THE EFFECTIVENESS OF USING FURNISHINGS TO IMPROVE THE HOUSING ACOUSTIC OF LOW-COST FLATS IN MALAYSIA

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Abstract
The acoustical performance of high-rise residential housing in the marketplace of Malaysia is under satisfactory as the residents are consistently dealing with internal and external noises. One of the most practical solutions to improve housing indoor acoustic comfort is by introducing furniture and furnishings which can absorb sound energy. The objective of this research is to evaluate and compare the acoustical performance of public low-cost multi-storey housing (PPR low-cost flats) in Kuala Lumpur in unfurnished and furnished conditions. Three scenarios: (1) empty housing unit without any furnishing, (2) housing unit furnished with basic furniture, (3) housing unit furnished with basic furniture and extra furnishings (carpet and curtains), were modelled in Google SketchUp and exported into ODEON Room Acoustic Software 13.0 for simulation. Results were then compared in the parameter of Reverberation Time (RT) and Speech Transmission Index (STI). Based on results, scenario (3) demonstrated the best improved result in overall after evaluating the performance of acoustical criteria. The more the furniture and furnishings with higher absorption coefficient introduced in the housing unit, the lesser the RT and higher STI, resulting in a better indoor acoustical environment.

Keywords: Indoor Furnishings; Multistory Housing Acoustic; Reverberation time; Simulation; Speech Transmission Index.

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INTRODUCTION

A house is the most important place in everyone's life as it is the place which provides each individual the ultimate rest physically and mentally away from all the distractions from the world. It is also the place where families carry out social activities as well as a place to entertain guests and friends to foster relationship. Therefore, a good housing should be able to provide occupants with good quality of living in every aspect including the acoustical aspect. Studies showed that acoustical comfort will affect the well-being of residents and noise annoyance will lead to serious health issue. Researches show that a noise greater than 50 dB is harmful to people's normal daily work and life (Wang et.al., 2018). The detailed hazards are: per auricular discomforts like earache, tinnitus and hear loss, and even deaf; harmful to cardiovascular and cause cardiovascular diseases. A study done by Halim, H et.al. (2017), which reveals that the residential areas of Klang Valley faced severe noise pollution problem whereby the noise level measured had exceeded permissible limit by WHO and Malaysia Guidelines. Despite the importance of housing acoustics, there is a lack of such studies in Malaysia. Therefore, the purpose of this research is focusing on evaluating the acoustical performance of housing in Malaysia, specifically the multi-storey low-cost housing in Kuala Lumpur.

Low-cost housing is a type of housing whereby the total cost of housing is being priced at an affordable range to those dwellers with low income. Throughout the Asian countries, almost all major cities are filled with high density housings that are of high-rise scale. Several policies had been implemented in the whole Malaysia with regards to low cost housing, one of them is the "Zero Squatter by 2005" policy. In line with the implementation of this policy, the government has been implementing the People's Housing Project (Program Perumahan Rakyat or PPR) scheme to provide sufficient affordable housing for the relocation of squatters in major town and cities. In Kuala Lumpur, 34,106 units of low-cost housing are being distributed through 24 PPR schemes. According to Goh, A. T. et. al. (2011), all the PPR scheme of high-rise scale followed the same design template, whereby there are 20 units per floor on an 18-storey high rise flat (refer Figures 1 and 2). Due to same planning layout, the acoustical performance of the housing unit will too be similar. Therefore, only one case study of PPR housing in Kuala Lumpur was being chosen to examine its indoor acoustical performance in this research.

