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COMPARATIVE STUDY ON ACOUSTICAL PERFORMANCE AND OCCUPANTS' SATISFACTION BETWEEN GREEN OFFICE BUILDINGS AND CONVENTIONAL OFFICE BUILDINGS IN MALAYSIA

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Green design features and strategies implemented in office buildings are to maximize the usage of energy efficient whilst reducing building impact onto human health and environment. Optimization of the Indoor Environmental Quality (IEQ) is taking into consideration for reducing building impact on human. However, through some amount of experiments based on rating tools for acoustical performances in green office buildings, the authors have come to the question about the effectiveness of green buildings' design strategies onto acoustical comfort in comparison to the conventional buildings. Thus, the objective of this study is to investigate the level of acoustic performance and occupants' satisfaction on their acoustic environment in green office buildings and in conventional office buildings in Malaysia. Two green office buildings and two conventional office buildings were chosen for the study. To investigate the acoustical performance, series of physical measurement were done to measure the relevant acoustical parameters. Occupants' satisfaction was studied through questionnaire surveys. Initial findings show that the acoustical performance in green office buildings is within the acceptable criteria range. However, in comparison to conventional buildings, it is considered unsatisfactory.

1. Introduction

In recent years, green building has become a popular trend in Malaysia's building industry. The widespread exposure has effectively influenced building owners and developers to realize the advantages green building has to offer. Since the establishment of Green Building Index (GBI) in 2009, the Malaysia's green building rating tools has received 256 applications for GBI certification [1]. The number of application grew each year and in 2013, it was reported that there were around 200 development projects which have been certified as green building by the GBI, whether fully or provisionally [2].

There are many attractive side advantages from building green. Developers see it as an opportunity to gain extra revenue by offering 'prestigious' properties through the green concept [2-3]. Some building owners on the other hand see it as a chance to save some money on building maintenance cost for the long run [3]. Although, the main purpose of green building is to maximizes the efficiency of resources usage while minimizing the building impact on human health and environment. [4-5].

This is where green building rating tools such as GBI comes in. GBI as a rating tool assists building construction's personnel in achieving a green certified building. Sets of guidelines and checklist would be implement in order to ensure the building achieve its aim of being green. Through GBI, buildings would be assessed on 6 key criteria before they can be certified as green building. The six criteria are: energy efficiency (EE), indoor environmental quality (EQ), sustainable site planning and management (SM), materials and resources (MR), water efficiency (WE), and innovation (IN) [6].

GBI has allocated 21 assessment points under indoor environmental quality (EQ) [7]. This is expected as people tend to spend most of their time indoors [8] and most of their waking hours are spent working in the office. Thus, indoor environmental quality is an important element in non-residential buildings such as an office.

EQ criteria highlighted its purpose as to 'achieve good indoor environmental performance in indoor air quality, acoustic, visual and thermal comfort' [6]. While all the elements stated under EQ criteria have their own significant role in creating a comfortable indoor environment, acoustics has an especially imperative task in creating a workable office environment [9]. Acoustic has the ability to influence a person's ability to work productively. Uncomfortable level of noise can distract a person from focusing on the task at hand thus decreasing productivity [10]. However, previous studies on both conventional and green office buildings reported that the occupants were not satisfied with the acoustical performance in their building [11].

Previous findings shows that while implementing green building design measures to improve on other green building elements and criteria, somehow designers failed to realized the negative effects it projected towards the acoustical performance of the building. Some examples of green building design measures that affected the acoustical performance of a building are the design measures done to achieve natural ventilation and maximum usage of daylighting, minimization of finishes and the open-plan layout [10-11].

Thus, the objective of this study is to investigate on the acoustical performance of green office buildings in Malaysia, as well as the occupants' satisfaction; and compare them with that of conventional office buildings in Malaysia. The comparison will assist in reviewing the effectiveness of green building concept on the acoustical performance of office buildings in Malaysia.

