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Acoustical investigation of open-plan offices in green buildings in Malaysia

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ABSTRACT

Open-plan office has become the most popular type of office layout. Organizations were inclined to employ open-plan office layout for its economic, flexibility and ideological reasons. Green building tends to utilize this concept of office layout for its ability to assist in maximization of daylight usage and natural ventilation. However reduced barriers in open-plan office resulted in poor acoustical performance. Thus, the objective of this study is to investigate and evaluate the level of acoustical performance of open-plan offices in green buildings in Malaysia. Investigation were limited to selected assessment parameters of background noise (BN) level, noise criteria (NC), reverberation time (RT) and speech transmission index (STI). The BN levels for all measured open-plan offices were found to be acceptable around 35 dB(A) while the NC ratings found the spaces to be somewhat quiet. RTs were varied from satisfactory 0.7s to an unacceptable 1.5s. STIs were found to be ample within good and fair speech intelligibility. However, it still provides equally ample speech distraction towards the occupants of the spaces.

Keywords: Acoustics, Green Building, Open-plan office

1. INTRODUCTION

Office is the most prominent type of working place and open-plan office is the most popular type of office layout [1-3]. Brill, Weidemann & BOSTI Associates as cited in Navai & Veitch [2] defined open-plan office as “a workspace whose perimeter boundaries do not go to the ceiling. Most often constructed of relocatable panels and panel-hung work surfaces, and storage or of relocatable panels with free-standing furniture or of non-relocatable, drywall boundaries (not to the ceiling) and free standing furniture”.

Among the reasons why this type of office layout became well-liked was for its economic reasons, it is cheaper to be constructed; its flexibility reasons, it needs effortless reconfiguration and rearrangement process; and its ideological reasons, which is with reduced barriers between co-workers, it will promote teamwork and effective collaboration through its increase opportunities of interaction [2-5].

Open-plan office relates to green building by its ability to assist in achieving green building main

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goal, which is to achieve energy efficiency. Besides the economic, flexibility and ideological reasons, green office buildings applied the concept of open-plan office because of its assistance in maximizing the usage of daylight and natural ventilation [6]. With minimum solid barriers and low partitions, daylight could be easily spread deeper into the office spaces. Natural ventilation will also be significant with open-plan office layout. This will lead to better indoor air quality, thermal and visual comfort (better lighting) for the building occupants. The ultimate advantages of employing this type of office layout is that by maximizing the usage of daylight and natural ventilation, the building would be able to reduce energy usage and thus achieve its aim of energy efficiency.

However, reduced barriers resulted in poor acoustical separation [6]. Two major acoustical issues of open-plan office are excessive background noise and speech privacy [2,7-10]. In Malaysia's green building rating tools, Green Building Index (GBI); there are very minimal acoustical requisite imposed to be considered by architects and designers. Furthermore the minimal requirement only refers to ambient internal noise level [11]. Unfortunately, speech noises is and has been considered to be the most distracting and unwanted type of sound in office environment [2,4,12-15]. Schlittmeier et al. [16] suggested that this is because cognitive performance which is essential in common office task responds negatively towards noises that contain speech and information rather than non-speech noises.

Hence, the objective of this paper is to investigate and evaluate the level of acoustical performance of open-plan offices in green buildings in Malaysia. However, there are limitation in the investigation where the measurement process were done without taking into account the design elements of the buildings as it would be difficult to make fair comparisons between the three green buildings because of its design discrepancies. Measurement would be limited to the selected acoustical parameters.

2. ASSESSMENT PARAMETERS AND ACCEPTABILITY CRITERIA

Recently, several evaluations have been constructed for speech signals to listeners in enclosures and can be explained by contemporary room-acoustic indicators. One of the important acoustical interests for satisfactory speech intelligibility is verbal communication. All activities in the office such as having a private conversation, group discussion, and even independent work relates closely to speech intelligibility (SI). SI is the accuracy in which listener can understand a spoken words or phrases in clarity. The intelligibility of speech in enclosure is measured in the presence of distortion in speech signal caused by noise in transmission path or affected by furniture in the room. It can also be influenced by the ambient background noise (BN) and the reverberation time (RT) of the enclosure. The electro-acoustic equipment within offices such as computer servers and air-conditioner would also attribute to poor acoustical performance in the space. Therefore, noise criteria (NC) rating was developed for wider application to evaluate the permissible value for a room or enclosure.

