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ACOUSTICAL PERFORMANCE OF MOSQUES: AN OVERVIEW OF CURRENT RESEARCH IN MALAYSIA

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This paper discusses the relationship between the mosques architectural design and their acoustical performances in Malaysia. The architecture styles—both modern and vernacular mosque, are catalogued and complied from the year 1400s and 2015 along with the physical characteristics which reflects their acoustical performances. This compilation includes consistencies and discrepancies of measurement and simulation results from various studies conducted by Malaysian researchers. The study highlights acoustical parameters such as reverberation time, background noise level, noise criteria and speech intelligibility in the mosque. In addition, the details study of building characteristics in the mosque e.g. architectural styles, volume and roof types, are discussed. The summary of acoustical performance compilation gives basic data for outlining acoustic criteria or guidelines in Malaysia. Clearly, that there is a need to collect more refine data for reliable acoustical performance guideline for mosque in Malaysia.

Keywords: mosque, acoustical performance, architecture

1. Introduction

Mosque is very important religious node and communal spaces for Muslim community and should function as an effective as a medium of conveying information [1-2]. In early 2017 statistics, there are 6426 mosques and 17734 madrasah have been registered [3]. Unfortunately, the architectural design of the mosques often neglected and rarely considered on their acoustical performance. Nowadays, the sound reinforcement systems were added after the mosque has been completed, to overcome the poor acoustical performance instead of investigating it in early design stage. The objectives of this paper is to review and report on the researches and existing data available from various studies done on acoustical performance in Malaysian mosques [4-16].

2. Methodology

The compilation was based on contribution related to research on acoustical performance of mosques in Malaysia found in libraries, major search engine, online research outputs and unpublished data by authors. The acoustical performance data contributed to the final compilation in addition to mosques characteristics availability. There are two of journal articles, seven of proceedings four chapters in book, thesis or dissertations found based on the searchable databases available until end of 2016. The total number of mosques involved in this study is 64 which

represent about 1% from total registered mosques in Malaysia. The distribution of mosques in Malaysia emanates from 33 mosques in southern, 20 mosques in central, nine (9) mosques in northern and two (2) mosques in eastern Peninsular Malaysia. No mosque from Malaysian Borneo (Sabah and Sarawak) represented in this study.

Table 1 presents the summarized data on the main characteristics involved of the 64 mosques. It includes information such as mosque's name, main prayer halls' dimension and architectural roof style. Some of the mosques' dimensions are not available or explicit details from the references. There are situation that the mosque was relocated from origin site and a few of mosques were demolished for new development but original drawing are still available for record. The methodology of the studies also have been listed and summarized in the table.

3. Discussions

3.1 Architecture & Planning

The mosques' architecture styles in this paper show diversity from traditional vernacular, sino-eclectic, neo-colonial and modern styles. Early mosques built in Malaysia are characterized by the local and region character. To some extent, the features that make a mosque or other structure notable or historically identifiable and still continue to be important daily lives of the people and relevant to the society or community. From the Table 1, less than ten mosques can be identified as traditional vernacular architectural styles. Furthermore, architectural style in mosque also spread through the influences or learning from foreign or by settlers moving to the country. Recent literature reported the approaches related to sustainable mosque architecture have potential to increase the awareness of sustainability in the construction industry [17]. First green mosque in Malaysia has been complete built in early 2015 and received platinum award from Malaysian Green Building Index (GBI). Today, most of the mosques have become one of tourist destination.

Generally, there is lack of study regarding the relationship between mosque architectural styles and their acoustical performance. Whilst it might be complicated to cataloguing on architectural styles itself, the main prayer hall shapes are not varies significantly as the space is designed to face toward Qibla (Mecca) direction. Even though there are several spatial configurations on the functional efficiency of the mosque layouts [2] but the floor plan of main prayer hall usually designed as rectangular or square shape. The main prayer hall commonly is constructed in hypostyle form with specific roof style, interior decoration and material furnishes.