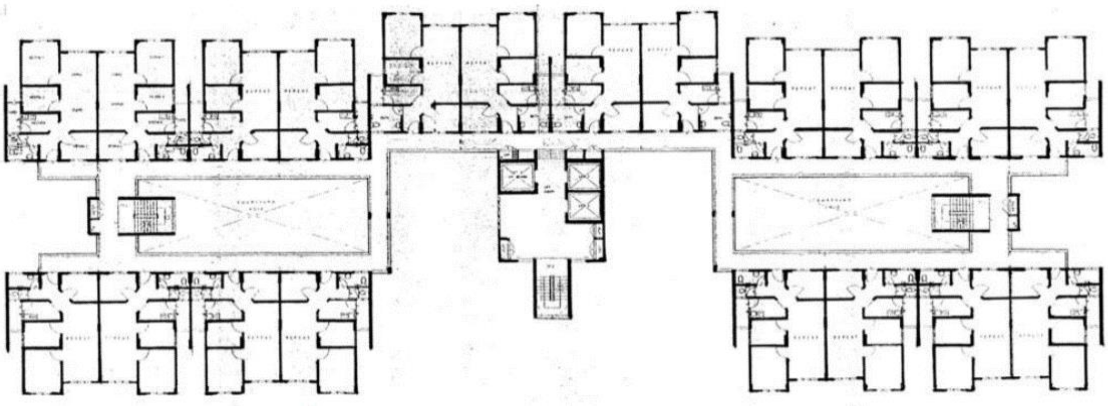


Figure 1: Typical Level Layout Plan for 18-storey PPR Low-cost Flat
(Source: Housing Department, DBKL, 2006)

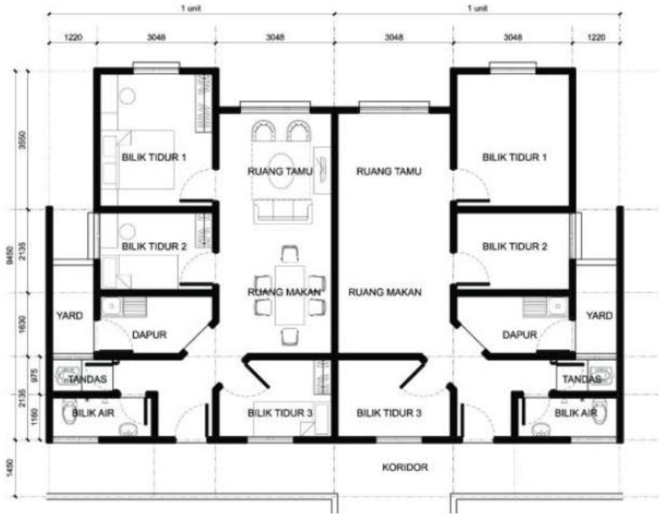


Figure 2: Standard PPR Housing Unit Floor Plan
(Source: Goh, A. T. et. al. 2011)

Generally, researchers showed that the acoustical performance of high-rise residential housing in the marketplace of Malaysia is under satisfactory as the residents are consistently dealing with internal and external noises. This phenomenon implies that the acoustical comfort of high-rise housing seems to be ignored by most developers and architects in the country and requires serious attention. The selected case study of PPR low cost housing scheme in this research, which is of multi-family housing typology, is expected to face the same issue in terms of the acoustical comfort of the housing unit. There are many researches being done to investigate on the quality of PPR housing in Malaysia. One of the studies done by Mohd-Rahim, F. A. et.al. (2019) revealed about the residents' satisfaction in terms of location, amenities, safety aspects, maintenance provision, housing management and social participation of the neighborhood. However, there is no research being done to investigate the indoor acoustical performance of PPR low-cost flats in Kuala Lumpur.

According to Azmi, N. et. al. (2019), the overcrowding problems in these low-cost flats will affect the quality of life of the occupants. High density living environment with more human activities will surely increase the level of noise pollution. The dwellers of PPR low-cost housings are mostly of low income and suffers from poor health status. Hence, a healthy housing environment is crucial for the urban poor to prevent further health deterioration.

