Acoustical investigation of open-plan offices in green building: Simulation experiment

Nazli CHE DIN[1]; Nurul Amira Abd JALIL; Nila Inangda KEUMALA; Asrul Sani RAZAK

Department of Architecture, Faculty of Built Environment, University of Malaya, Malaysia

ABSTRACT

The authors have previously reported on the measurement results from the investigation and evaluation done on the acoustical performance of open-plan offices in green buildings in Malaysia. This research uses the results from field measurements for verification on the optimum modeling process for two existing open-plan office in term of calculation time and accuracy of the simulation. Two models of open-plan office layout were constructed in four different level of model detailing utilizing 3D modeling tool. Using ODEON Room Acoustic Simulation Software, the authors examined the effects of the geometrical properties to identify the appropriate model setting for further simulation process. The simulated results of two acoustical parameters; reverberation time (RT) and speech transmission index (STI) for each model setup are then compared between each other, and further compared with field measurement results. The study concludes that the modeling process in term of number of surfaces is affecting the acoustical parameters. The discrepancy of simulated RT and STI data between model setup will be discussed.

Keywords: Reverberation time, STI, Open-plan I-INCE Classification of Subjects Number(s): 51.7, 76

1. INTRODUCTION

In recent years, there is intensive development on computer based room acoustic modeling technique (1). A significant dimension on acoustic sound field input in academic and industry of architectural acoustics is useful in becoming an important supplement or noticeably defined in process of time and accuracy for teaching, learning, research and marketing purposes (2-5). There is several 3D modeling softwares that have been increasingly used in architecture firms for efficient demand for acoustic solutions at early stage of architectural design process. Although it is useful to have access to architect's detailed 3D model, if available, it is often questionable on the degree of model detailing whether it is satisfactory for a good acoustical simulation studies (6).

Previous findings showed that the process of implementing green building design measures was to improve on green building elements and criteria, the designers failed to realize the negative effects of the design when it was subjected towards acoustical performance of the building. Some examples of green building design measures that affected the building's acoustical performance are those that attempted to achieve natural ventilation and maximum usage of day lighting, minimization of finishes and the open-plan layout (7). Furthermore, the comparison between measurements of three green buildings and two conventional buildings from previous work has revealed that the results of background noise and reverberation time in green buildings in certain rooms exceeded the acceptable criteria given (8).

Based on previous measurement data, the objective of this study is to compare and verify the computer simulation for predicting the efficiency of selected acoustical parameters in two types of open- plan office layout in green office building using ODEON Room Acoustic Simulation Software (9). The comparison between previous works of obtaining measurement on site with simulated 3D models will assist in reviewing the effectiveness of the level of geometric detail towards acoustical performance of open-plan offices before further adjustment and future refinement to be undertaken.

[1]nazlichedin@um.edu.my

2. METHODOLOGY

2.1 Field Measurement

In previous study, the investigation of field measurement of selected open-plan offices in green buildings in Malaysia was presented. Two open-plan office rooms were selected for assessing the acoustic performance. The selection based on the following: general information of rating, open-plan layout and room characteristic. The space shape, size, spatial arrangement and other factors contributed to the final selection.

Table 1: Main physical characteristics of selected spaces

No	Building	Code	Dimensions of room (m)			Volume (m^3)	Room capacity
			L	W	H		
1	A	GOP1	8.0	12.0	3.3	316.8	10
2		GOP2	30.5	8.0	3.3	805.2	35

Figure 1 – Photo and plan layout of GOP1 in Building A

2.1.1 Building Description

Table 1 summarizes the main physical characteristics of the selected spaces. Information such as rooms' length, width, height, volume and expected capacity when fully occupied were presented. Room capacities were derived from the furniture layout and may vary by the changes of office layout, design and management's organization. The selection of green office building was based on the list of GBI certified building that has constantly proven its energy efficiency by the significant reduction of the building energy index (BEI).

