THE ACOUSTIC COMFORT IN HIGH-RISE HOSTELS: OBJECTIVE AND SUBJECTIVE MEASUREMENTS IN MALAYSIA

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ABSTRACT

Objective and subjective measurement in examining acoustic exposure in high-rise buildings were conducted in three high-rise hostels located in Klang Valley, Malaysia, namely, 12th Residential College, University of Malaya (H1), 11th Residential College, Universiti Putra Malaysia (H2), and Murni Student Apartment, Universiti Tenaga Nasional (H3). This study is aimed at assessing the effects of acoustic comfort in high-rise hostel rooms at different floor levels. Measurements were taken in the month of May until July in 2007. One measured room has been selected on the first, fifth and top floors at each block in these high-rise hostels. 298 female students accommodating these hostels participated in the questionnaire investigation. Findings revealed that sound pressure levels increase with the room floor level due to wind and air temperature influences. It is also observed that mean difference for occupants that can hear road traffic noise significantly differed that is similar to the objective measurements where the highest sound pressure level (SPL) detected was in H3, followed by H2 and lastly H1.

Keyword: *Sound Pressure Level, Wind Direction, Traffic Noise, Window Design, Acoustic Comfort Vote, High-rise Hostels*

1. INTRODUCTION

Acoustic comfort is employed when the environment is sufficiently 'quiet' in order for the task to be carried out comfortably and without distraction, i.e. with no unwanted sounds (noise) or vibration (CIBSE, 2006). In a naturally ventilated building, achieving indoor acoustic comfort can be challenging especially in a hot climate country like Malaysia. Naturally ventilated buildings depend highly on the usage of windows to release heat gains and act as a natural cooling mechanism. However, windows in some circumstances deprive privacy by allowing outdoor noise to transmit indoor. Outdoor sound propagation is influenced by air temperature, humidity, and wind current conditions. Since sound is influenced by these factors, it tends to change direction and speed accordingly. In hot climate countries, air temperature generally decreases with altitude where sound generated at ground level will bend upward towards higher altitudes (Cowan, 1994).

The importance of acoustic comfort investigation does not depend on objective measurement alone. Subjective measurement should be incorporated as well. Zannin et al. (2002) in their acoustic comfort investigation in Brazil suggested that despite reduction on the urban noise pollution recorded through objective measurement, subjective findings show an increase on the perception of the urban noise, mainly the noise generated from the neighbourhood of the interviewed occupants. In the UK, Skinner and Grimwood (2005) undertook a survey of environmental noise levels collected from 1160 24-hour noise measurement at samples of dwellings and over 5500 questionnaire responses from the adult population from 1990 until 2000. They found that in the last ten years, there has been an increase in the proportion of people reporting being annoyed by noise from neighbours and road traffic. Similar Sound Pressure Level (SPL) increase was also detected from their 16 h (day-time) and 8 h (night time) L_{Aeq} indicators. In another subjective measurement conducted on occupants in houses exposed to road traffic noise has been done by Klæboe and co-workers (Klaeboe et al., 2004). 3947 occupants in Norway were asked whether they felt annoyed with the traffic noise when they were indoors and outdoors. The responses were that indoor occupants were more annoyed than outdoors especially the ones with inferior window quality.

In terms of dwelling condition, occupants in crowded interior spaces often complained of noisy conditions and lack of privacy. If it is not addressed, this condition will cause stress. Winchip et al. (1989) found that parents living in a large household experienced more stress than those without children. Miedema and Vos (1999) found that noise annoyance is not related to gender but has an effect on age. Their data was collected from investigations of noise exposure from aircrafts, road traffic and railways in Europe, North America and Australia. When exposed to similar noise exposure level, relatively young and relatively old persons are less annoyed than those persons of in between ages. This is due to deterioration of hearing sense in relatively old persons and is not related to environmental noise condition. In Germany, Kuerer (1995) suggests that acoustic comfort is connected to building insulation design. Based on the Classes of Acoustical Comfort in Housing proposed by the European Commission, the acoustic comfort for occupants in several types of dwelling typology is investigated by the means of their indoor sound propagation. Indoor sounds are concise of speech, footsteps, sanitary noise and recreational noise. Most of the occupants are satisfied with the Class II standard acoustic quality where occupants usually find quietness and rest in their homes. But if further improvement is needed, additional costs of 0.3% are required to build houses to meet the Class III acoustic quality which can also reduce outdoor noise. In the city of Curitiba, Brazil, Zannin et al. (2003) reveal that occupants in residential areas suffer from noise pollution above 65 dB(A) that is mainly caused by traffic noises. They also added that acceptable noise level in residential areas should be less than 62 dB(A) as recommended by US Department of Housing and Urban Development.