2. Assessment parameters

ISO 11690-1:1996 (E) [12] indicated the recommended BN for meeting and conference room, and open-plan office is 30 – 35 dB(A) and 35 – 45 dB(A) respectively. Beranek, as cited in Maekawa et al. [13] recommended the acceptable noise level for offices are between 38 – 48 dB(A) for small offices and conference room, and 48 – 58 dB(A) for general offices. ANSI/ASA S12.2-2008 recommended NC for conference room at NC 25 – 30 depending on the size and NC 35 – 40 for open plan areas. Alternatively, Cavanaugh [14] recommended the acceptable NC 34 – 43 as acceptable level for executive office and NC 42 – 52 for conference rooms, office and workspaces. Hodgson [9] in his study applied the acceptability criteria of NC 30 – 35 for meeting and conference rooms, and NC 35 – 40 for open-plan office. GBI's point merit for acoustical requirement suggested that the internal noise level for open-plan office must not exceed 45 dB(A) and closed office must not exceed 40 dB(A) [7].

While ISO 111690-1:1996 (E) [12] 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 [11] stated that the optimum RT for comfort and easy verbal communication is below 0.75 s.

Assessment parameters and acceptability criteria of previous research are summarized and presented as per Table 1 below.

Table 1. Assessment parameters and acceptability criteria applied in this study

Assessment parameter	Acceptability criteria
Background noise level (BN)	30 – 35 dB(A) in meeting and conference room 35 – 45 dB(A) in open-plan office
Noise Criteria (NC)	NC 30-35 in meeting and conference room NC 35-40 in open-plan office
Reverberation time (RT) in seconds	0.6 – 1.2 s at frequency of 500 Hz

3. Methodologies of Research

For the purpose of this study, three green office buildings and two conventional office buildings were selected. Two meeting/conference room and two open-plan office were chosen from every building as sample spaces to represent green and conventional office spaces. The selection was based on their general information of rating, open-plan layout and room characteristic. Space shape, size, spatial arrangement and other factors contributed to the final selection, in addition to building accessibility.

3.1 Building Description

Table 2 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. Selected spaces varied from very small space with 76.1 m^3 volume to large volume area of over 1000 m^3. Room capacities were derived from the furniture layout and may vary by the changes of office layout, design and management's organization. The three green office buildings selected are GBI certified building and have constantly proven their energy efficiency by the significant reduce building energy index (BEI) in their building.

Table 2. Main physical characteristics of selected spaces for all buildings

No	Building Type	Building	Code	Dimensions of room (m)			Volume (m^3)	Room capacity
				L	W	H		
1	Green	Building A	DOP1	16.8	15.0	3.0	756.0	12 (+16)
2			DOP2	16.6	17.0	3.0	846.6	17 (+9)
3			DMR1	8.4	6.5	3.0	163.8	18
4			DMR2	16.8	11.9	3.0	599.8	49
5		Building B	LOP1	13.6	13.7	3.0	559.0	13
6			LOP2	29.0	11.9	3.0	1035.3	26
7			LMR1	9.9	4.5	3.0	133.7	17
8			LMR2	16.0	13.0	3.0	624.0	56
9		Building C	GOP1	8.0	12.0	3.3	316.8	10
10			GOP2	30.5	8.0	3.3	805.2	35
11			GMR1	6.0	4.7	3.3	93.1	12
12			GMR2	12.0	7.3	3.3	289.1	20
13	Conventional	Building D	POP1	25.2	12.3	2.7	836.9	25 (+18)
14			POP2	21.8	10.1	2.7	594.5	23 (+8)
15			PMR1	8.4	4.7	2.7	106.6	14
16			PMR2	5.5	4.8	2.7	71.28	10
17		Building E	NOP1	32.1	6.4	2.7	554.7	23
18			NOP2	20.4	7.1	2.7	391.1	20
19			NMR1	8.1	4.1	2.7	89.7	14
20			NMR2	8.9	6.1	2.7	146.6	20

3.1.1 Building A

Building A is an eight storey high rise building with GFA of around 14,000m^2. The building was designed to achieve the status of green building and received green building certification from the GBI a year after its completion. Two key elements which were prioritized during the design stage were energy efficiency and daylight harvesting. The shape of the building plays a significant role as 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 means of light shelf. The atrium in the middle also plays an important role in daylight harvesting.

3.1.2 Building B

Building B comprises of six floors with 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 building divided into two wings 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 minimize heat absorption. The atrium is an important feature of the building as it demonstrates the EE elements of the building as it is naturally ventilated and lit, decorated with greeneries and water features as cooling elements for the building.