Among the literature studied, Hodgson [17] reported the result of the physical acoustical measurement. The study was focused on occupants' satisfaction in green office buildings; and comparison between occupants' satisfaction in green office buildings and conventional office buildings were also carried out. The types of acoustical complaints were also being surveyed to determine the major acoustical problems.

The GBI's point merit for acoustical requirement can be found under its indoor environmental quality (IEQ). IEQ is the second criteria in the GBI with the purpose of "to achieve good quality performance in indoor air quality, acoustics, visual and thermal comfort". Among the 21 score points allocated under this criteria (non-residential building category); only 1 score point is reserved for acoustics. It is under EQ13 – Internal Noise Level. This score point focus on the ambient internal noise level and specify that the sound level of open plan office must not exceed 45 dB(A) [11]. This requirement is similar to Bradley and Gover [7] criteria for acoustic comfort in open-plan offices which stated that the ambient noise of 45 dB(A) is the most preferable. ISO 11690-1:1996 [18] indicated the recommended BN for open-plan offices is between 35-45 dB(A) and ANSI S12.2-2008 [19] recommended the background noise for open-plan areas to be between 44-48 dB(A) with noise criteria of NC 35-40. However, in others such as Cavanaugh [20], NC 42-52 was recommended as acceptable level for office and workspaces. Beranek, as cited in Maekawa et al. [21] recommended the acceptable noise level for general offices are between 48-58 dB(A).

While ISO 11690-1:1996 [18] recommended the reverberation time (RT) to be between 0.8 – 1.3 s for rooms with the volume between 200 m^3 to 1000m^3, Hodgson [17] stated that the optimum RT for comfort and easy verbal communication is below 0.75 s.

There are three common speech intelligibility prediction models widely applied for measuring transmission quality of speech: the Speech Intelligibility Index (SII) [22], the Speech Transmission

Index (STI) [23], and the Speech Recognition Sensitivity (SRS) [24]. However, this study will deliberately be using STI in conducting the measurement to measure the speech intelligibility of the rooms. STI indicated the suitable score or rating to facilitate the qualification by labeling from "bad" to "excellent". Poor speech transmission criteria are below 0.45, and good criteria yield above 0.6 [21]. Another reason STI is being selected as measurement parameters is because through STI data collected, it would be easier to determine the distraction distance (r_D) as per demonstrate in ISO 3382-3 [25].

Table 1 – Measurement parameters and acceptability criteria applied in this study

Measurement parameter	Acceptability criteria
Background noise level (BN)	35 – 45 dB(A)
Noise criteria (NC)	NC 35 - 40
Optimum reverberation time RT_{500HZ} in s	0.8 – 1.3 s at frequency of 500 Hz
Speech Transmission Index (STI)	0.45 – 0.60 Fair 0.60 – 0.75 Good 0.75 – 1.0 Excellent

3. METHODOLOGIES OF RESEARCH

The first stage of this study was the selection of sample spaces as representative of green office buildings in Malaysia. Three GBI certified office buildings were selected for acoustical performance assessment. Two open-plan offices were chosen from each building. The selection was based on the following: general information of rating, open-plan office layout and room characteristics. The space shape, size, spatial arrangement and other factors contributed to the final selection, besides the constraint of building accessibility.

3.1 Building Descriptions

The room volume might play an important role on the acoustical characteristics. Table 3 presents the data summarizing the main physical characteristics of the selected spaces from the three buildings. Information such as room's length, width, height, volume and expected capacity when fully occupied were included. Selected spaces varied in volume from small space of 316.8 m^3 to large space with volume over 1000 m^3. The number of occupants residing the spaces varied between each buildings according to office layout, design and the building owners' organizations. The three office buildings were certified as green building by the GBI and have since prove their energy efficiency by the significantly reduced building energy index (BEI). Following are brief descriptions of selected buildings.