Literature reviews highlight the importance of both objective and subjective measurements in acoustic comfort examinations (Zannin et al., 2002; Skinner & Grimwood, 2005; Klaeboe et al., 2004). Furthermore, not many investigations on this matter have been conducted in high-rise dwelling located in hot climate countries. Therefore this study is aimed at assessing the effects of acoustic comfort in high-rise hostel rooms at different levels by means of objective and subjective measurements in three sites in Klang Valley, Malaysia. Results are expected to show sound pressure levels increase with the room floor level due to wind and air temperature influences. Readings are measured in terms of A-weighted sound levels as found in many references (Cowan, 1994; Kuerer, 1995; Zannin et al., 2008; El Dien, H.H. and Woloszyn, 2005).

2. METHODOLOGY

2.1 Case Study Sites

Selected case studies were identified in Petaling Jaya, Serdang and Bangi. Petaling Jaya with latitude of 3" 6'N, longitude of 101" 39 east of Greenwich is just a 5-minute drive to Kuala Lumpur and is known for having the country's oldest university, Universiti Malaya. Petaling Jaya is 60.8 m above sea level. Serdang is located to the south of Kuala Lumpur and is made famous by Universiti Putra Malaysia. Bangi is a new development town with one public university and one semi-public university. The latter university, namely Universiti Tenaga Malaysia is chosen as one of the sites.

Three high-rise hostels, namely, 12th Residential College, University of Malaya (H1), 11th Residential College, Univerisiti Putra Malaysia (H2), and Murni Student Apartment, Universiti Tenaga Nasional (H3) were selected. These hostels were chosen because they were the tallest dwelling buildings in each university campus and naturally ventilated. The dimensions, window orientations, and window to wall ratio (WWR) for typical room in each case are as follow:

a) H1: 4.90m (l) x 3.30m (w) x 3.00m (h); North and South; 0.35
b) H2: 4.30m (l) x 3.60m (w) x 2.90m (h); North, South, East and West; 0.26
c) H3: 6.50m (l) x 5.30m (w) x 3.20m (h); North and West; 0.32

These different room locations were chosen to measure the A-weighted sound pressure level reduction differences at slightly above ground, middle, and top level of a high-rise dwelling building. The occupancy number for H1 and H2 rooms was two and three persons, respectively. H1 was the only hall of residence with a balcony (2 m projection). Each case has different window designs, namely, adjustable louver windows with transparent polymer door finish in H1; set of six top hung windows in H2 and two sides hung with one fixed window in the middle in H3.

The distance for each high-rise hostel from a nearby highway was about 20 m, 10 0m, and 70 m for H1, H2 and H3, respectively. In terms of sound proofing mechanism around the case studies' perimeters, H1 was heavily muffled by tall trees with 2 m high concrete sound barrier, H2 was separated by basketball courts and another high-rise hostel with similar height, and there was no sound proofing mechanism around H3.

2.2 Objective Measurement Procedures

Environmental noise assessment was done using sound pressure. Sound pressure is denoted in terms of decibels by squaring it to be in proportion with sound power. The result in quantity is known as the sound pressure level (SPL) (Cowan, 1994). In this study, selected high-rise building case studies were located in free fields with different types of sound barrier installations. Measurements were taken using Dawe dB sound pressure level meter (Figure 1). Sound pressure readings were recorded continuously starting from 8 a.m. until 5 p.m (9-hour period) for three days. Date of measurements for 7 façade orientations, namely: north, south, south-east, west, north-west, north-east, and south-west in H1, H2 and H3 were conducted starting from 12th May until 3rd July 2007. The SPL in A-weighted scale was positioned 0.75 m above the floor. Its quarter-inch diameter electric microphone was pointed outward through an open window next to a study desk. The major noise source in these case studies propagates from nearby highways located in each site.