The volume in the main prayer hall is one of important parameter affecting the acoustical characteristics in the mosques. In this study, the main prayer halls varied from 171 m^3 to volumes over 80000 m^3. The traditional vernacular architecture style usually designed with smaller volume compared to modern architecture styles. There is insufficient studies for comparing between different space volumes in larger number of mosques as case studies, thus raise a question what is the most optimum or desired acoustical parameters e.g. reverberation time, in mosque.

In this compilation, the mosques' roof types consist of 27% of pyramidal types, 70% of dome type and 3% of others roof type were identified. The earlier mosques—traditional vernacular architectural styles generally constructed with pyramidal roof to response local climate. The later mosques reflect the influence of external architectural styles, in particularly the dome. The dome, due to its shape, generates unequal distribution of sound wave and might contribute to poor speech intelligibility. Harun M. [12] developed acceptable accuracy for speech intelligibility (SI) prediction models using mosque's dome as case study in providing the estimation of SI in early design stage.

Finally, the location of mosques were planned to ensure it is accessibility from the surrounding community. However, the earlier mosques are now usually surrounded by higher density settlement and expose to noisier environment. Adzahan Z. and Nazli C.D. [6] conducted study related to distance from main prayer halls to the nearest road by corresponding to the type or ranking of the road. The study suggests that road traffic noise is a significant factor contributes to higher background noise which often penetrates into the mosque.

