Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

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To cite this article: A W Razali *et al* 2024 *J. Phys.: Conf. Ser.* **2721** 012007

Classroom architectural design evolution: Acoustic evaluation of public-school classrooms in Malaysia

A W Razali[*1,2], N Che Din[2], M N Yahya[3] and R Sulaiman[4]

[1]Department of Quantity Surveying, Faculty of Built Environment, Universiti Malaysia Sarawak, Malaysia
[2]Department of Architecture, Faculty of Built Environment, Universiti Malaya, Malaysia
[3]Department of Transportation Engineering Technology, Faculty of Engineering Technology, Pagoh Higher Education Hub, Universiti Tun Hussein Onn Malaysia
[4]Department of Building Surveying, Faculty of Built Environment, University Malaya, Malaysia

*Email: rawafi@unimas.my

Abstract. Education transformation greatly emphasises curriculum modification to produce impactful future generations and yet often disregards the impact of classroom design in achieving desired education outcomes. The prioritisation of optimal acoustic quality in classroom design is crucial due to the inherent reliance on auditory abilities in the process of teaching and learning. Therefore, a comprehensive acoustic standard guideline for classrooms, ANSI Standard 12.60, was launched in 2002 and adopted for school classrooms in the USA. However, the scenario might be different in Malaysia, as there is no acoustic standard guideline established. Therefore, this study seeks to identify the actual acoustic conditions of classrooms that were constructed in the post-independence era. On-site acoustic measurements were performed to evaluate significant acoustic parameters, including reverberation time (RT), background noise level (BNL), speech transmission index (STI), and sound pressure level (SPL). The findings revealed that the RT for both classrooms was within the recommended value, while the BNL and STI of both classrooms failed to comply with the established recommended guidelines. In a similar vein, these findings translate the degree of awareness among the education institutions and construction sector of the importance of classroom acoustics in providing a better learning experience among students.

1. Introduction

A comprehensive movement of education system reformation in Malaysia that centres on curriculum changes to cater to future needs is indeed a remarkable effort by the government. Curriculum development has long been recognised as a crucial aspect of educational advancement and reform, particularly in developing nations primarily to furnish the necessary education required for the development of human resources, thereby addressing the demands arising from the country's social, economic, and political progress [1]. The non-formal pedagogy that emerged in the early 19th century placed significant emphasis on religious, moral, spiritual, martial arts, and handicraft teaching [2]. However, the current educational landscape in Malaysia, as outlined in the Malaysian Education Blueprint 2013-2023, has shifted its focus towards student knowledge acquisition, the development of critical thinking skills, fostering leadership qualities, promoting bilingual proficiency, and constructing a national identity [3].

While progressively emphasising curriculum advancement, the most prominent factors, namely the comfort level in establishing a conducive classroom environment for both students and teachers are not taken into account. A classroom must be designed to provide an excellent environment which includes several factors such as thermal, lighting, air quality and acoustics. However, this primary concern failed to be addressed during the design phase of school development. Throughout the decades and up to the current day, the architectural design of public schools in Malaysia have remained consistent from the first school establishment. The public schools in Malaysia, encompassing both primary and secondary levels, adhere to a standardised architectural design and spatial planning established by the Malaysian Public Works Department. This uniformity is achieved through the replication of a prototype architectural design across all public schools in the country. The spatial arrangement of conventional school building design is derived from the curriculum requirements of contemporary elementary and secondary education. Typically, the physical arrangement of traditional schools is characterised by a linear layout featuring corridors on one side [4].

1.1. Overview of school design in Malaysia

The current emphasis on curriculum transformation appears to overshadow the significance of physical facility attributes, specifically classroom design, which is widely regarded as a primary determinant in fostering an optimal learning atmosphere. Throughout the decades, from its inception to the present day, the architectural design and approach of public schools in Malaysia have remained unchanged [5]. From the observation, public school design in Malaysia can be categorised into two distinct types: one-off design and standard design. The term "one-off design" pertains to a design characterised by a distinctive layout and building facade that distinguishes it from other structures. Whereas the standard design refers to school design that incorporates repetitious external appearance, layout, space arrangement and building materials. According to Nordin et al. [6], public school design can be categorised into three distinct periods: the post-independence era until the 1970s, the era spanning the 1980s and 1990s, and the post-millennium period. While the variations in the facades design of these three groups were minimal, similarities were seen in other aspects such as the room's form and layout, materials, size and capacity, and other dedicated facilities. Figure 1 shows the public-school design categories in Malaysia.