Goh, A. T. et. al. (2011) reported sound insulation for indoor environment having possibility correlation on quality living environment in PPR low-cost housings. Furthermore, strong correlation of sound pollution can be found for outdoor environment. Moreover, annoyance of residents in units may arise from outside noises with difference sound pressure level in wide range of frequencies e.g. floor impact noise (Nazli et. al.,2006), traffic noise (Halim, H et.al., 2017), etc. These noises will travel or transmitted to the building itself. Interfering noise resulted to influence speech intelligibility in everyday living conditions. On the other hand, reverberation time is also an important factor similarly as speech intelligibility for indoor environments. Reverberation times below than 1 s are necessary for good speech intelligibility in smaller rooms. However, it is more desirable for sensitive groups, such as the elderly, which a reverberation time below 0.6 s is needed for adequate speech intelligibility even in a quiet environment.

With regards to the noise pollution in both indoor and outdoor environments (Kim, 2015), acoustical engineers have come out with several ways to reduce noise level, which include soundproofing treatments to the wall, floor and ceiling, as well as the use of furniture which can absorb sound energy. Nevertheless, the low-income occupants of PPR low-cost housings in Kuala Lumpur will not be able to afford the costly soundproofing treatments to their house. They are only capable of paying for basic home furniture for daily living, dining and sleeping with minimal furnishings such as curtains and carpet etc. Therefore, basic furniture and furnishings are the most practical solutions to improve the acoustical comfort in the PPR housing unit.

Meanwhile, furniture selection and its arrangement within a housing unit are largely determined by the dweller's lifestyle as well as the housing layout. Based on a research done by Saruwono et. al. (2012), there is two (2) types of furniture arrangement in a living space of apartment-type family housing in the context of Kuala Lumpur suburb. They are Type (A) Clustered furniture arrangement, defines the living, dining and entertainment zones and Type (B) Centralised furniture arrangements along the four sides of the wall and the living, dining and entertaining zones are not clearly delineated (Figure 3). The furniture arrangement may be not representing the actual condition for PPR housing unit, but it is shown a clear definition of preferences and placement based on functional reasons that configuration can be adopted in this study. Meanwhile, the authors also identified the common items available in each living room are the settees, coffee table, dining table and chairs, small table for the television and shoe rack.

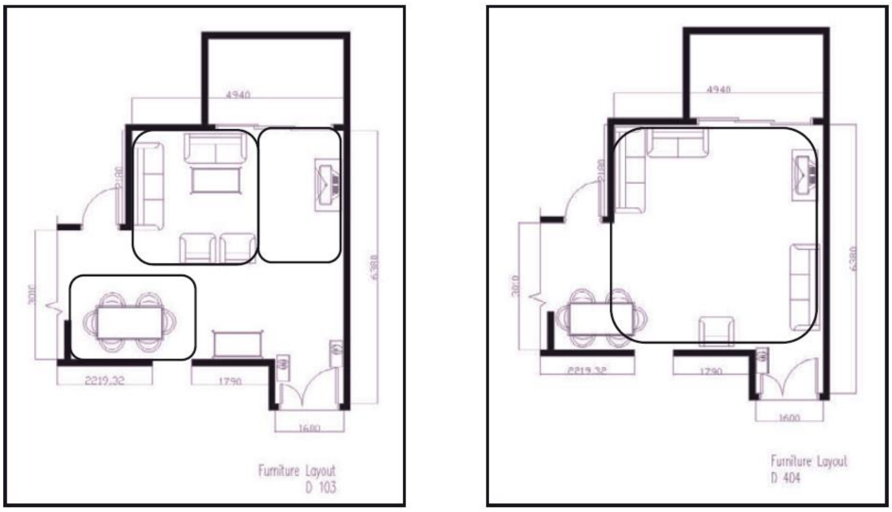


Figure 3: Type (A) Clustered furniture arrangement & Type (B) Centralised furniture arrangements
(Source: Saruwono et. al., 2012)

According to studies, different interior furnishings will influence the acoustical performance of an indoor space. Therefore, the purpose of this research was to evaluate and compare the indoor acoustical performance of the selected case study of PPR low-cost housing unit by emphasizing the effect of furnishings with fixed plan layout and building materials used based on three scenarios: (1) empty housing unit without any furnishing, (2) housing unit furnished with basic furniture, (3) housing unit furnished with basic furniture and extra furnishings, by using computer simulation ODEON Room Acoustic Software 13.0. Different noise sources were assigned in different rooms and the receivers were distributed evenly throughout the housing unit. Two evaluation criteria: i) Reverberation Time (RT), and ii) Speech Transmission Index (STI) which are important parameters for housing acoustic evaluation were measured. The data collected were analyzed and compared against the recommended acoustic standards available internationally. The result would illustrate the effectiveness of using house furniture and furnishings in improving the acoustical performance of PPR housing unit.