3.1.1 Building A

Building A is an eight storey air-tight building with GFA of around 14,000m^2. The building was designed and planned from the beginning to achieve the status of green building and received green building certification from the GBI a year after its completion. Besides aiming at reaching optimum satisfaction in all GBI criteria, the two key elements which were seriously considered during the design stage are energy efficiency and daylight harvesting. The shape of the building plays a significant role in the building design. The tilted façade assist the building by self-shading itself which consequently reduce heat transfer into the building; and at the same time maximizes daylight intake by the accompaniment of light shelf. The atrium in the middle also plays an important role in daylight harvesting. Thermal comfort was achieved by radiant cooling slabs complemented by conventional cold air supply system. Noise control measures depended highly fact that air ventilation noises are reduced since the radiant cooling slabs were being applied, which explains the bare ceilings. Other green deign strategies applied are rainwater harvesting and energy harvesting using photovoltaic panels.

3.1.2 Building B

Building B comprises of six floors with a total built-up area of 16,000m^2. The building was built as an energy efficient (EE) building and has received a green building certification from the GBI. The building layout is an L-shape two wings building connected by a middle atrium. To achieve the status of EE building, careful measures were taken during the planning and design stage. Passive design strategies such as building orientation and appropriate façade treatment were applied to optimize the usage of daylight and minimizing heat absorption. The atrium pose as an important feature of the building as it demonstrates the EE elements of the building as it is naturally ventilated, naturally lit by daylight and aesthetically pleasing due to the greeneries and water features design within. Other EE systems and features also applied in its artificial lighting strategies, air-conditioning system and office equipment selection.

3.1.3 Building C

Building C is a small four storey office building cum training centre with a total GFA of 4,800m^2. The building is the first completed green-rated office building in Malaysia and were certified as green building by the GBI two years after its completion. The construction of the building serves to promote sustainable green building concept in Malaysia. Design to be completely energy efficient (EE), the building concept was focused on the innovation of green technology to minimize energy and fossil fuel usage and to promote the usage of renewable energy. The building has an elongated building layout with self shading design profile where the upper floors were cantilevered to shade the lower floors. This was done to maximize daylight utilization and also to control glare. The atrium in the middle which divides the building into two sections is lit by daylight through the usage of skylight photovoltaic. The cooling and ventilation system is made up of radiant cooling slabs and air supply system. Other green design features implemented are the usage of EE office equipment and rainwater harvesting.

Table 3 – Main physical characteristics of selected open-plan offices from building A, B and C

No	Code	On-site measurement			Calculated parameter	
		Dimension of room (m)			Volume (m^3)	Capacity
		L	W	H		
Building A						
1	DOP1	16.8	15.0	3.0	756.0	12 (+16)
2	DOP2	16.6	17.0	3.0	846.6	17 (+9)
Building B						
3	LOP1	13.6	13.7	3.0	559.0	13
4	LOP2	29.0	11.9	3.0	1035.3	26
Building C						
5	GOP1	8.0	12.0	3.3	316.8	10
6	GOP2	30.5	8.0	3.3	805.2	35