Table 1: List of studied mosques description and their physical characteristics

No	Methodology	Mosque	Roof Type	Main Prayer Hall (approximately)			References
				Volume (m^3)	Length (m)	Width (m)	
1	Measurement	Masjid Batu Uban	Pyramidal	171	7	7	Authors (4-6)
2	Measurement	Masjid Kg Duyung	Pyramidal	413	12	8	Authors (4-6)
3	Measurement	Masjid Dato Dagang	Pyramidal	777	12	12	Authors (4-6)
4	Measurement	Masjid Tengkera	Pyramidal	786	14	14	Authors (4-6)
5	Measurement	Masjid Kg Kling	Pyramidal	963	16	13	Authors (4-6)
6	Measurement	Masjid Lebuh Acheh	Pyramidal	1001	17	14	Authors (4-6)
7	Measurement	Masjid Kg Laut	Pyramidal	1012	21	13	Authors (6)
8	Measurement	Masjid Sultan Alae'ddin	Dome	1030	9	9	Authors (6)
9	Measurement	Masjid Sg Gulang-Gulang	Pyramidal	1109	19	15	Authors (6)
10	Measurement	Masjid Kapitan Keling	Dome	3014	26	21	Authors (6)
11	Measurement	Masjid Zahir	Dome	3409	18	19	Authors (Unpublished data)
12	Measurement	Masjid Muhammadi	Pyramidal	5571	18	35	Authors (Unpublished data)
13	Measurement	Masjid Sultan Abu Bakar	Pyramidal	8440	23	38	Authors (Unpublished data)
14	Measurement	Masjid Sultan Ibrahim	Pyramidal	9244	26	37	Authors (Unpublished data)
15	Measurement	Masjid Dato Panglima Kinta	Dome	1401	16	14	Authors (Unpublished data)
16	Measurement	Masjid Raja Haji Fi Sabilillah	Dome	8126	35	24	Authors (Unpublished data)
17	Measurement	Masjid Tuanku Mizan	Dome	81257	42	56	Authors (Unpublished data)
18	Measurement	Masjid Univeristi Putra Malaysia (UPM)	Dome-like	52000			A.H. Abdullah and Z.A. Zulkefli (7)
19	Measurement	Masjid Jamek Serdang	Dome	575			A.H. Abdullah and Z.A. Zulkefli (7)
20	Measurement	Masjid Al-Bukhary Senai	Dome	11034			S. Idris (8)
21	Meas. & Calc.	Masjid Taman Putri Kulai	Pyramidal	3425			M.N. Dimon, et al. (9)
22	Meas. & Sim.	Masjid Sayyidina Abu Bakar UTEM Melaka	Pyramidal	19500	33*	33*	A. Putra, et al. (10)
23	Measurement	Masjid Jamek Sungai Besi	Pyramidal	539			A. R. Othman and M. R. Mohamed (11)
24	Measurement	Masjid Jamek Selayang Lama	Dome	710			A. R. Othman and M. R. Mohamed (11)
25	Measurement	Masjid Jamek Jalan Haji Salleh, Sentul	Pyramidal	809			A. R. Othman and M. R. Mohamed (11)
26	Measurement	Masjid Jamek Tengku Abdul Aziz Shah	Pyramidal	1687			A. R. Othman and M. R. Mohamed (11)
27	Measurement	Masjid Jamek Sungai Mulia	Dome	4219			A. R. Othman and M. R. Mohamed (11)
28	Measurement	Masjid Jamek Bandar Manjalara	Dome	12200			A. R. Othman and M. R. Mohamed (11)
29	Measurement	Masjid Sultan Ismail (UTM)	Dome	38288			M. Harun (12)
30	Measurement	Masjid Pekan Nanas	Flat	6734*	34*	22*	M. Harun and A K Said (13)
31	Measurement	Masjid Jamek Yong Peng	Dome	11404*	36*	36*	M. Ula, et al. (14)
32	Measurement	Masjid Kampung Rimba Terjun Pontian	Dome	2359*	21*	21*	M. Ula, et al. (14)
33	Simulation	Masjid Kg Bukit Belimbing	Pyramidal	617			Authors (15-16)
34	Simulation	Masjid Sultan Suleiman	Dome	1844			Authors (15-16)
35	Simulation	Masjid Jamek Kuala Lumpur	Dome	2971			Authors (15-16)
36	Simulation	Masjid Sultan Alaedin	Dome	1030			Authors (15-16)
37	Meas. & Calc.	Masjid Al-Mizan Kempas	Dome	6365	27	30	M. Harun (12)
38	Meas. & Calc.	Masjid Taman Bukit Kempas	Dome	584	13	12	M. Harun (12)
39	Meas. & Calc.	Masjid Jamek Taman Kencana	Dome	6316	32	24	M. Harun (12)
40	Meas. & Calc.	Masjid Sultan Ismail UTM (Dewan Muslimah)	Dome	2500	7	7	M. Harun (12)
41	Meas. & Calc.	Masjid Jamek Larkin Jaya	Dome	13700	78	22	M. Harun (12)
42	Meas. & Calc.	Masjid Jamek Parit Betak, Pontian	Dome	1109	17	13	M. Harun (12)
43	Meas. & Calc.	Masjid Jamek Bandar Benut, Pontian	Dome	11009	36	32	M. Harun (12)
44	Meas. & Calc.	Masjid Jamek Bandar Kota Tinggi	Dome	6634	44	21	M. Harun (12)
45	Meas. & Calc.	Masjid Bandar Mersing	Dome	4856	31	21	M. Harun (12)
46	Meas. & Calc.	Masjid Jamek Sedili Besar Mersing	Dome	6748	29	25	M. Harun (12)
47	Meas. & Calc.	Masjid Jamek Pasir Gudang	Dome	6492	34	18	M. Harun (12)
48	Meas. & Calc.	Masjid Institut Kemahiran Belia Negara Pagoh	Dome	6560	30	25	M. Harun (12)
49	Meas. & Calc.	Masjid Jamek Bandar Tenggara, Kota Tinggi	Dome	4162	30	18	M. Harun (12)
50	Meas. & Calc.	Masjid As-Syifa Bandar Penawar, Johor Bahru	Dome	12627	50	34	M. Harun (12)
51	Meas. & Calc.	Masjid Sultan Ismail Batu Pahat	Dome	26016	46	37	M. Harun (12)
52	Meas. & Calc.	Masjid Jamek Al-Amin, Tangkak	Dome	10383	37	26	M. Harun (12)
53	Meas. & Calc.	Masjid Jamek Tangkak	Dome	11456	46	35	M. Harun (12)
54	Meas. & Calc.	Masjid Jamek Bandar Kluang	Dome	1135	15	12	M. Harun (12)
55	Meas. & Calc.	Masjid Jamek Labis	Dome	1058	18	14	M. Harun (12)
56	Meas. & Calc.	Masjid Jamek Kampung Jawa, Segamat	Dome	6397	29	25	M. Harun (12)
57	Meas. & Calc.	Masjid Jamek Tandop, Alor Star	Dome	3751	27	24	M. Harun (12)
58	Meas. & Calc.	Masjid Jamek Kepala Parit Dalam, Alor Star	Dome	2436	20	17	M. Harun (12)
59	Meas. & Calc.	Masjid Al-Bukhary, Alor Setar	Dome	14709	27	24	M. Harun (12)
60	Meas. & Calc.	Masjid Taman Uda, Alor Star	Dome	2409			M. Harun (12)
61	Meas. & Calc.	Masjid Jamek Al-Jara Taman Sri Rampai	Dome	8933	32	30	M. Harun (12)
62	Meas. & Calc.	Masjid Angkatan Tentera Malayisa (ATM)	Dome	1283	15	15	M. Harun (12)
63	Meas. & Calc.	Masjid Jamek Al-Solihin, Bangi	Dome	9293	36	32	M. Harun (12)
64	Meas. & Calc.	Masjid Maktab Penguruan Islam Bangi	Dome	4814	31	30	M. Harun (12)