3.1.3 Building C

Building C is a small four storey office building and training centre 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. 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, by utilising photovoltaic panels as its skylight element.

3.1.4 Building D

Building D consists of 8 floors complete with basement parking with GFA of approximately 70,000 m^2. The building design sprawled over a big site. The entrance statement is a scaled-up metal freestanding archway and the building is divided into two elongated blocks, connected by a garden court. The garden consists of shallow water feature as acting as a cooling element for the garden and the building. The two office blocks are designed similarly with each floor contains two sections of 8,000 m2 office area, connected by a long open corridor with atrium concept. The façade is mostly metal and glass with special design shading device. Internally, office spaces are a typical office building with carpeted floor complete with acoustical ceiling treatment.

3.1.5 Building E

Building E is an 18-storey tower and 5-storey podium with approximately more than 45,000 m^2 in GFA. The building is part of a master plan of 4 curved towers in a centralized boulevard. The floor plan of the tower is an almond shape with the core located at one end of the floor plan. Façade treatment is designed using steel frame and screen and movable timber screens. The building incorporated some green building feature as having the building oriented east-west to minimize solar exposure and etc. However, this building is not a GBI certified building. Typical office floor are a large open office with individual small office rooms located at the outer part of the space. Hence, major parts of the office area are illuminated by artificial lighting throughout the day.

3.2 Field Measurement

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

The 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 to achieve position of a sitting person. 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. To provide a compact presentation, the data collected were calculated and averaged. It was necessary to measure the internal room's BN to determine the NC rating.

Measurement for RT was conducted using an omni-directional speaker as a sound source. The speaker was positioned at one selected point at the height of 1.2 m. he volume was adjusted around 67-69 dB(A) to radiate sine wave and sweep signals. Measurement of RT was taken at every receivers point respectively.

3.3 Questionnaire Survey

The preliminary questionnaire survey was divided into 3 sections. Section A focus on occupants' general information such as gender, age, duration of work at workspace and etc. Section B focused on assessing occupants' general view on office environment in general. Two types of questions were asked, their view on the importance level of the elements in an office environment and their satisfaction level on the same elements, at their office.

Section C of the survey focused on the acoustical environment. The first question required the occupants to rate the level of noisiness in their office environment. The second question surveyed on how the noises in their office environment affect their basic office task. Likert style scale has been applied for section B and C of the survey.

4. Results and Discussions

4.1 Field measurement

To ensure convenient to the reader, a comparison of the BN, NC rating and RT_{500} is presented in Table 3. Table 3 shows the BN values for all open-plan offices are excellent within the permissible limit of noise level for all buildings. However, meeting rooms of green buildings are over than 35 dB(A) which exceeded from the maximum recommended noise level except LMR1. In addition, DMR1 and GMR2 does exceed from GBI assessment criteria based on averaged value being above 40 dB(A).

The NC ratings of measured BN indicate a *very quiet to quiet* environment for all rooms measured as presented in Table 3. However, the DMR1 and GMR2 are closely to the preferences of NC rating ranging between NC-30 to NC-35. It is should not be exceeded from NC-35 because the noise can interfere the speech delivered and concentration while discussion held.

The preferences of $RT_{500\ Hz}$ are ranging between 0.6 – 1.2 s depending on room's volume. However, below than 0.75 is preferable for the comfort of verbal communication. Most of the rooms in green buildings exceeded the 0.75 s except the DOP2, LOP2, and LMR1. Furthermore, the DOP1, LOP1, DMR2 and GMR1 show the higher RT where the RTs are exceeded from 1.2 s. For both conventional buildings, the RT values are excellent below than 0.75 s except POP2 but not exceeded from 1.2 s. There complementary aspects which can explain this phenomenon: (i) the rooms were typically installed with low-absorptive materials, (ii) the use of sound diffusion was not sufficient to prevent focused reflections.