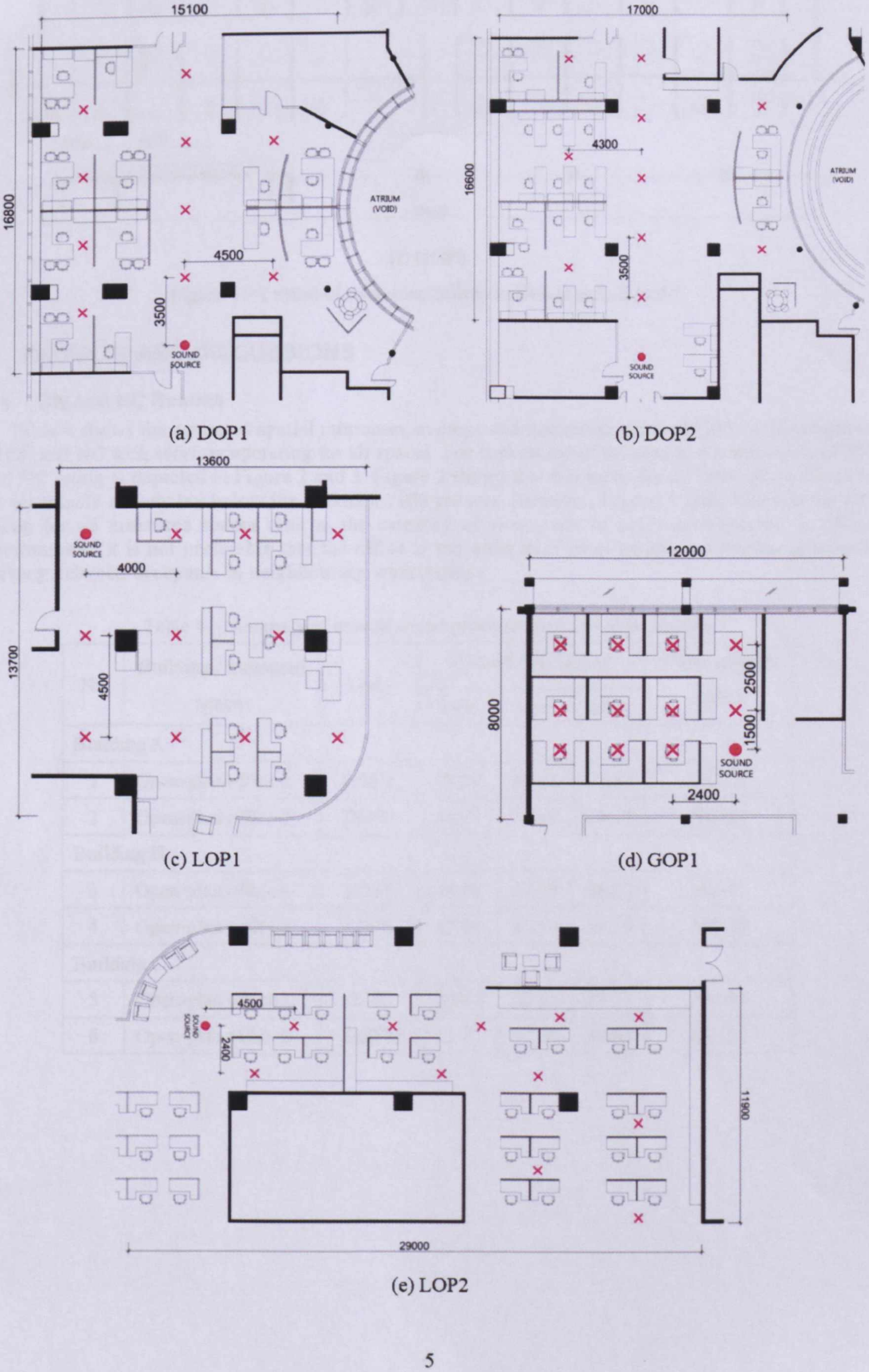
3.2 Measurement Procedures

To evaluate the acoustical characteristics of the selected open-plan offices, PC-based acoustic measuring system and analyzer were utilized. The PC-based measuring system (dBBati32) was integrated with a type class 1 sound level meter (01dB Solo Metravib) as analyzer. Based on the shape and floor area of each space, an adequate number of listener positions were chosen as measurement points to achieve sufficient coverage of the area

The BN was measured using sound level meter (SLM) in dB(A), set for 1/3 octave band. The SLM was positioned at 1.2m above floor level to achieve the position of a sitting person. The measurements were conducted whilst the office areas were vacant but with all the services; e.g.: lighting, air-conditioning and etc. in operation. A wind screen was used to reduce the effect of airflow.

At every point, measurements were done for two minutes with one second interval time; and series of measurements were extracted using commercial software. So as to provide compact presentation, the collected data were calculated and averaged. It was necessary to measure the internal room's background noise (BN) to determine the NC rating.

To verify the effect of room characteristics in acoustical quality, measurement of RT and STI were also conducted. Omni-directional speaker was used as sound source and was positioned at 1.2m height at a selected location. The volume was adjusted around 67-69 dB(A) to radiate sine wave and sweep signals. The measurement points and sound source locations are as shown in Figure 1.



