligibility in large auditoria case study: Kuwait State Mosque. *Applied Acoustics, 54(4)*, pp 273-289.

Howarth, M., & Lam, Y. (2000). An assessment of the accuracy of a hybrid room acoustics model with surface diffusion facility. *Applied Acoustics, 60*(2), 237-251.

Karabiber, Z. (1999). *Acoustieal problems in mosques: A case study on the three mosques in Istanbul.* Paper presented at the The 25th German Acoustics DAGA conference, Berlin, Germany.

Kayili, M. (2002). *Anatolian traditional acoustic works and works done by Sinan the Architect.* Paper presented at the Proceeding of 6th National Acoustical Congress TAKDER, Antalva, Turkey.

Krokstad, A., Strom, S., & Sorsdal, S. (1968). Calculating the acoustical room response by the use of a ray tracing technique. *Journal of Sound and Vibration, 8*(1), 118-125.

Naylor, G. (1992). *Treatment of early and late reflections in a hybrid computer model for room acoustics.* Paper presented at the 124th ASA Meeting, New Orleans.

Naylor, G. M. (1993). ODEON--Another hybrid room acoustical model. *Applied Acoustics, 38*(2-4), 131-143.

Orfali, W. (2007). *Room Acoustic and Modern Electro-Acoustic Sound System Design during Constructing and Reconstructing Mosques.* Universitätsbibliothek.

Ozgur, E., Ozis, F., & Alpkocak, A. (2004). *DAAD: A New Software for Architectural Acoustic Design.* Paper presented at the The 33rd International Congress and Exposition on Noise Control Engineering Prague, Czech Republic.

Prodi, N., & Marsilio, M. (2003). On the effect of domed ceiling in worship spaces: A scale model study of a mosque. *Building Acoustic, 10(2)*, pp 117-133.

Rindel, J. H. (2000). The use of computer modeling in room acoustics. *Journal of Vibroengineering, 3*(4), pp 219-224.

Rindel, J. H. (2010). Room Acoustic Prediction Modelling. *XXIII Encontro De Acustica Salvadora-Ba.*

Suri, R. L. (1966). *Acoustics Design and Practice* (Vol. Volume 1). New York: Asia Publishing House.

Utami, S. S. (2005). *An Acoustical Analysis of Domes Coupled to Rooms, with Special Application to the Darussholah Mosque, in East Java, Indonesia*. Brigham Young University.

Vian, J. P., & Maercke, D. V. (1986). *Different computer modeling methods-their merits and their applications.* Paper presented at the Int. Congr. Acoust. (ICA'86), Toronto, Ont., Canada.

Vorländer, M. (1989). Simulation of the transient and steady state sound propagation in rooms using a new combined ray tracing/image source algorithm. *The Journal of the Acoustical Society of America, 86*, 172.

Xing, T. (2009). *A Teaching Tool For Architectural Acoustics.* University of Southern California.