Building A is a small four storey office building and training center facility with a total GFA of 4,800m^2. The building is the first green office building in Malaysia and was certified by the GBI two years after its completion. As the design was done to be completely energy efficient (EE), the building concept was focused on green technology innovation to minimize energy and fossil fuel usage and to promote the use of renewable energy. The building has an elongated building layout with self-shading design profile where the upper floors are cantilevered to provide shade the lower floors. This was done to maximize daylight utilization and also to reduce glare. The atrium that divides the building into two sections is naturally lit by utilizing photovoltaic panels as part of the skylight element.

2.1.2 Measurement Procedure

To evaluate the acoustical characteristics in office buildings, PC-based acoustic measuring system and analyzer were utilized. The PC-based measuring system (dBBati32) was integrated with type class 1 sound level meter (01 dB Solo Metravib) as analyzer. Based on the shape and floor area of each space, ample number of receiver points were selected to be measure.

The background noise (BN) was measured using sound level meter (SLM) in dB(A), set for 1/3 octave band. The SLM was positioned at 1.2 m above floor level and the measurements were conducted while the office spaces were unoccupied, but with all services such as lighting and air-conditioning in operation as per usual working hours. Two minutes measurements with one second interval time were taken at every receiver points.

Measurement for reverberation time (RT) and speech transmission index (STI) were conducted using an omni-directional speaker as sound source. The speaker was positioned at one selected point at the height of 1.2 m. The volume was adjusted around 70 dB(A) to radiate exponential sweep signals. Measurement of RT and STI were taken at every receivers point respectively.

Figure 2 – Photo and plan layout of GOP2 in Building A

2.2 Computer Simulation

A computer model based on measured acoustic parameters i.e. reverberation time (RT) and speech transmission index (STI) for open-plan offices was produced by using ODEON Room Acoustic Simulation Software Version 12 (9).