*Indicator- *: measured by author, Meas: Measurement, Calc: Calculation, Sim: Simulation*

3.2 Acoustical performance

Among the literature studied, major focus on five selected acoustical parameters was being discussed in this paper.

3.2.1 Background noise level (BN) & Noise criteria (NC)

Almost articles published in this compilation available on data of background noise (BN). However, only 73% of BN data (BN ON) available in this paper are shown for BN when facilities

such lighting, fan and air-conditioning were in operation mode. 18 mosques' BN are not given in references. Figure 1 (a) shows comparison between surface area with BN. Mostly, below than 1000 m^2 of surface area having higher BN compared to surface area over than 1000 m^2 generally having tendency below than 55 dBA. Even though the trend line of positive correlation was in moderate, the range of BN shown in this compilation having potential characteristics between 40 - 60 dBA depending on the area of main hall's surface.

In most similar references, the noise criteria (NC) also are highlighted by the researchers. On the other hand, Harun M. [12] shows balanced noise criteria (NCB) for showing spectral imbalance of background noise level at low and higher frequency, however, the author re-calculated back to NC to provide fair and similar comparison in this study. The lowest NC found is NC-33 and highest NC is NC-61. The averaged of BN and NC found in this compilation when facilities in operating in main prayer halls are 50.2 dBA and NC-44, respectively.

3.2.2 Reverberation time (RT)

23% of reverberation times (RTs) data from 250 – 4000 Hz are available, but higher percentage of RTs can be found from 250 – 2000 Hz. The most available RTs can be obtained was in 1000 Hz. The researcher may use only RTs of 500 and 1000 Hz due to the common practice of optimum reverberation time given and referred.

Figures 1(b) and 1(c) illustrated comparison for both frequencies of 500 Hz and 1000 Hz with their respective volume of main prayer halls of mosques. Both frequencies show moderate correlation but 1000 Hz frequency extended more relationship towards the space volume compared to 500 Hz. The highest obtained RT for 500 Hz was 4.5s and 1000 Hz was 3.5s.

Details comparison of RT in 1000 Hz for different type of roof was presented in Figs. 1(d) and 1(e). Strong positive correlation can be found in pyramidal roof type which the tendency shows consistently that RT become higher when the volume become larger. The moderate correlation can be observed in dome roof types and mostly their RTs were over than 1.0s. It is suggested that the dome roof types might contributed uneven distribution of sound wave and resulted higher RT [12].