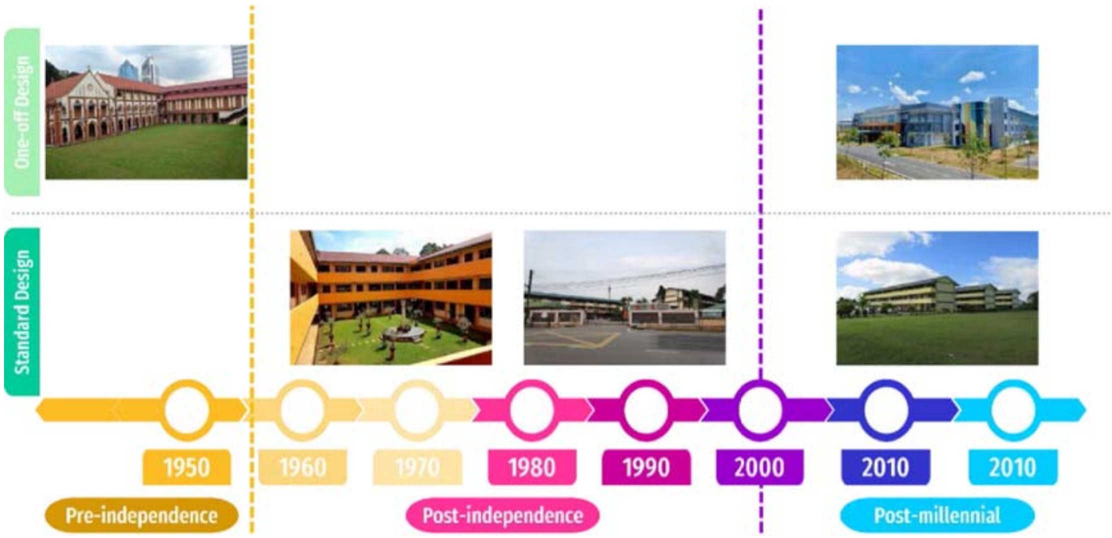


Figure 1. Public school design categories according to the construction period [6]

1.2. Overview of classroom acoustic

Apart from environmental attributes, namely thermal comfort, lighting and indoor air quality, acoustic is considered the most prominent attribute to provide a conducive learning environment in classrooms [8]. In the educational context, the predominant forms of communication are oral, encompassing both speaking and listening. It has been approximated that students allocate a significant portion of their time in the classroom, ranging from 45% to 75%, to the process of comprehending the speech of their teachers and peers [9][10]. Listening in an environment with poor acoustics necessitates greater concentration [11] which could lead to a decrease in students learning achievement [8]. Thus, students learning development is greatly influenced by the classroom acoustic quality [12]. On the other hand, the acoustics of the classroom have a substantial impact on the teacher's well-being. Teachers have to elevate their voices to be heard by students in a classroom environment having a high reverberation time [13][14]. This condition is primarily a result of uncontrolled sound reflection originating from an excessive level of background noise and thus educators are required to speak louder than usual [15], and eventually leads to greater hearing difficulties among the students [16].

In response to the aforementioned concerns, most developed nations have produced acoustic standard guidelines for the school classroom. According to the Acoustical Society of America (ANSI/ASA S12.60) [17], it has been determined that classrooms with volumes below 283 m^3 should have a maximum reverberation time (RT) of 0.6 s, while classrooms with volumes ranging from 283 m^3 to 566 m^3 should have a maximum RT of 0.7 s. While the regulation established by Bulletin 93 [18], it is recommended that the reverberation time (RT) in primary school classrooms should be less than 0.8 s, while in secondary school classrooms, it should be less than 1 s. In terms of indoor noise preference, it is stipulated in both acoustic guidelines that the permissible maximum level of background noise should not exceed 35 dBA.