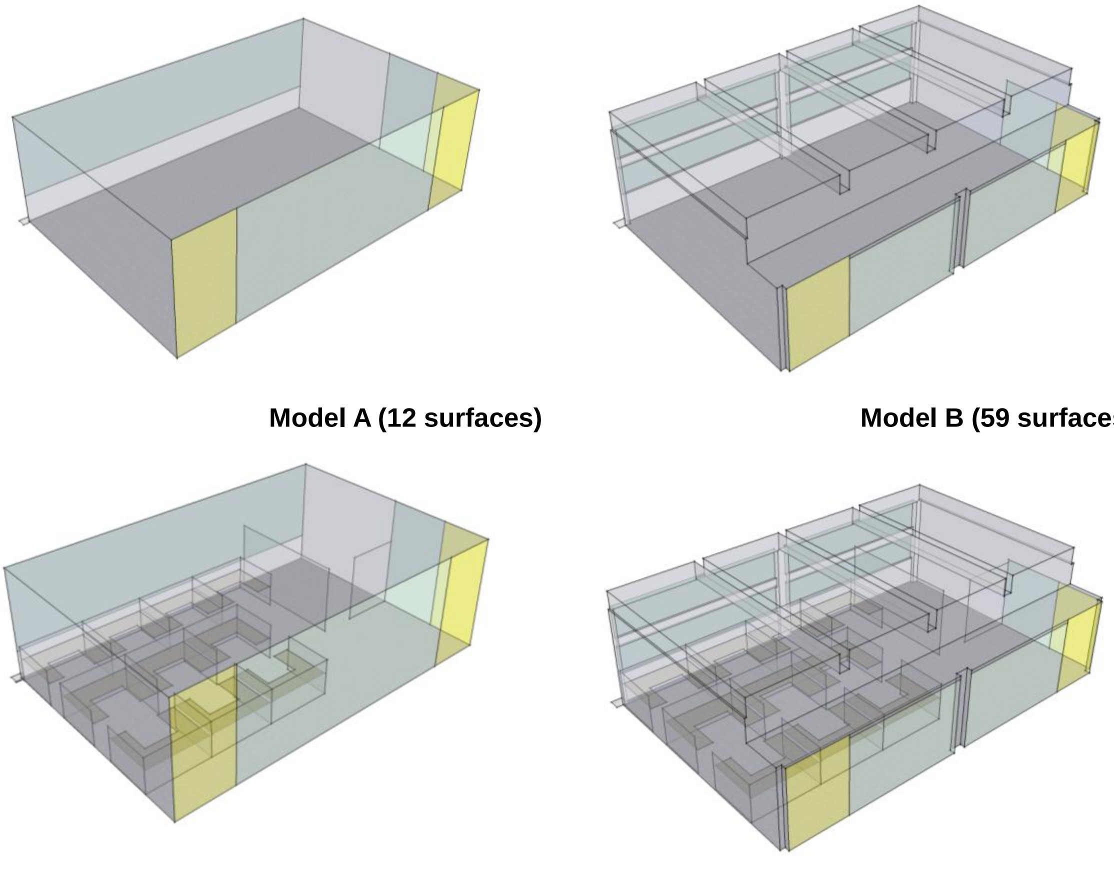
2.2.1 Model construction

It is anticipated that having too many geometry details might resulted in less practical model for the purpose of acoustic simulation. Therefore, in the first stage of the study, four different level of model detailing were developed. First step is to model the room geometry in digital environment utilizing SketchUp, a 3D software modeling tool. Two levels of model detailing were constructed based on plan layout given: i.e. Model A & B. Then, another two models were constructed based on Model A and B with the addition of furniture modeling; i.e. Model C & D. Both models of GOP1 and GOP2 are shown in Fig. 3 and 4.

2.2.2 Model calculations and analysis

In the process of acoustical simulation of the constructed models, the SketchUp 3D data formats were exported to ODEON. Then, each surface was assigned with specific material properties, i.e. absorption and scattering. The challenge of this assignment of material properties was to obtain the appropriate material properties for all surfaces that are not available in the library. Some plausible material properties were used attained from books and other literature.

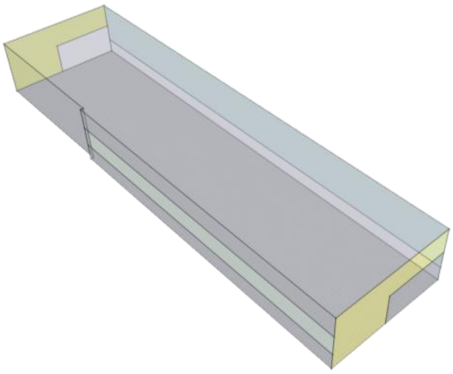
To achieve the basic calculation setup, a quick estimation of reverberation time was performed to identify the impulse response length covering at least 2/3 of the reverberation time. Other parameters setup is shown in Table 2. The input recorded for background noise for GOP1 is 36.3 dB (A) and GOP2 is 35.3 dB (A), and this was determined by measuring the value using the results of overall background noise in previous research.



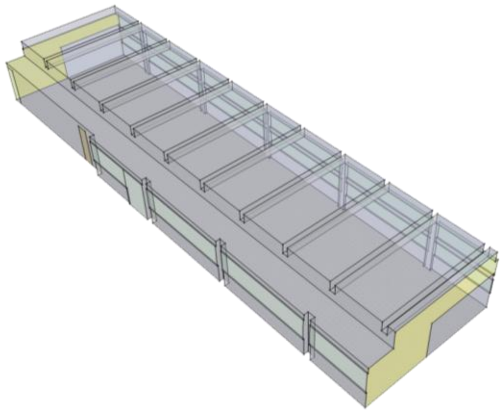
Model A (12 surfaces) **Model B (59 surfaces)**

Model C (47 surfaces) **Model D (94 surfaces)**

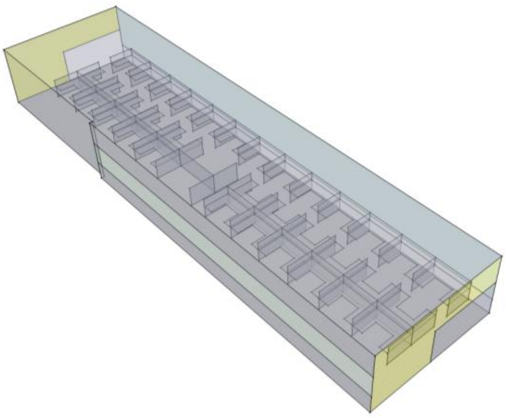
Figure 3 – Model of the GOP1 were constructed in four types of geometry level