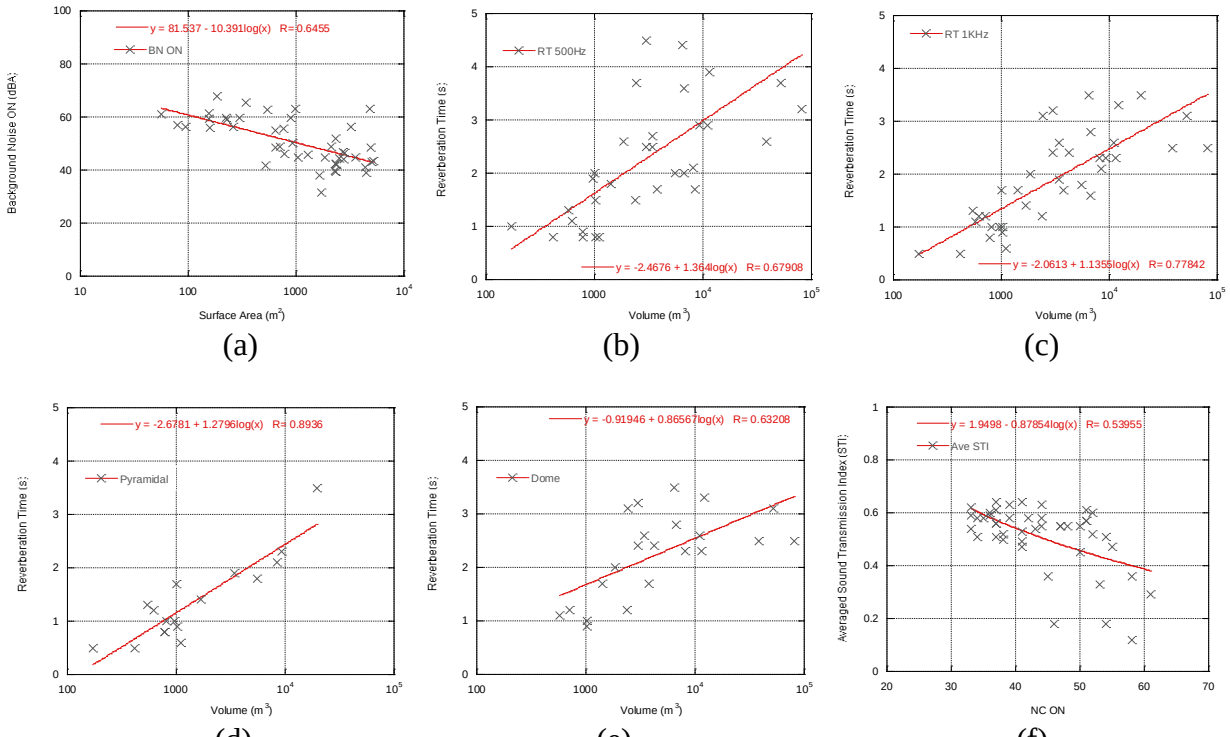

Figure 1: Comparison of selected acoustical parameters; (a) BN vs, Surface Area, (b) RT at 500 Hz, (c) RT at 1000 Hz, (d) RT for pyramidal roof, (e) RT for dome roof, and (f) Averaged STI vs. NC.