Limited studies were observed regarding the acoustic performance of classrooms in public schools in Malaysia. Based on a study performed by Ismail et al. [19], the average noise levels measured in eight empty classrooms varied from 58.66 dBA to 62.89 dBA, surpassing the maximum value allowed by ANSI/ASA S12.60 and Bulletin 93, which is 35 dBA. The study by Tong et al. [20] yielded comparable findings. The mean noise level of six classes was found to be more than 40 dBA, surpassing the recommended background noise level of 35 dBA. The RT results observed in the identical classes varied between 0.96 seconds and 1.32 seconds. In general, the RT values did not adhere to the required range of 0.6–0.8 seconds.

Hence, the primary objective of this study is to assess the acoustic performance of two (2) distinct classrooms located in separate public schools that were built in the post-independence period. The study places attention on acoustic parameters namely reverberation time (RT), background noise level (BNL), speech transmission index (STI), and sound pressure level (SPL).

2. Method

Two (2) secondary public schools were selected for the purpose of this study. Both schools were constructed during the post-independence era spanning from 1957 until 1999. The rationale for selecting post-independence schools as the focus of this research is to examine the impact of classroom design on acoustic performance, which in turn influences the educational environment. Future research will incorporate several school design categories in order to have a more comprehensive understanding of acoustic performance in relation to diverse design categories.

2.1. Classroom description

The measurements were carried out within the confines of a classroom at two distinct public secondary schools located in Melaka, Malaysia, namely Schools A and B. According to the information presented in Figure 2, School A is situated in Batu Berendam, Melaka, whereas School B is situated in Sungai Udang. The designs of both schools were classified within the post-independence era due to their construction dates in 1968 and 1981. Both educational institutions are situated in close proximity to a major road, resulting in their exposure to high levels of noise pollution caused by direct traffic noise. Figure 3 illustrates the interior perspectives of both classrooms. Table 1 presents supplementary data pertaining to the description of the classroom, encompassing surface materials, floor area, and volume.

Table 1. Summary of classroom descriptions.

School	Classroom	Floor area (m^2)	Volume (m^3)	Surface Material
School A	Classroom A	65.7	187.2	Floor – Cement render Wall – Semi-plastered brick wall Ceiling – Plywood/asbestos
School B	Classroom B	65.7	201	Floor – Cement render Wall – Plastered brick wall Ceiling – Cement rendered

Figure 2. Aerial photography of location (a) School A and (b) School B (Source: google maps).

(a) (b) (c) (d)

Figure 3. Interior layout and design of school classroom A (a & b) and school classroom B (c & d).

2.2. On-site measurement

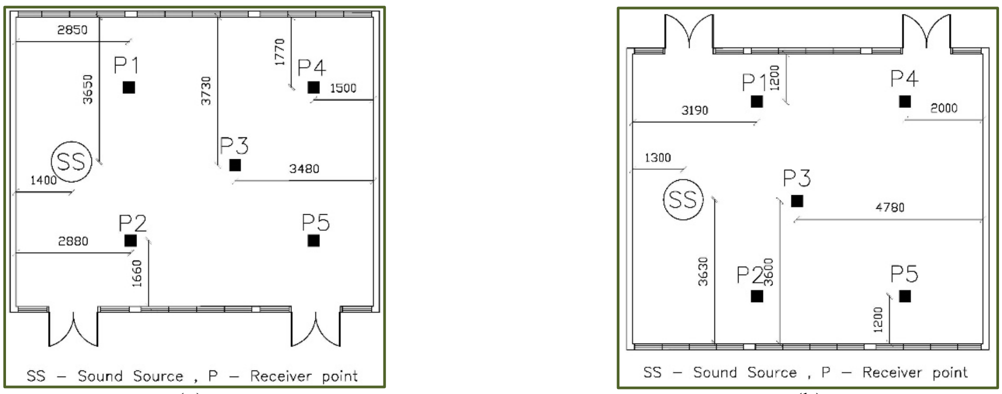
The study conducted measurements on four acoustic parameters in both classrooms, specifically background noise level (BNL), reverberation time (RT), speech transmission index (STI), and sound pressure level (SPL). The measurements were performed in two distinct classrooms, referred to as Classroom A and Classroom B, utilising different equipment configurations.