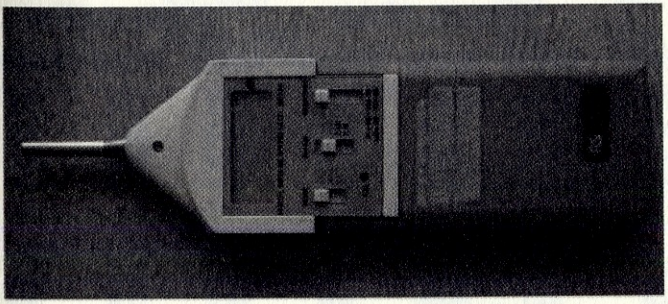

Figure 1: Dawe dB sound level meter

Hourly weather data starting from 8 a.m. until 5 p.m. was obtained from Petaling Jaya (for H1) and KLIA (for H2 and H3) meteorological station. The anemometer head in each weather station was located 29 m and 10 m above ground in Petaling Jaya and KLIA meteorological station, respectively.

2.3 Subjective Measurement Procedures

Targeted subjects were female students living on the selected high-rise hostels. The decision to approach female students was based on the argument by Miedema and Vos (1999) stressing that noise annoyance is not gender related and due to limited measurement period. To aid participating occupants that are not familiar with technical terms, the questionnaire was prepared with Bahasa Malaysia translation and glossary of comfort terminologies. Occupants were asked to vote their acoustic comfort during rainy days and clear days within the last six months. Then they were asked to vote their acoustical comfort three times daily, namely, morning (8:00 to 11:59 a.m.), afternoon (12:00 to 4:29 p.m.) and evening (4:30 to 6:30 p.m.). Table 1 shows the description of questions to assess acoustic comfort in high-rise hostels in Malaysia, which is adapted from Osgood's Semantic Differential measurement instruments, i.e.: *'noisy (-3) – quiet (3)'*; *'never (-3) – always (3)'*; and *'annoyed (-3) - not annoyed (3)'* (Osgood et al, 1957). These acoustic comfort votes are analysed using ANOVA repeated measures in SPSS version 12.

3. RESULTS

3.1 Objective Measurement

A summary of the weather data during the measurement period is shown in Table 2. In general, air temperatures detected during the measurement period in eight case studies were constant with about ±2.0°C standard deviation that ranged from 25°C to 34°C. Relative humidity during the measurement was less constant, due to rainy condition usually in the evening. Not much variation was also detected in wind speed. Wind directions for H1, H2 and H3 were roughly north to north-east, north-west to south-west, and south-east to south-west, respectively (data not presented in this paper). Results obtained from the window of measured rooms in three high-rise hostels at different orientations are shown in Table 3. In general, SPL increased with the room floor level. Window orientations was observed to have no influence on the sound level unless the window was facing a highway. Rooms in H3 received the highest SPL compared to the other rooms because there was a highway just 70 m from these hostel blocks. The overall sound distribution showed very small variation below ±4dB(A) in all cases.

Table 1: Description of Questions in Section E

	Questions	Scale type	Day condition/ time
1	Do you find this room to be…	'noisy' to 'quiet'	Rainy day
2	Do you find this room to be…	'noisy' to 'quiet'	Clear day
3	Can you hear road traffic noise when the window in your room is opened?	'never' to 'always'	None
4	Can you hear road traffic noise when the window in your room is closed?	'never' to 'always'	None
5	How do you classify the exterior noise level heard from your room during these hours?	'annoyed' to 'not annoyed'	i) Morning ii) Afternoon iii) Evening