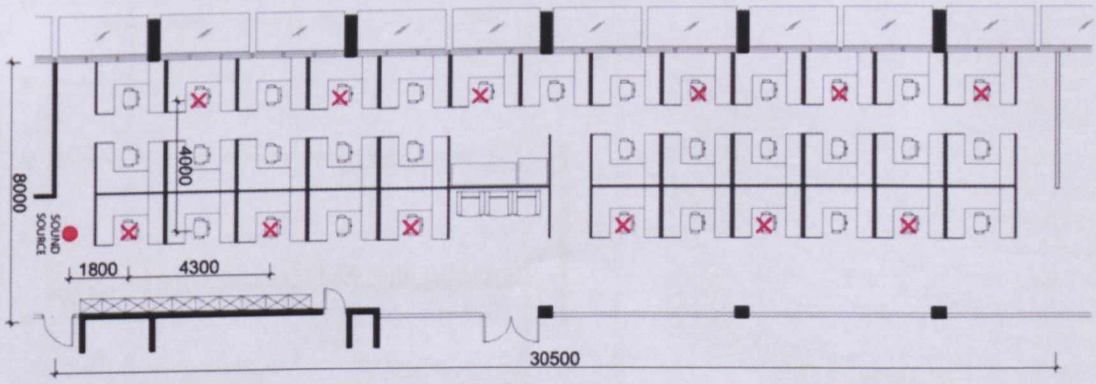
(a) DOP1

(b) DOP2

(c) LOP1

(d) GOP1

(e) LOP2



(f) GOP2

Figure 1 – Layout of open-plan offices in Building A, B and C

4. RESULTS AND DISCUSSIONS

4.1 BN and NC Results

Table 4 shows the averaged spatial minimum, average and maximum values of SPL in A-weighted of BN and NC with services operating for all spaces. For convenient of the reader, a comparison of BN and NC rating is depicted in Figure 2 and 3. Figure 2 shows that BN value for all open-plan offices to be acceptable as they lay below the maximum BN criteria. However, Figure 3 indicated that the NC rating for all measured spaces rank in the category of *very quiet to quiet* environment. In office environment, it is not preferable that the office is too quiet as it would create a problem of speech privacy between occupants in neighbouring workstations.

Table 4 – Summary of overall sound pressure level and noise criteria

No	Building / measured spaces	Code	Overall SPL (dBA)			Noise Criteria (NC)
			Min	Ave	Max	
Building A						
1	Open-plan office 1	DOP1	29.54	30.28	31.63	NC-19
2	Open-plan office 2	DOP2	36.77	36.37	38.66	NC-24
Building B						
3	Open-plan office 1	LOP1	36.98	37.29	38.22	NC-27
4	Open-plan office 2	LOP2	30.93	31.79	34.79	NC-20
Building C						
5	Open-plan office 1	GOP1	35.84	36.33	37.71	NC-23
6	Open-plan office 2	GOP2	33.77	35.00	36.61	NC-22