Reverberation Time (RT)

After the source of a sound has stopped, it will take some time for the sound to diminish. The rate of the decay of the sound will be affected by factors such as room geometry and the dampening in the room. "The reverberation time (RT60) is defined as the time it takes for the sound energy to diminish by 60 dB" (Nilsson et al, 2008).

According to Erik Ipsen, the Acoustic Design Specialist and Head of R&D at Knauf Danoline, the recommended reverberation time (RT) is 0.9s for homes and 0.5s for bedrooms (Sound of Architecture staff, 2015).

Speech Transmission Index (STI)

Speech Transmission Index is used as a physical measure to the quality of speech transmission. The highest index of STI is value 1, indicating a perfect speech intelligence, while the closer the value approaches zero, the more information is lost. Figure 4 shows that good STI rating range from 0.6 to 0.75.

Figure 4: Speech Transmission Index and Common Intelligibility
(Source: Steeneken HJ et al, 1980)

RESEARCH METHOD

The primary purpose of this research was to evaluate and compare the acoustical performance between an unfurnished and furnished PPR low-cost housing unit. Research method started with the selection of PPR housing layout and furniture layout. Only one site was selected as case study: PPR Kg. Muhibbah Puchong with 17-storey high-rise flat (Figure 5) due to the reason that all PPR high rise scheme shared similar design in terms of the unit and story layout. There are eight (8) blocks with total of 2844 units (KPKT, 2018). The case study is located about 200m from the main road and express highway. It is also surrounding by residential and commercial environment with nearby of river. The construction method of these flats is post and beam construction with brick in fill wall. The height of each floor is 2.8m. This information was obtained from Housing Department, DBKL.

In terms of selection of furniture layout, Clustered Furniture Arrangement is chosen to be modeled in the typical PPR housing unit due to the restriction of the design which is narrow and rectangular. Common items found in Clustered Furniture Arrangement which include the settees, coffee table, dining table and chairs, small table for the television and shoe rack were incorporated into the 3D model of the housing unit for simulation. Apart from that, basic furniture for kitchen (kitchen cabinet) and bedrooms (mattress, table and chair) were also built in the 3D model.

Three 3D models of the PPR housing unit were modelled using SketchUp. Each model represented one scenario. In Scenario 1, the 3D model comprised of an empty living area with ceiling, wall, floor, window and doors. Meanwhile in Scenario 2, all the selected furniture was being added into the initially empty 3D model. In Scenario 3, extra furnishings such as carpet and curtain were being incorporated to investigate the effect of addition.

After the completion of room modeling in Google SketchUp, models were exported into ODEON software. When assigning a new room in ODEON, its validity was checked. The check performed by ODEON involved checking whether the data were consistent and in the correct format. This involved water tightness test of the room through 3D Billiard window. Water tightness test is to check whether the room model is completely enclosed in order to ensure the accuracy of simulation. Figure 5 showed the 3D model of a furnished PPR housing unit in Google SketchUp. Table 1 shows a description of each scenario.