Table 2: List of acoustical performances of 65 mosques derived from literatures

No	Mosque	BN ON	NC ON	Reverberation Time (s) 250 Hz	500 Hz	1K Hz	2K Hz	4K Hz	Ave STI	RASTI
1	Masjid Batu Uban	61.0	51	1.4	1.0	0.5	0.9		0.57	
2	Masjid Kg Duyung	56.3	47	0.9	0.8	0.5	0.8		0.55	
3	Masjid Dato Dagang	59.4	54	1.2	0.8	0.8	1.0		0.51	
4	Masjid Tengkera	61.3	51	0.7	0.9	0.8	0.8		0.57	
5	Masjid Kg Kling	67.9	48	1.5	1.9	1.0	0.8		0.55	
6	Masjid Lebuh Acheh	59.8	47	1.2	2.0	1.7	1.2		0.55	
7	Masjid Kg Laut	56.3	50	0.8	0.8	0.9	0.6		0.55	
8	Masjid Sultan Alae'ddin	56.9	52	0.6	0.8	0.9	0.8		0.52	
9	Masjid Sg Gulang-Gulang	59.8	55	1.0	0.8	0.6	0.6		0.47	
10	Masjid Kapitan Keling	62.7	58	4.2	4.5	3.2	2.4		0.36	
11	Masjid Zahir	65.5	61	2.2	2.5	2.6	2.5		0.29	
12	Masjid Muhammadi	54.9	50	3.0	2.0	1.8	1.4		0.45	
13	Masjid Sultan Abu Bakar	50.1	45	2.0	1.7	2.1	2.3		0.36	
14	Masjid Sultan Ibrahim	63.1	58	3.1	2.9	2.3	1.7		0.12	
15	Masjid Dato Panglima Kinta	58.9	53	2.7	1.8	1.7	1.3		0.33	
16	Masjid Raja Haji Fi Sabilillah	59.7	54	3.2	2.1	2.3	1.9		0.18	
17	Masjid Tuanku Mizan	51.9	46	2.7	3.2	2.5	2.3		0.18	
18	Masjid Univeristi Putra Malaysia (UPM)	63.0		4.0	3.7	3.1	2.7	2.0	0.39	0.36
19	Masjid Jamek Serdang	55.9		1.3	1.3	1.1	0.8	0.7	0.55	0.61
20	Masjid Al-Bukhary Senai		41	3.0	2.9	2.6	1.9	1.5		
21	Masjid Taman Putri Kulai			3.6	2.7	1.9	1.5	1.4	0.45	
22	Masjid Sayyidina Abu Bakar UTEM Melaka			3.7	5.7	3.5	3.0	1.7	0.40	
23	Masjid Jamek Sungai Besi					1.3				0.67
24	Masjid Jamek Selayang Lama					1.2				0.65
25	Masjid Jamek Jalan Haji Salleh, Sentul					1.0				0.71
26	Masjid Jamek Tengku Abdul Aziz Shah					1.4				0.69
27	Masjid Jamek Sungai Mulia					2.4				0.57
28	Masjid Jamek Bandar Manjalara					3.3				0.48
29	Masjid Sultan Ismail (UTM)	39.7	34	2.3	2.6	2.5	1.8		0.58	
30	Masjid Pekan Nanas			3.2	2.0	1.6	1.2			
31	Masjid Jamek Yong Peng			3.2	3.9	2.3	2.0	2.0		
32	Masjid Kampung Rimba Terjun Pontian			1.6	1.5	1.2	1.3	1.1		
33	Masjid Kg Bukit Belimbing			1.2	1.1	1.2	1.1	0.7	0.45	
34	Masjid Sultan Suleiman			2.7	2.6	2.0	1.6	1.3	0.28	
35	Masjid Jamek Kuala Lumpur			2.6	2.5	2.4	1.8	1.4	0.24	
36	Masjid Sultan Alaedin			1.7	1.5	1.0	1.2	0.9	0.33	
37	Masjid Al-Mizan Kempas	44.3	39						0.63	
38	Masjid Taman Bukit Kempas	41.7	37						0.64	
39	Masjid Jamek Taman Kencana	48.8	44						0.58	
40	Masjid Sultan Ismail UTM (Dewan Muslimah)	38.0	33						0.62	
41	Masjid Jamek Larkin Jaya	42.9	37						0.56	
42	Masjid Jamek Parit Betak, Pontian	48.7	44						0.63	
43	Masjid Jamek Bandar Benut, Pontian	44.6	38						0.52	
44	Masjid Jamek Bandar Kota Tinggi	44.0	38						0.50	
45	Masjid Bandar Mersing	39.5	34						0.51	
46	Masjid Jamek Sedili Besar Mersing	39.6	33	3.2	3.6	2.8	2.3	2.0	0.54	
47	Masjid Jamek Pasir Gudang	42.4	36						0.60	
48	Masjid Institut Kemahiran Belia Negara Pagoh	42.1	37						0.61	
49	Masjid Jamek Bandar Tenggara, Kota Tinggi	31.4	33						0.59	
50	Masjid As-Syifa Bandar Penawar, Johor Bahru	38.9	35						0.58	
51	Masjid Sultan Ismail Batu Pahat	43.5	37						0.56	
52	Masjid Jamek Al-Amin, Tangkak	46.5	41						0.49	
53	Masjid Jamek Tangkak	41.2	36						0.59	
54	Masjid Jamek Bandar Kluang	46.2	41						0.47	
55	Masjid Jamek Labis	55.6	51						0.61	
56	Masjid Jamek Kampung Jawa, Segamat	42.5	37	4.5	4.4	3.5	2.6	2.1	0.51	
57	Masjid Jamek Tandop, Alor Star	44.6	39	2.2	1.7	1.7	1.8	1.7	0.58	
58	Masjid Jamek Kepala Parit Dalam, Alor Star	44.7	41	3.1	3.7	3.1	2.1	1.9	0.53	
59	Masjid Al-Bukhary, Alor Setar	48.5	43						0.54	
60	Masjid Taman Uda, Alor Star	45.9	41						0.64	
61	Masjid Jamek Al-Jara Taman Sri Rampai	56.4	52						0.60	
62	Masjid Angkatan Tentera Malayisa (ATM)	48.4	44						0.55	
63	Masjid Jamek Al-Solihin, Bangi								0.62	
64	Masjid Maktab Penguruan Islam Bangi	46.8	42						0.58	