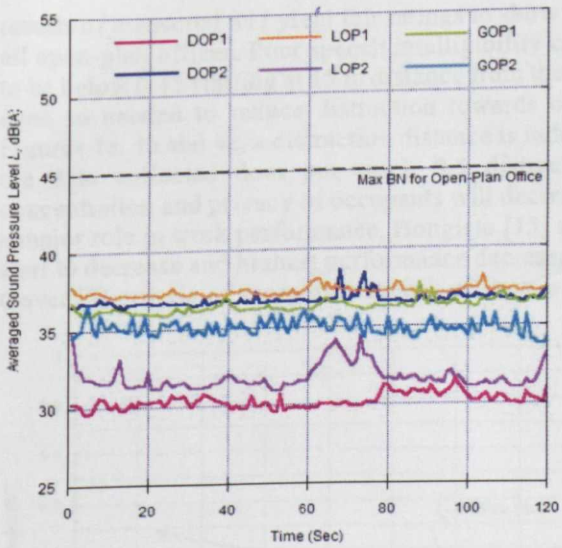


Figure 2 – Background noise level

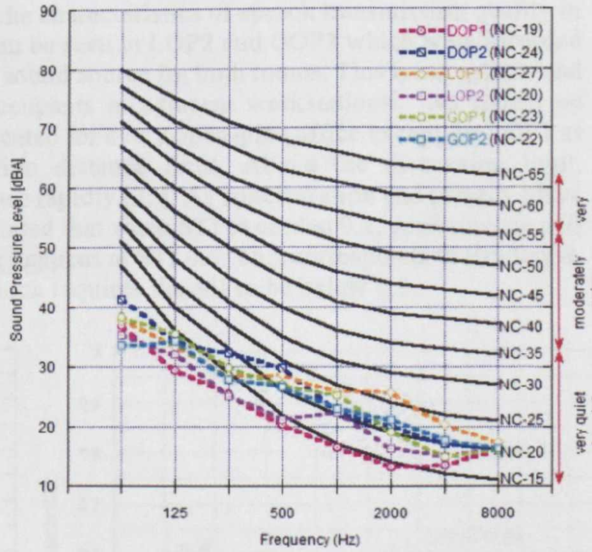


Figure 3 – Noise criteria level

4.2 RT and STI Results

It is possible to identify the characteristics of room by measuring the RT in different measurement points. Although the materials, shape and the volume of the room give significant effects to the acoustical quality, these were not taken strictly into consideration in this stage of the study. The RTs of each point at different locations for all rooms are averaged and summarized in Table 5. The preferences of RT_{500Hz} range from 0.8 – 1.3s depending on the room's volume. However, RT below 0.75s is preferable for the comfort of verbal communication. It was found that DOP2 and LOP2 have RT lower than the preference of 0.75s. While GOP1 and GOP2 exceed the 0.75s mark, their RT still rest below the maximum recommendation which is 1.3s. However, two spaces which are DOP1 and LOP1 have exceeded 1.2s criteria with 1.5s and 1.41s each. Some complementary aspects which can explain this phenomenon are: (i) the rooms were typically installed with low-absorptive materials, (ii) the use of sound diffusion was not sufficient to prevent focused reflections.

Table 5 – Summary of reverberation time (RT) in measured spaces

No	Building / measured spaces	Code	Averaged RT (500 Hz)
Building A			
1	Open-plan offices 1	DOP1	1.50
2	Open-plan offices 2	DOP2	0.70
Building B			
3	Open-plan offices 1	LOP1	1.41
4	Open-plan offices 2	LOP2	0.71
Building C			
5	Open-plan offices 1	GOP1	1.09
6	Open-plan offices 2	GOP2	1.12

On the other hand, to reach the intended speech intelligibility, the overall performance of the room is important in open-plan offices. Figure 4a, 4b and 4c show the comparison of STI values of each open-plan offices of the three buildings with respect to distance from the sound source. In general, the measured STI shows basic tendency for their respective rooms relatively independent on the distance, that the longer the distance is, the lower the STI becomes. Although high speech intelligibility is needed in spaces such as classrooms, offices need moderate speech intelligibility. As overall, the results of measured STI yield fair ratings to show the characteristics of speech transmission quality in all open-plan offices. Poor speech intelligibility can be seen in LOP2 and GOP2 which were recorded to be below 0.45 starting at 15 m distance from the sound source for both rooms. This is acceptable and even so needed to reduce distraction towards occupants in adjacent workstations. As shown on Figures 4a, 4b and 4c, a distraction distance is indicated for every open-plan office except for LOP1 as the data collected does not reach 0.5 distraction distance limit. Above the distraction limit, concentration and privacy of occupants will decrease rapidly [25]. As concentration and privacy plays a major role in work performance, Hongisto [15] stated that when STI exceeded 0.2, performance will start to decrease and highest performance decrease happens at STI 0.6. This corresponds to Bradley & Gover [7] criteria of acceptable speech privacy which requires the SII to be below 0.2.