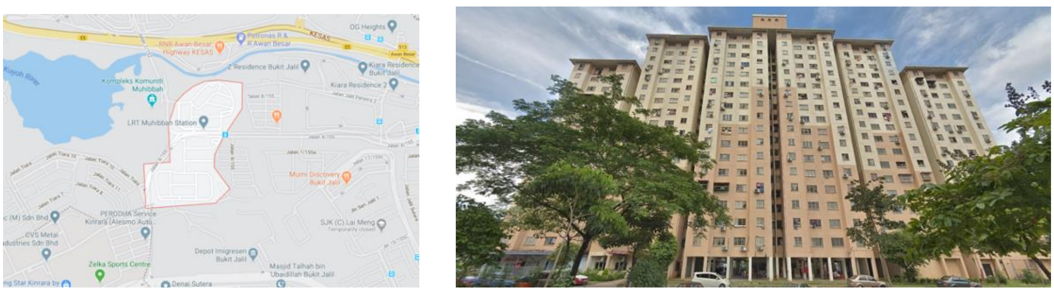
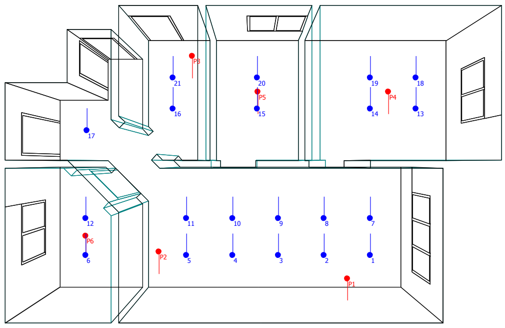
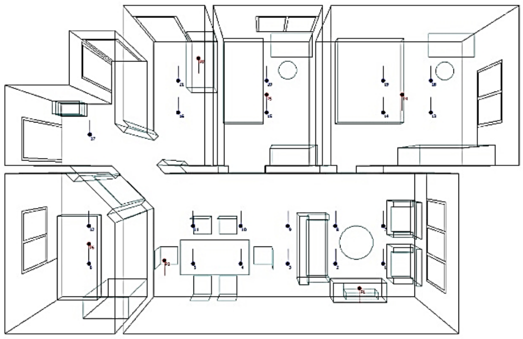
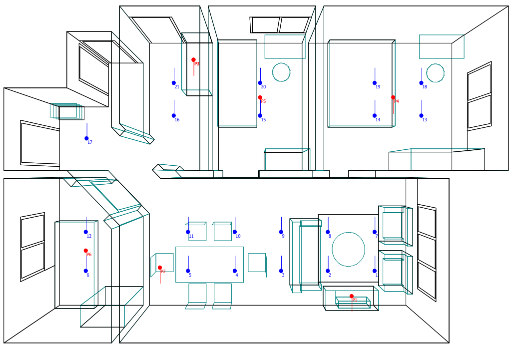


Figure 5: Location and photo of the case study
(Source: Google Map, 2020)

Table 1: Description of each Scenario

Scenario	Distribution of sound source and receiver points	Indoor condition
Scenario 1		i) furniture: none ii) finishes applied: smooth concrete painted ceiling, plaster painted brick wall, smooth concrete as floor finish iii) wooden door iv) glass window v) additional furnishing: none
Scenario 2		i) furniture: - house entrance: shoe rack - living room: sofa set, TV, TV table cabinet, coffee table - dining room: dining table & chairs - kitchen: kitchen cabinet - bedrooms: mattress, table, stool& wardrobe ii) finishes applied: smooth concrete painted ceiling, plaster painted brick wall, smooth concrete as floor finish *(same as Scenario 1)* iii) wooden door *(same as Scenario 1)* iv) glass window *(same as Scenario 1)* v) additional furnishing: none
Scenario 3		i) furniture *(same as Scenario 2)*: - house entrance: shoe rack - living room: sofa set, TV, TV table cabinet, coffee table - dining room: dining table & chairs - kitchen: kitchen cabinet - bedrooms: mattress, table, stool & wardrobe ii) finishes applied: smooth concrete painted ceiling, plaster painted brick wall, smooth concrete as floor finish *(same as Scenario 1)* iii) wooden door *(same as Scenario 1)* iv) glass window *(replaced by curtain)* v) additional furnishing: - carpet in living room - curtain in living room and all bedrooms

Materials assignment

For this research, building materials used are chosen as close as possible to the real material based on the on-site observation and report provided by Ministry Housing and Local Government (KPKT, 2018). The appropriate materials used from ODEON material library for this research are shown in Table 2.