3.2.3 Speech transmission index (STI) and Rapid speech transmission index (RASTI)

Higher BN or NC found in the previous section may influence to the speech intelligibility. 84% of averaged speech transmission indexes (STI) data are found in related publication. The highest and lowest averaged STI data recorded in participating mosque are 0.64 and 0.12, respectively. Even though the correlation observed in Fig. 1(f) is moderate relationship between STI and NC, the basic tendency for their respective main prayer halls relatively independent on the NC, that the lower the NC is, the higher the STI becomes. Further study on the distance and details analysis need to take strictly into consideration due to their materials, shape and volume give significant effects to acoustical quality.

Rapid Speech Transmission Index (RASTI) nearly having similar approach to investigate speech intelligibility. However, not many studies have been published. Among the reports in the relevant literature, only eight (8) mosques are provided data on RASTI parameter. Carvalho A.P.O. [18] found the relations between RASTI and other acoustical and architectural parameters appear as an interesting necessity. The average RASTI value obtained in this study is 0.59.

3.2.4 Other parameter

Other related acoustical parameters have been investigated are early decay time (EDT), clarity (C50), definition (DF) and lateral function (LF). In this paper, only one study has been identified by using computer simulation for a case study in mosque [10].

3.3 Other related study

Some other details studies have been reported about the building features in the mosque such as materials used [9], dome [12], and mihrab [5, 15-16]. Most study involved concentrating on physical aspects but none of the study made available in psychological aspects.

4. Conclusions

In this paper, a series of data compilation of 65 mosques related to architectural aspects and their acoustical performances have been discussed. Even though most of researchers focused on reverberation time parameter but the correlation is still in moderate agreement. The published data compilation may be useful as a fundamental input for future acoustics research for mosque acoustic via simulation method. There is need to establish the acceptable criteria or guideline for mosque during its designing stage. The overall guideline on mosques acoustic could be enhanced further if extensive qualitative research is conducted also on human perception and preference on the acoustic performance on mosques in Malaysia.

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REFERENCES

1 Rasdi, M. T. M. and Utaberta, N. The design of mosque as centre of community development from the perspective of sunna and Wright's organic architecture, *Journal of Islamic Architecture*, **1** (1), 1-7, (2008).

2 Baharudin, N. A. and Ismail, A. S. Communal mosques: Design functionality towards the development of sustainability for community, *Procedia – Social and Behavioral Sciences*, **153**, 106-120, (2014).

3 JAKIM. (2017). *Statistik*. [Online.] Available: http://masjid.islam.gov.my/index.php.

4 Nazli, C. D., Jalil, N. A. A., Ahmad, Y., Othman, R. and Otsuru, T. Measurement of the acoustical performance of traditional vernacular mosques in Malaysia, *Proceedings of the 42nd International Congress and Exposition on Noise Control Engineering*, Innsbruck, Austria, 15–18 September, (2013).