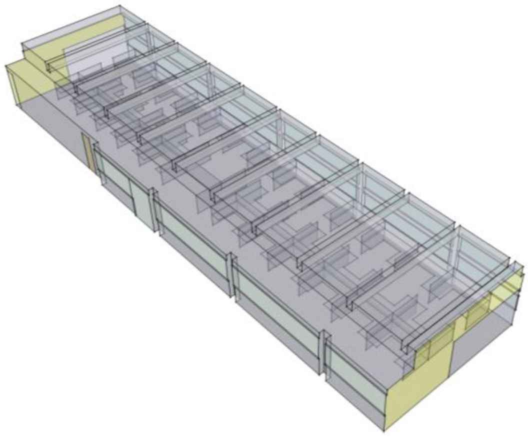
Model A (13 surfaces)



Model B (146 surfaces)



Model C (115 surfaces)



Model D (248 surfaces)

Figure 4 – Model of the GOP2 were constructed in four types of geometry level

Table 2 – Calculation parameter setting in ODEON for model simulation.

No. of sound source	: 1 (set at 1.2 m high)
Sound source type	: BB93_RAISED_NATURAL.S08 (Total power: 75.4 dB(A))
No of multi point source	: GOP1-11 points; GOP2-12 points (all set at 1.2m high)
ODEON calculation setup	: Precision
Impulse response length	: 2000 ms
Temperature input	: 24°

3. RESULTS AND DISCUSSIONS

3.1 Sound Pressure Level

The difference between the measurements in each room and the simulations of four digital models using ODEON was calculated. In Fig. 5, the comparison of sound pressure levels between the measured and the simulated conditions is presented.

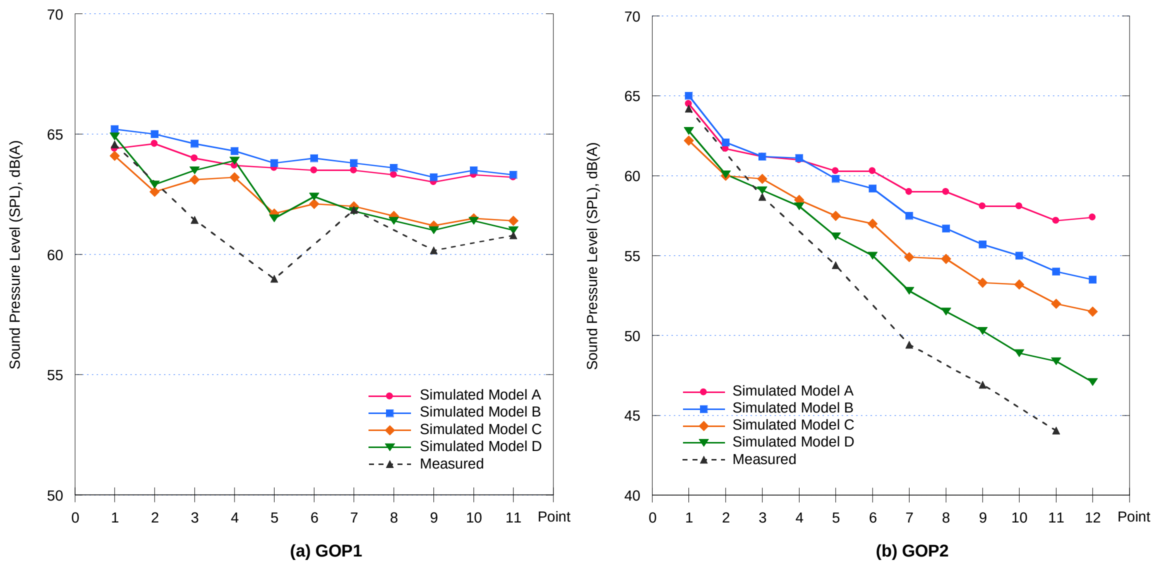


Figure 5 – Comparison of sound pressure level between measured and models simulated.