Table 2: Summary of Weather Data for H1, H2 and H3

	Weather data collected from Petaling Jaya and KLIA meteorological station											
	H1 North (12 – 15 May)			H1 South (19-21 May)			H2 East (27 – 29 May)			H2 South (3 -5 June)		
	DB(°C)	RH(%)	WS(m/s)	DB(°C)	RH(%)	WS(m/s)	DB(°C)	RH(%)	WS(m/s)	DB(°C)	RH(%)	WS(m/s)
Mean	30.8	65.3	2.0	30.4	65.9	2.3	28.8	78.1	1.7	29.2	75.4	1.8
Min.	24.6	51.0	0.4	26.6	50.0	0.8	25.4	66.0	0.4	25.2	62.0	0.0
Max.	34.4	92.0	4.6	34.4	87.0	4.9	31.0	96.0	2.9	31.6	96.0	4.1
Std. dev.	2.9	11.3	0.9	2.3	11.3	1.0	1.6	8.1	0.6	2.1	9.7	1.1
	H2 North (10 – 12 June)			H2 West (17-19 June)			H3 West (24 -26 June)			H3 North (1 – 3 July)		
Mean	29.5	73.5	2.1	29.4	70.7	2.7	29.5	73.8	12.3	31.3	63.3	2.2
Min.	25.5	65.0	0.7	25.3	54.0	0.8	25.3	62.0	0.6	28.0	51.0	0.9
Max.	31.2	91.0	3.5	33.0	91.0	4.9	31.9	93.0	4.2	33.0	82.0	3.7
Std. dev.	1.2	6.2	0.9	2.1	10.3	1.0	1.8	8.8	1.0	1.4	9.5	0.8

Notes: DB = dry bulb temperature; RH = relative humidity; WS = wind speed.

Table 3: Sound Level at Three Room Levels on the First, Fifth and Top Floors of H1, H2 and H3

Orientations		First floor			Fifth floor			Top floor		
		H1	H2	H3	H1	H2	H3	H1 (9th)	H2 (7th)	H3 (10th)
North	Mean, dB(A)	46.06	46.83	55.45	46.72	51.82	61.53	49.30	53.30	63.81
	Min., dB(A)	40.70	42.30	51.50	42.40	47.30	58.30	42.80	47.40	62.50
	Max., dB(A)	49.80	51.00	59.30	53.90	56.50	63.90	54.00	57.90	65.90
	Std. dev., dB(A)	±2.26	±2.34	±1.85	±2.49	±3.08	±1.38	±3.06	±3.39	±0.90
South	Mean, dB(A)	53.46	42.39	-	52.98	44.92	-	55.04	46.40	-
	Min., dB(A)	48.30	37.10	-	46.30	39.90	-	51.20	39.40	-
	Max., dB(A)	58.70	46.30	-	60.10	49.60	-	61.10	54.00	-
	Std. dev., dB(A)	±2.16	±2.65	-	±2.95	±2.45	-	±2.13	±2.53	-
East	Mean, dB(A)	-	47.35		-	49.96	-	-	51.46	-
	Min., dB(A)	-	42.13		-	42.12	-	-	46.85	-
	Max., dB(A)	-	50.62		-	59.63	-	-	61.80	-
	Std. dev., dB(A)	-	±1.83		-	±4.31	-	-	±3.71	-
West	Mean, dB(A)	-	47.53	48.81	-	48.77	52.88	-	48.56	60.72
	Min., dB(A)	-	44.93	43.90	-	45.98	48.60	-	45.50	57.30
	Max., dB(A)	-	49.48	54.30	-	51.32	59.60	-	52.38	63.40
	Std. dev., dB(A)	-	±1.19	±1.99	-	±1.08	±3.16	-	±1.36	±1.44

Table 4: F Value for 8 Sets of Objective Measured Results

Case set (each set has three room levels)	*F* value
H1 North	12.17
H1 South	5.56
H2 East	11.60
H2 North	43.31
H2 South	16.66
H2 West	14.19
H3 North	274.43
H3 West	206.11

Statistical analysis using One-way ANOVA test for SPL at three different room floor levels show F value to be significant beyond the 0.01 level in all cases (Table 4). The mean SPL measured in H3 varies significantly for the room levels, shown through large F values of 274.43 and 206.11 for H3 north and H3 west, respectively. Meanwhile mean differences detected in H1 and H2 rooms show almost similar F values, except for H2 north rooms which is slightly higher than other rooms in both high-rise hostels. The lowest F value is presented in H1 South rooms, i.e. 5.56.

3.2 Subjective Measurement

A total of 298 occupants participated in the subjective measurement, i.e. 100 persons in H1, 108 in H2 and 90 in H3. The mean votes for acoustical comfort during rainy and clear days show no significant difference in all cases. The responses for the following question on whether occupants can hear road traffic noise when the window is opened or not present significant mean votes differences beyond the 0.01 level: $F(1, 99) = 22.41$; $F(1, 107) = 30.11$ and $F(1,89) = 40.18$ in H1, H2 and H3, respectively. The eta squared value obtained for H1, H2 and H3 are 0.185; 0.220; and 0.311, respectively, thus showing large population effect. Figure 2 shows the acoustical comfort votes in H1, H2 and H3 when the windows are opened and closed. Majority of occupants in H3 vote that the traffic noise from nearby highway is always heard indoors compared to their counterparts in H1 and H2. Dramatic reduction in H3 occupants' response is shown when windows are closed.