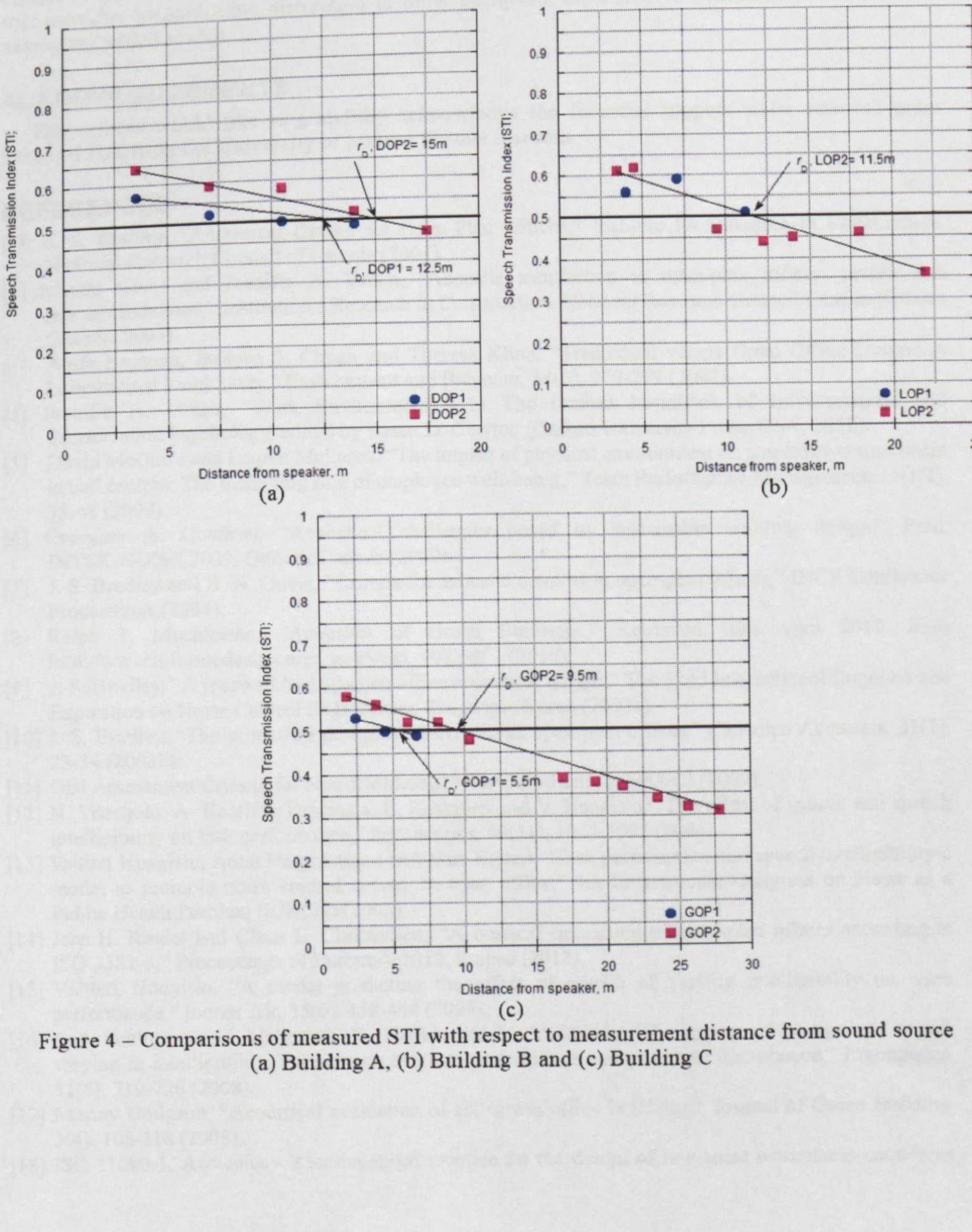


Figure 4 – Comparisons of measured STI with respect to measurement distance from sound source (a) Building A, (b) Building B and (c) Building C

5. CONCLUSIONS

In conclusion, the measurement results revealed that the overall acoustics performance of open-plan offices in selected green buildings in Malaysia is within the acceptable range of acoustical criteria. However, there are still rooms for improvement which can be done to better refurbish the acoustical comfort of the spaces. While BN is acceptable for all measured spaces, it is not an overstatement to say that the spaces are too quiet as per shown in the NC ratings. A quiet environment may seem desirable, but too quiet of a room invites other acoustical problems such as speech privacy and intelligibility. Although it is agreeable that the BN should not exceed the recommended maximum level, speech noises must also be taken into account when designing an office spaces as it is the most unwanted type of noise in open-plan offices. Although STI data proved to decrease with distance, it still provides inappropriate distraction to other occupants especially to occupants in workstations nearby the sound source.

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