(a) GOP1; (b) GOP2

In GOP1 results, it clearly shows that the inclusions of furniture models in Model C & D bear similar results to the measured results at selected points. However, some discrepancies were observed at certain points, whereby the maximum deviation for Model D is 2.52 dB (A) for point 5. Furthermore, similar basic tendencies can be found in GOP2 but the discrepancy is higher when the distance becomes larger.

On the whole, discrepancy occurred between measured and simulated SPL in Model D is lower than 5.0 dB (A). At this stage, it can be concluded that the modeling gives satisfactory results of simulation for the level of geometry details in Model D, supported by the use of appropriate absorption and scattering materials properties in both rooms' conditions.

Table 4 – Reverberation time between measured and simulated for GOP1

GOP1	**Frequency (Hz)**				**Mean**	**Relative**
	250	**500**	**1000**	**2000**	**500-2k**	**difference (%)**
Measured	***1.05***	***1.09***	***0.99***	***1.04***	***1.04***	
Model A	1.69	1.18	1.10	1.08	1.12	7.4
Model B	1.93	1.33	1.15	1.12	1.20	14.3
Model C	1.19	1.07	1.07	1.07	1.07	2.8
Model D	1.25	1.13	1.08	1.09	1.10	5.6

Table 5 – Reverberation time between measured and simulated for GOP2

GOP2	**Frequency (Hz)**				**Mean**	**Relative**
	250	**500**	**1000**	**2000**	**500-2k**	**difference (%)**
Measured	***1.13***	***1.12***	***1.06***	***1.10***	***1.09***	
Model A	1.92	1.49	1.43	1.41	1.44	27.7
Model B	1.84	1.27	1.10	1.08	1.15	5.4
Model C	1.27	1.19	1.26	1.23	1.23	12.1
Model D	1.21	1.09	1.06	1.09	1.08	0.9

3.2 Reverberation Time (RT)

The main factor concerning the acoustics parameter in room acoustics is often the reverberation time. In this study, the simulation for all models are predicted based on the T_{30} and their use are justified using desirable precision between the measured under subjective limen below 5% as proposed by the manual(9).

Table 4-5 shows the comparison of reverberation time between measured and simulated results in 250 Hz to 2000 Hz region. In addition, the averaged reverberation time within 500 Hz to 2000 Hz is calculated to obtain the relative difference between all simulated models with the measured result.

Model C and D show the low relative differences in Table 4. Furthermore, only Model C is excellent under desirable precision below 5% of subjective limen.

In Table 5, low relative differences can be observed in Model B and D for GOP2 as shown in Table 5. Model D obtains excellent result whereby the relative difference is only 0.9%.

Even though a just-noticeable difference in reverberation time according to ISO 3382-1 is 5% but Hodgson (10) and Bistafa and Bradley (11) proposed a relative difference of 10% for engineering-type accuracy for reverberation time predictions in practical applications. Model D can be considered to meet this requirement, if the 10% of relative difference is taken into consideration as a basis for achieving a fair result.

3.3 Speech Transmission Index (STI)

Figure 6 plots the speech transmission index of four simulated models and the measured results. In this study, just-noticeable difference (*jnd*) on STI was set as indicator to be 0.05 for further discussion on the basis of desirable precision. Table 6 is provided for *jnd* details of STI of both rooms to ensure the convenience for the reader.

On the whole, the similar basic tendencies can be observed for all STI for the measured and the simulated in GOP1 and GOP2. However, the STI shown in Figures 5 and 6 becomes lower when the distance becomes higher. In GOP 1, fair agreement of intelligibility rating can be achieved in averaged for all points whereas the GOP2 only can be achieved until point 5 which is above than STI of 0.45.

The *jnd* provided in Table 6, presented by the Model A in GOP1 shows significant results as compared to other models. However, Model D is indicated with a just-noticeable different of two points is above the *jnd* indicator value. The Model D in GOP2 shows significant results compared to other models in all points except point 1 where the location is near to the sound source.