When occupants were asked to vote for their acoustical comfort during three different periods of the day, namely; in the morning, afternoon and evening, the mean votes collected for the room levels differed significantly beyond the 0.01 level: $F(2, 198) = 9.321$ and $F(2, 214) = 8.510$ in H1 and H2, respectively. Both results show medium effect size in their populations, with eta squared value of 0.086 and 0.074, in H1 and H2, respectively. Meanwhile in H3, the means for this particular vote is insignificant.

4. DISCUSSIONS

4.1 Objective Measurement Results

SPL detected in three selected high-rise hostels selected are within the range of 40 to 64 dB(A) (Table 3) and it is considered over the noise rating suggested for living room in urban dwellings which is 30 noise rating (NR) or 24 dB(A). NR is estimated from Table 1.15 in CIBSE Guide A (2006). This condition is perhaps caused by insufficient building insulation installation as mentioned by Kuerer (1995). However, this paper is limited to investigate the influence of wind direction to SPL in rooms at different floor levels.

Objective measurements show that SPL increases with higher measured room floor levels. ANOVA tests also confirmed that mean difference for each façade increases in relation to the distance and location of the traffic noise source. Slightly higher mean difference in H2 north rooms with F value of 43.31 was observed because these rooms were facing the nearby highway and the wind direction detected during the measurement period was travelling from the opposite direction, i.e. south-east to south-west. However, since the noise source was further away from the measured rooms' locations, the SPL detected decreases but remain louder than those measured from other rooms. Much higher mean differences detected in H3 north rooms indicate that rooms facing a nearby highway about 70 m distance with no sound proofing mechanism vary more significantly than the other two hostels. Low mean variation between SPL measured in three different room levels located in H1 South was due to the noise source from the highway that was not carried by the northern wind direction. The particular highway is located to the west of this high-rise hostel blocks and it is muffled by 2 m concrete sound barriers and tall trees. Therefore it shows that wind travelling from the direction of the nearby highway (noise source) is most likely allowing noise to travel towards the measured rooms. In addition, due to relatively hotter ground temperatures, traffic noise brought in by the wind bends upwards towards cooler air, thus creating more audible noise in measured rooms at upper floor levels.

4.2 Subjective Measurement Results

From the subjective measurement, it is found that occupants in high-rise hostels were not acoustically influenced when asked to describe their room acoustic condition during both rainy and clear day. Mean votes between acoustical comfort in the morning, afternoon and evening revealed medium population size effect by occupants in H1 and H2 but is not significant in H3. Meanwhile, mean votes between acoustical comforts surveyed when windows were opened and closed differed significantly with large population size effects in all three high-rise hostels. This particular large population size effects were in good agreement with SPL measured earlier, where the highest SPL detected was in H3, followed by H2 and lastly H1. Therefore it can be stressed that occupants'