5 Ahmad, Y., Nazli, C. D., and Othman, R. Mihrab design and its basic acoustical characteristics of traditional vernacular mosques in Malaysia, *Journal of Building Performance*, **4** (1), 44–51, (2013).

6 Adzahan, Z. and Nazli, C. D. Measurement of the acoustical performance in Malaysian mosques: Relationship with their respective locations and indoor facilities, *Proceedings of the 12th Western Pacific Acoustics Conference (WESPAC)*, Singapore, 6-9 December, (2015).

7 Abdullah A. H., and Zulkefli, Z. A. A study of the acoustics and speech intelligibility quality of mosques in Malaysia, *Applied Mechanics and Materials*, **564**, 129–134, (2013).

8 Idris, S. *Acoustic quality and thermal comfort inside Al-Bukhary mosque, Senai, Johor Darul Takzim*, Bachelor of Engineering Thesis, Universiti Teknologi Malaysia, (2014).

9 Dimon, M. N., Adzim, S. D. A. M, Hassan, H., Azliza, N. and Jusoh, M. Z. Good speech intelligibility through novel acoustics material of geometric perforated panel in mosques, *Proceedings of the International Symposium on Room Acoustics (ISRA)*, Melbourne, Australia, 29-31 August, (2010).

10 Putra, A. Kassim, D. H., Yaakob, M. Y., Abdullah, Y. Assessment of the acoustical performance in Malacca mosque, Malaysia: A case study on the Sayyidina Abu Bakar Mosque, *Proceedings of the 20th International Congress on Sound & Vibration (ICSV20)*, Bangkok, Thailand, 7-11 July, (2013).

11 Othman, A. R. and Mohamed, M. R. Influence of Proportion towards speech intelligibility in mosque's praying hall, *Proceedings of the Asia Pacific International Conference on Environment-Behaviour Studies*, Famagusta, Cyprus 7-9 December, (2011).

12 Harun, M. *Speech Intelligibility Prediction Models in Room with Reflective Dome*, Doctor of Philosophy Thesis, Universiti Teknologi Malaysia, (2005).

13 Harun, M. and Said, A. K. *Acoustics challenges in mosques*, Chapter in book of Contemporary Issues on Mosques Acoustics, UTM Press, Skudai, Johor (2007).

14 Ula, M., Azami, M. S. I. M., Hanafiah, M. N. M., Hamid, S. Z. A., Rahman, A. F. and Adzim, S. D. A. M. *Reverberation time of Masjid Jamek Yong Peng and Masjid Jamek Kampon Rimba Terjun Johor*, Chapter in book of Contemporary Issues on Mosques Acoustics, UTM Press, Skudai, Johor (2007).

15 Nazli, C. D., Adzahan, Z., Razak. A. R., Abdullah, Z., Jusoh, M. Z. and Dimon, M. N. Comparison of the acoustical performance of mihrab design in mosques using computer simulation studies, *Proceedings of 44th International Congress and Exposition on Noise Control Engineering*, San Francisco, USA, 9-12 August, (2015).

16 Nazli, C. D., Adzahan, Z., Razak. A. R., Jusoh, M. Z., Dimon, M. N. and Abdullah, Z., The effect of noise criteria levels on speech intelligibility in various types of mihrab design, *Proceedings of 22nd International Congress on Acoustics*, Buenos Aires, Argentina, 5-9 September, (2016).

17 Tohid, Z. and Rahim, A. A. Sustainable Masjid Architecture and Public Buildings, *Proceedings of 6th Asia-Pacific International Conference on Environmental-Behaviour Studies*, Barcelona, Spain, 31 Aug – 5 Sept, (2015).

18 Carvalho A. P. O. Relations between rapid speech transmission index (RASTI) and other acoustical and architectural measures in churches, *Applied Acoustics*, **58**(1), 33-49, (1999).