Table 3. Comparison of BN, NC rating and RT between green buildings and conventional buildings

No	Building / Space	Code	Volume (m^3)	BN, dB(A)	NC	RT (500Hz), s
Building A (Green)						
1	Open-plan Office (Lvl 4)	DOP1	756.0	30.28	NC-20	**1.50**
2	Open-plan Office (Lvl 6)	DOP2	846.6	36.77	NC-24	0.70
3	Meeting Room (Lvl 6)	DMR1	163.8	**44.94**	NC-35	1.14
4	Meeting Room (Lvl 7)	DMR2	599.8	**39.25**	NC-30	**1.24**
Building B (Green)						
5	Open-plan Office (Lvl 2)	LOP1	559.0	37.29	NC-27	**1.41**
6	Open-plan Office (Lvl 3)	LOP2	1035.3	31.79	NC-20	0.71
7	Meeting Room (Lvl 2)	LMR1	133.7	27.87	NC-20	0.68
8	Meeting Room (Lvl 5)	LMR2	624.0	**35.92**	NC-21	0.98
Building C (Green)						
9	Open-plan Office 1 (Lvl 2)	GOP1	316.8	36.33	NC-23	1.09
10	Open-plan Office 2 (Lvl 2)	GOP2	805.2	35.00	NC-22	1.12
11	Meeting Room 1 (Lvl G)	GMR1	93.1	**37.79**	NC-26	**1.29**
12	Meeting Room 2 (Lvl G)	GMR2	289.1	**45.65**	NC-35	1.10
Building D (Conventional)						
13	Open-plan Office (Lvl 3-A)	POP1	927.0	41.06	NC-32	0.63
14	Open-plan Office (Lvl 3-B)	POP2	691.1	32.08	NC-20	0.93
15	Meeting Room 1 (Lvl 3-C)	PMR1	115.8	25.39	NC-13	0.33
16	Meeting Room 2 (Lvl 3-D)	PMR2	76.1	27.68	NC-20	0.33
Building E (Conventional)						
17	Open-plan Office 1 (Lvl 9)	NOP1	510.4	29.70	NC-19	0.49
18	Open-plan Office 2 (Lvl 14)	NOP2	408.5	32.82	NC-21	0.64
19	Meeting Room 1 (Lvl 9)	NMR1	86.1	25.29	NC-18	0.57
20	Meeting Room 2 (Lvl 14)	NMR2	142.9	23.66	NC-18	0.52

4.2 Questionnaire survey

Questionnaires are distributed randomly to a group of office staffs that are age ranging from 20 to 50 years old and above. The number of respondents is 71 people in the green office buildings and 90 people in the conventional office buildings.

The highest age group of the respondents in both office buildings are between 30 to 40 years old, which is 48.4%, followed by 29.8% age between 20 to 30 years old. 41% of the respondents are male and 59% are female.

The overall satisfaction level of subject's *quiet office environment* and *sound privacy* for both types of buildings is shown in Fig. 1. The subjects on *quiet sound environment* and *sound privacy* in green buildings have similar tendencies with the conventional buildings. However, almost 35% of respondents have higher satisfaction as observed in Fig.1.

Meanwhile in Fig. 2(a), based on the survey on level of difficulty to perform basic office tasks in green buildings, almost 12% of respondents were always having difficulties in concentrating in general and discussion. However, below than 10% have experience having difficulties in all office tasks as shown in Fig. 2(b).

It can be said that the survey results in both types of buildings are having similar tendencies in general on the building occupants' perception.