The background noise BNL levels of both rooms were assessed under the following conditions: (i) opened windows and doors, (ii) with and without ceiling fan in operation, and (iii) unoccupied. The BN levels were evaluated in two separate rooms, referred to as Classroom A and Classroom B. In Classroom A, measurements were taken at nine (9) different locations, whereas in Classroom B, measurements were taken at five (5) positions. The sound level measurements were conducted using a Cirrus CR:171B sound level metre, which was placed at a vertical distance of 1.2 metres from the floor level, aligning with the height of the student's ears. The sound pressure level, known as the equivalent sound level (LAeq), was measured across a range of frequencies from 63 Hz to 8000 Hz. These measurements were taken for a duration of two minutes at multiple points throughout the classrooms. The measurements were recorded using the A-weighting. The placements of the sound source and receivers in Classroom A and B are illustrated in Figure 4.

For RT measurement procedures, dodecahedron loudspeaker with omnidirectional characteristics was employed as the sound source. This loudspeaker was linked to a Crown XLS1000 sound amplifier in order to generate the sound signal. The sound signal emitted was recorded using the GRAS 46AE ½" microphone, positioned at a height of 1.2 metres above the floor, and coupled to the Scarlett 2i4 audio interface. The microphone captured the sound signal, which was afterwards recorded. The ODEON room acoustic software version 17 was utilised to determine the RT values. The measurement of the RT was carried out at a receiver location that was identical to the location where the background noise level measurement was undertaken. Figure 5 depicts the schematic diagram of the equipment arrangement utilised for RT measurement.

The speech intelligibility level was evaluated by means of the STI. A BOSE 101MM speaker was strategically placed at the lecturer's designated teaching area, positioned at a height of 1.7 metres above the floor, with the purpose of functioning as the sound source. The Minirator MR2 signal generator was employed to generate a sweep signal that emulates a raised human voice level. Subsequently, the aforementioned signal was linked to the Crown XLS1000 audio amplifier. The sound signal was recorded and processed by the Blue Solo 01dB sound level metre connected to the dBBati acoustic measurement software. Figure 6 shows the configuration of the equipment used for the measurement of STI.

SPL was assessed in order to evaluate the decrease in sound signal across varying distances. The sound source configuration utilised for sound pressure level SPL measurement is similar to that of the STI measurement arrangement. The emitted sound signal was characterised as pink noise, possessing an average sound pressure level ranging from 66 - 70 dB which represents a human voice raised when measured at a distance of 1 metre. The SPL was recorded at the respective positions of the receivers using a Cirrus CR:171B sound level positioned at a height of 1.2 metres above the floor.



(a) (b)

Figure 4. Sound source and receivers' location at (a) Classroom A and (b) Classroom.

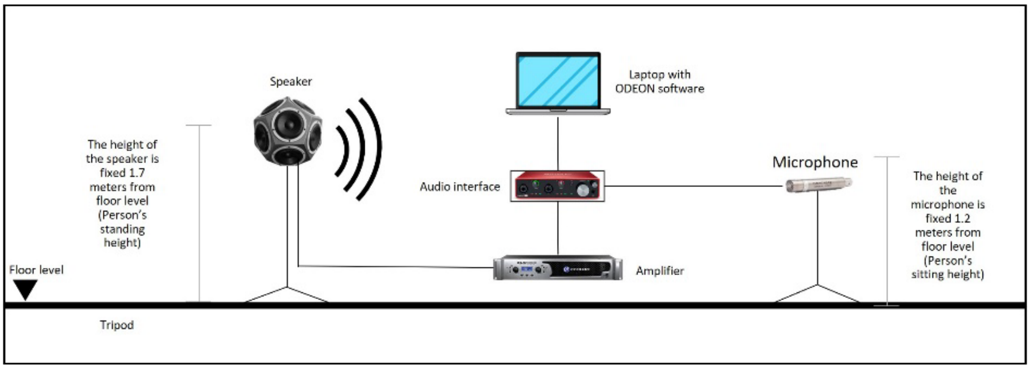


Figure 5. Schematic drawing of equipment configuration for RT measurement.