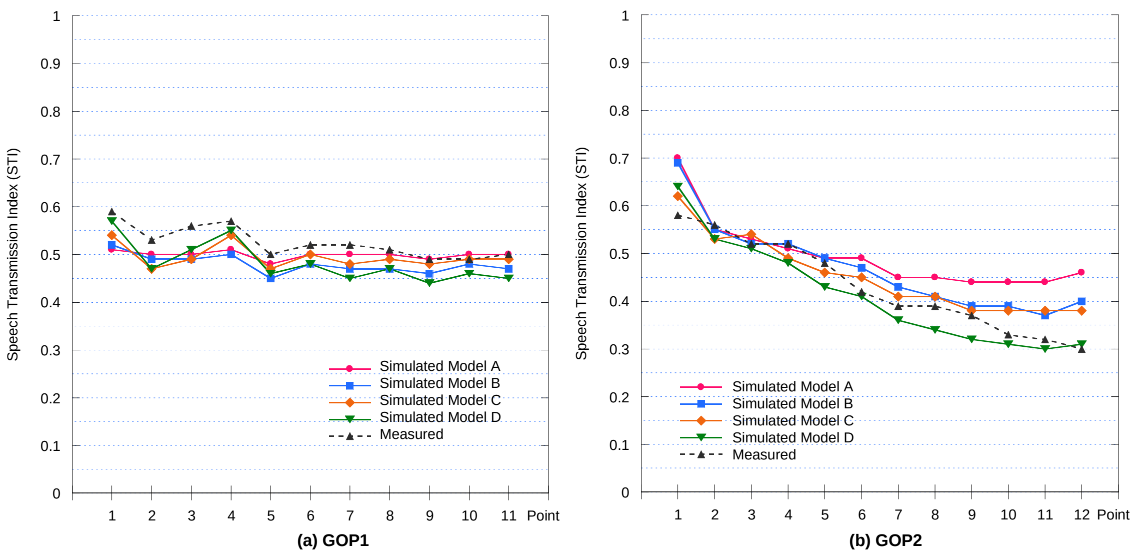


Figure 6 – Comparison of speech transmission index (STI) between measured and models simulated.

(a) GOP1; (b) GOP2

Table 6 – JND of STI between measured and simulated for both rooms

	GOP1				GOP2			
Model	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
1	0.08	0.07	0.05	0.02	0.12	0.11	0.04	0.06
2	0.03	0.04	0.06	0.06	0.01	0.01	0.03	0.03
3	0.06	0.07	0.07	0.05	0.01	0.00	0.02	0.01
4	0.06	0.07	0.03	0.02	0.01	0.00	0.03	0.04
5	0.02	0.05	0.03	0.04	0.01	0.01	0.02	0.05
6	0.02	0.04	0.02	0.04	0.07	0.05	0.03	0.01
7	0.02	0.05	0.04	0.07	0.06	0.04	0.02	0.03
8	0.01	0.04	0.02	0.04	0.06	0.02	0.02	0.05
9	0.00	0.03	0.01	0.05	0.07	0.02	0.01	0.05
10	0.01	0.01	0.00	0.03	0.11	0.06	0.05	0.02
11	0.00	0.03	0.01	0.05	0.12	0.05	0.06	0.02
12					0.16	0.10	0.08	0.01

0.00 - 0.03

0.031 - 0.05

> 0.05

4. CONCLUSIONS

The focus of this study was to verify the effectiveness of model detailing construction towards acoustical performance of open-plan offices. A comparison between existing measured results and computer-generated model of two open-plan offices in several detailing construction was conducted. Two objective parameters, reverberation time (RT) and speech transmission index (STI) were used to gauge the effectiveness of the computer modeling tool. Based on these parameters, the RT results showed fair agreement for Model D within below 10% of relative differences. Even though the STI results showed some discrepancies observed in *jnd*, on the whole, the maximum deviation is lower than 0.07. Further experimental investigations are now being pursued intensively for future refinement and adjustment.

ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledge the financial support under research grant RG165/12SUS from the University of Malaya for this research.

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