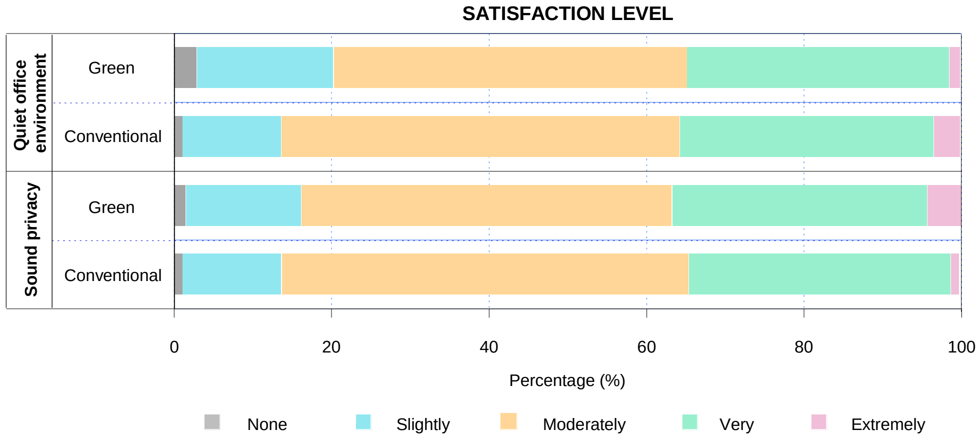
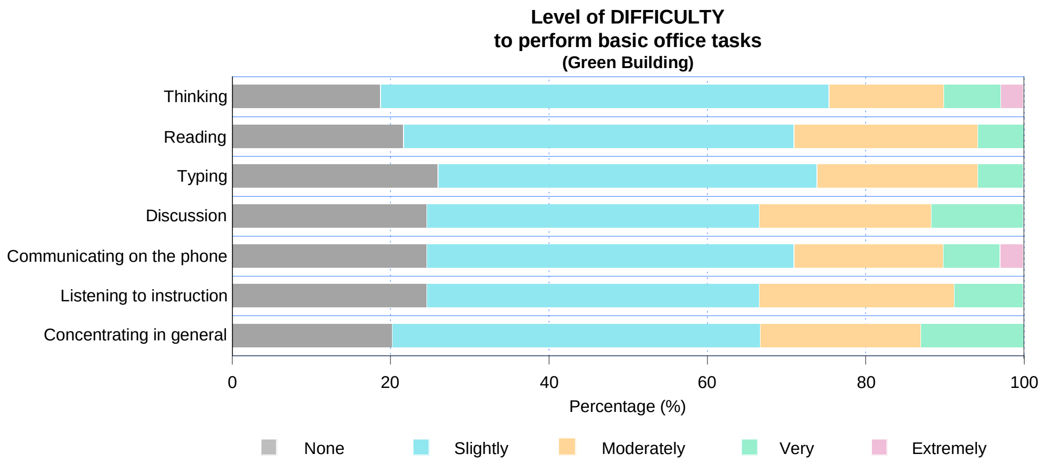
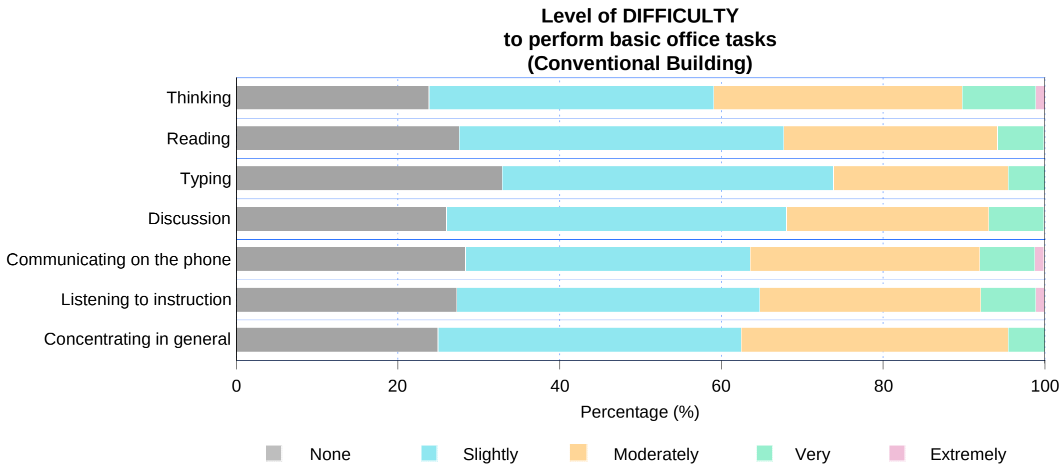


Figure 1. Satisfaction level for both types of buildings



(a)



(b)

Figure 2. Level of difficulty to perform basic office tasks (a) Green (b) Conventional.

5. Conclusions

Investigation on the acoustical performance of green office buildings in Malaysia, as well as the occupants' satisfaction; and compare with that of conventional office buildings in Malaysia was performed. In this study, the comparison between measurements of three green buildings and two conventional buildings have been compared and revealed that the background noise and reverberation time in green buildings in certain rooms resulting over the acceptable criteria given. Even though, preliminary results of the occupants' satisfaction showed both buildings gave similar tendencies in overall subjects, but it is indicated the effectiveness of green building strategies are not give significant acoustical improvements and need to take careful consideration both in strategies and assessment aspects.

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