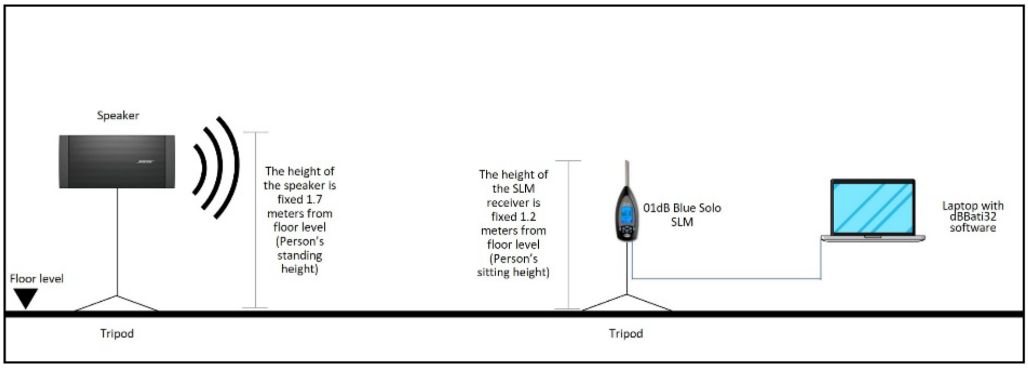


Figure 6. Schematic drawing of equipment configuration for STI measurement.

3. Results and discussions

3.1. Background Noise Level (BNL) and Noise Criteria (NC)

The evaluation of ambient noise encompassed the measurement of average equivalent sound levels (LAeq) at several locations within Classrooms A and B. According to Building Bulletin 93 [17] and ANSI/ASA S12.60 [18], it is recommended to maintain a maximum BNL of 35 dB (A) in an unoccupied classroom. The data on the LAeq measured in both rooms is presented in Figures 7a and 7b, respectively. Based on the collected data, the average LAeq values for Classroom A and Classroom B in the absence of ceiling fan operation are recorded as 54.4 dBA and 46.6 dBA, respectively. Nevertheless, the sound level increased to 59.8 dBA and 62.1 dBA in Classroom A and B respectively when the ceiling fans were operated. The primary contributing element to the elevated BNL in both rooms, which did not achieve the suggested threshold of 35 dBA, is attributed to the noise generated by the ceiling fans in Classroom B and traffic noise from the main road for Classroom A.

Therefore, the impact of ambient noise is deemed insignificant in the classrooms due to their distance from sources of traffic disturbance and defective ceiling fans. The NC values for two measured rooms are presented in Figures 7c and 7d. The findings indicate that the NC values for both rooms did not meet the maximum recommended value of NC-30, as indicated by Raichel [21] . The utilisation of ceiling fans set at an NC-56 and NC-57 value resulted in the identification of elevated NC ratings for Classroom A and Classroom B.