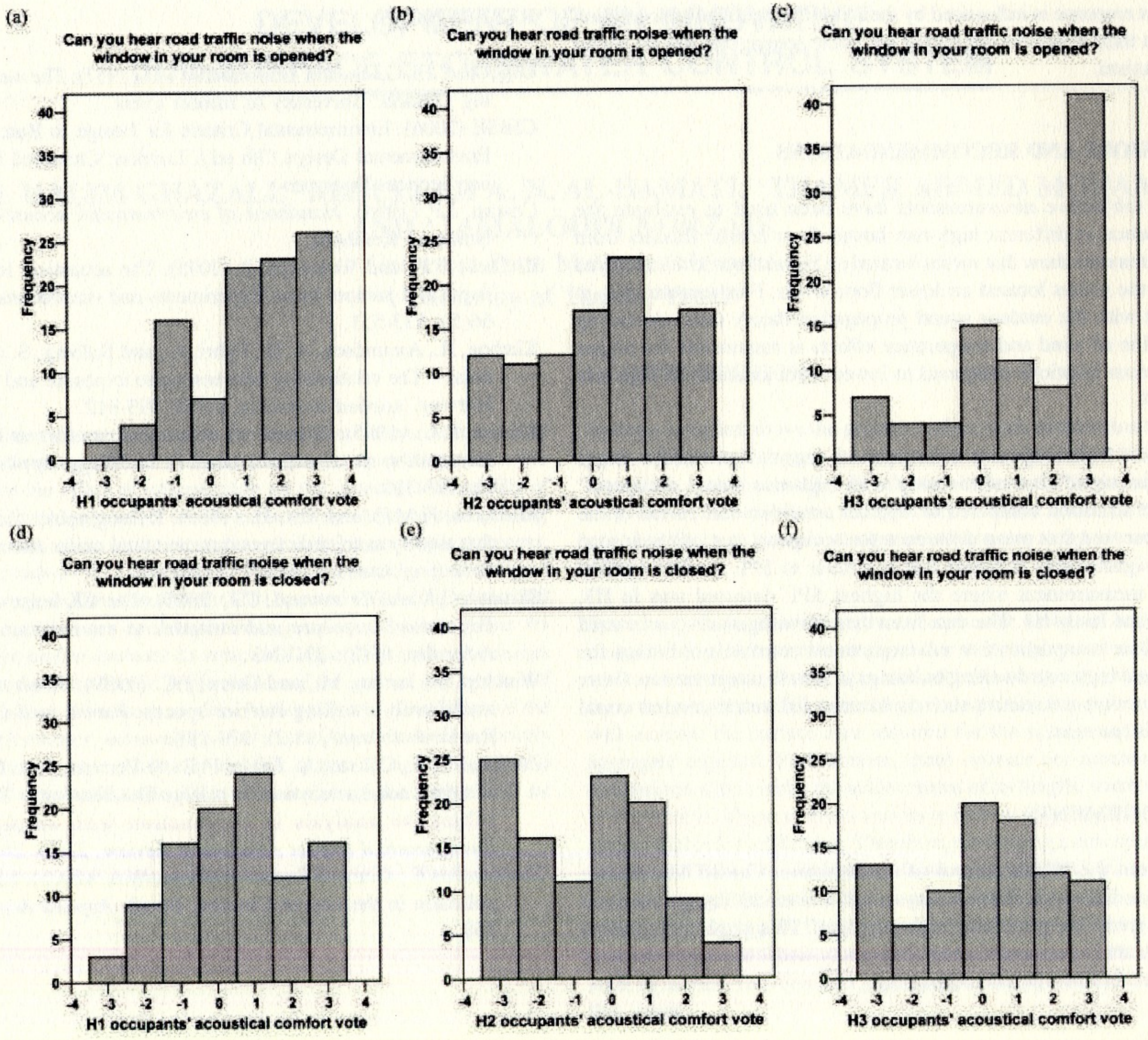

Figure 2: Acoustical comfort when windows were opened and closed collected from occupants in three high-rise hostels, i.e.: (a) window opened in HH1; (b) window opened in HH2; (c) window opened in HH3; (d) window closed in HH1; (e) window closed in HH2; & (f) window closed in HH3.

acoustic comfort response is influenced by their environmental noise condition especially when their windows are facing the noise source that has no sound proofing mechanism.

5. CONCLUSIONS AND RECOMMENDATIONS

Objective and subjective measurements have been used to evaluate the acoustical influence at different high-rise hostel floor levels. Results from objective measurements show that rooms located on higher floor levels received more SPL than the rooms located on lower floor levels. Furthermore, it is in good agreement with the outdoor sound propagation theory thus concluding that a combination of wind and temperature effects is responsible for higher SPL in higher room locations compared to lower room locations in high-rise hotels measured.

Meanwhile, results from subjective measurements suggest that window usage presents the most significant relationship with high-rise hostel occupants' acoustic comfort sensation compared to weather condition and period of the day. It is also observed that mean difference for occupants that can hear road traffic noise is significantly different that is similar to SPL results obtained from objective measurement where the highest SPL detected was in H3, followed by H2 and lastly H1. The data from these investigations can be used to develop a more comprehensive environmental comfort prediction for naturally ventilated high-rise dwelling buildings in hot climate countries. Other environmental comfort parameters such as thermal and visual comfort could be included in the process.

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