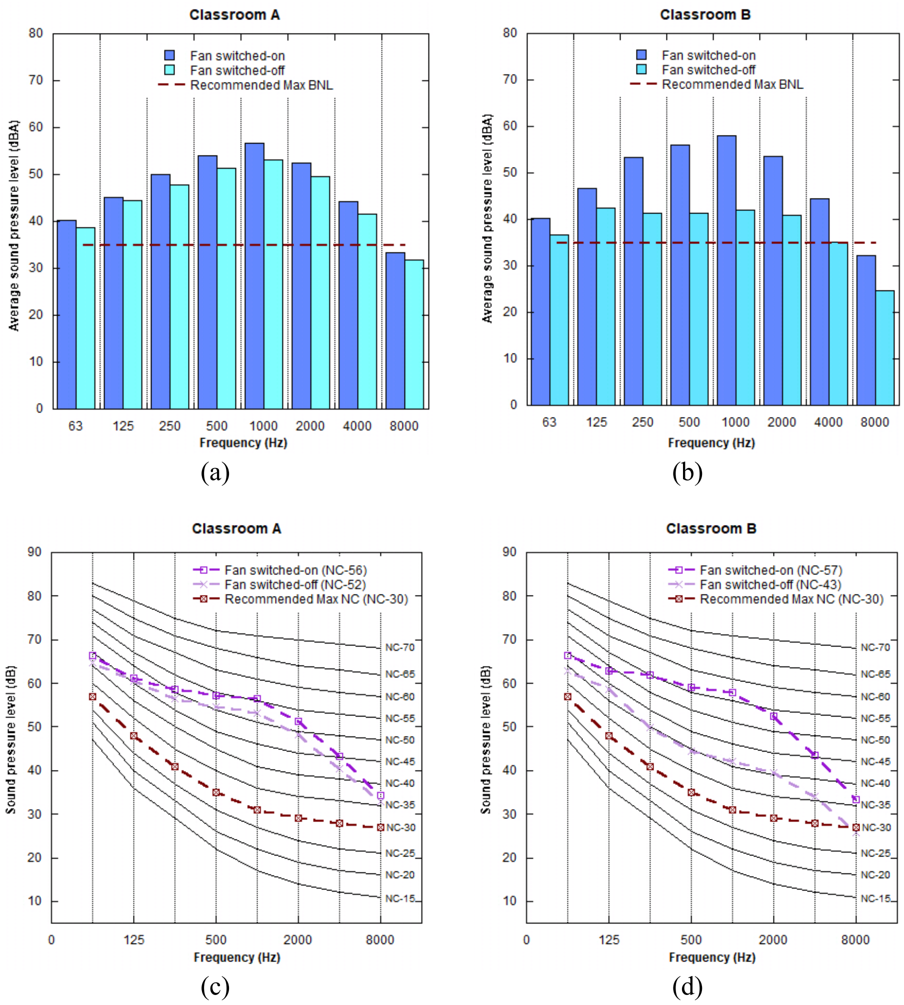


Figure 7. Summary results of (a & b) background noise level and (c & d) noise criteria of both classrooms.

3.2. Reverberation time (RT)

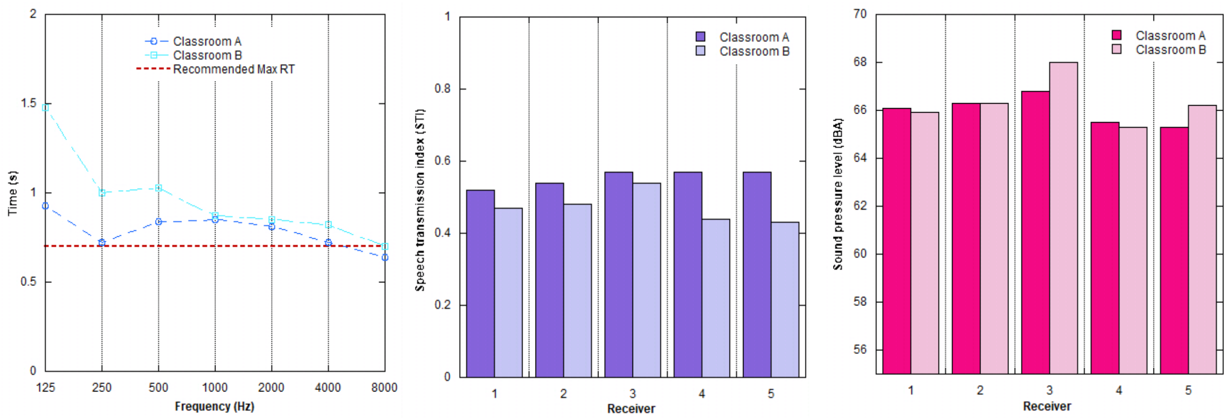
According to the guidelines outlined in Building Bulletin 93 [18], an unoccupied and furnished classroom must adhere to a maximum RT of 0.8 seconds for primary classroom and 1 seconds for secondary classroom. According to the ANSI/ASA S12.60 [17] standard, a RT of 0.6 s is recommended for classroom volumes below 283 m^3, while classroom volumes beyond 283 m^3 should have an RT of 0.7 s. Figure 8a presents the measured RT data in Classroom A and Classroom B, respectively. The mean RT for Classroom A and Classroom B are 0.79 s and 0.96 s, respectively. These values do not meet the acceptable criteria set out by ANSI/ASA S12.60 guideline. However, the results met the recommended value outlined in Building Bulletin 93. Despite the predominantly reflective nature of the surface materials employed in both classrooms, the recommended value for the RT is nevertheless attained due to the complete opening of doors and windows, hence replicating the actual teaching and learning environment. Nevertheless, this situation presents an additional concern, namely the excessive level of BNL resulting from adjacent traffic and mechanical ventilation systems.

3.3. Speech transmission index (STI)

The main acoustic performance consideration in educational settings is the intelligibility of speech, a critical factor in promoting students' educational development. The STI rating was assessed in both classrooms where receivers were positioned at different locations. Figure 8b depicts the variability in STI ratings among receivers positioned in different places within Classroom A and Classroom B, respectively. The findings indicate a "fair" STI rating, with an average rating of 0.55 and 0.47 for Classroom A and Classroom B, respectively. The "fair" rating is influenced by two key criteria, namely the BNL and the RT value. Peng and Wu [22] have reported a degradation in the STI value inside a classroom environment characterised by an excessive degree of background noise. Furthermore, Abdullah et al. [23] found that the use of suitable absorptive materials to reduce RT leads to an improvement in the STI rating within educational settings. Hence, it is imperative to adhere to the prescribed BN and optimal RT in order to attain favourable outcomes in the context of STI.

3.4. Sound pressure level (SPL)

The sound decay rate at various receiver locations in both classrooms was determined by measuring the SPL. The method section above provides comprehensive information regarding the measurement details. Figure 8c illustrates the SPL results taken at different positions within Classroom A and Classroom B, respectively. The SPL exhibited a decrease as the distance from the sound source increased. The sound decay results of approximately 5 dB(A) were recorded by receivers 4 and 5, located on the posterior side of Classroom A and Classroom B. While an approximate decay rate of 3 dBA was recorded for receivers located in close proximity to the sound source. According to ANSI/ASA S12.60 [17], it is anticipated that sound levels in a classroom will exhibit a drop of around 3 dB for each doubling of distance.



(a) (b) (c)

Figure 8. Acoustic performance results of (a) reverberation time, (b) speech transmission index and (c) sound pressure level for Classroom A and Classroom B.

4. Conclusion

The present study investigates the classrooms acoustic performance in two (2) distinctive public schools in Malaysia. The measurement of acoustic parameters namely BNL, RT, STI and SPL were evaluated through on-site measurement. The findings revealed that BNL for both classrooms was beyond the maximum recommendation value of 35 dBA. The BNL results recorded for Classroom A and Classroom B were 59.8 dBA and 62.1 dBA respectively. Nevertheless, the data obtained from the RT measurements were deemed to be within permissible parameters, as specified in Building Bulletin 93. The classrooms' STI ratings did not meet the minimum recommended value of 0.6, indicating a "Fair" assessment, due to elevated levels of BNL. Hence, it is evident that the school classroom design prevalent throughout the post-independence era is inadequate in facilitating optimal acoustic conditions for educational settings. The implementation of design modifications in educational classrooms is vital in order to achieve optimal acoustic performance while concurrently fostering a favourable teaching and learning environment for both educators and students.

Acknowledgement

The authors extend gratefulness to Ministry of Higher Education Malaysia for funding the current research under the Fundamental Research Grant Scheme (DP KPT FRGS/1/2022/TK06/UM/02/17) and Bumiputera Academic Training Scheme Malaysia. Our deepest gratitude goes to Vibrant Echo Sdn Bhd for the support and dedication to this research.

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