Table 2: Description materials used for scenario

Type of surface	Material from ODEON library				
Floor & ceiling	*Material 102, Smooth concrete, painted or glazed*				
	Frequency (Hz)	250	500	1000	2000
	Abs. Coefficient	0.01	0.01	0.02	0.02
Wall	*Material 1000, Smooth brickwork with flush pointing, painted*				
	Frequency (Hz)	250	500	1000	2000
	Abs. Coefficient	0.01	0.02	0.02	0.02
Window	*Material 10006, Glass, ordinary window glass*				
	Frequency (Hz)	250	500	1000	2000
	Abs. Coefficient	0.25	0.18	0.112	0.07
Door	*Material 10007, Solid wooden door*				
	Frequency (Hz)	250	500	1000	2000
	Abs. Coefficient	0.10	0.06	0.08	0.10
Shoe rack, wardrobe & kitchen cabinet	*Material 3068, Plywood paneling, 1cm thick*				
	Frequency (Hz)	250	500	1000	2000
	Abs. Coefficient	0.22	0.17	0.09	0.10
Chair (dining room & bedroom)	*Material 11059, Wooden or padded chairs or seats (per item) in m^2*				
	Frequency (Hz)	250	500	1000	2000
	Abs. Coefficient	0.00	0.15	0.00	0.18
Table (living room, dining room & bedroom)	*Material 11060, Empty desk*				
	Frequency (Hz)	250	500	1000	2000
	Abs. Coefficient	0.13	0.14	0.17	0.18
Sofa	*Material 11063, Standard leather couch*				
	Frequency (Hz)	250	500	1000	2000
	Abs. Coefficient	0.35	0.73	0.95	0.89
Television	*Material 11061, Empty plastic or metal chairs (per chair) in m^2*				
	Frequency (Hz)	250	500	1000	2000
	Abs. Coefficient	0.00	0.14	0.00	0.14
Mattress	*Material 11064, Standard mattress*				
	Frequency (Hz)	250	500	1000	2000
	Abs. Coefficient	0.40	0.81	0.99	0.89
Curtain	*Material 8006, Curtains hung 90mm from wall*				
	Frequency (Hz)	250	500	1000	2000
	Abs. Coefficient	0.06	0.39	0.63	0.70
Carpet	*Material 7007, 10mm soft carpet on concrete*				
	Frequency (Hz)	250	500	1000	2000
	Abs. Coefficient	0.08	0.21	0.26	0.27

Define sources and receivers

Before simulations were carried out by ODEON, sound source and receiver were defined orderly. For this study, three single point sources that are commonly found in a living area were being defined, each represents different noise source based on mainly activities happened in specific spaces.

Table 3 shows the actual noise level of these noise sources according to the Center for Hearing and Communication (CHC) in New York city, and the type of point sources files used in ODEON software. Table 3 showed the ODEON point sources used for this study. The source files chosen may not be identical with the related activities due to the limitation of available point sources files in ODEON but the closest sound pressure level (dBA) are chosen based on selected frequencies for representing each noise source and their related activities.

Apart from 6 points sources, 17 receivers were set 1.2m above the floor and distributed evenly across all spaces. Figure 6 showed the respective locations of sources and receivers in the ODEON model, with red dots indicating the sources and blue ones are the receivers.

Table 3: ODEON point sources used for this study

Noise sources related to activities	Noise Level (dBA) based on CHC	Point Source Files in ODEON								Sound Pressure Level (dBA)
Living Room		*BB93_RAISED_NATURAL.SO8*								
TV Audio, Social Activities, etc	70.0	**Frequency**	125	250	500	1000	2000	4000	8000	78.0
		dB	59.0	69.5	74.9	71.9	63.8	57.3	48.4	
Dining Room		*BB93_NORMAL_NATURAL.SO8*								
Normal Conversation, Dining, etc	60.0	**Frequency**	125	250	500	1000	2000	4000	8000	72.1
		dB	55.0	65.3	69	63	55.8	49.8	44.5	
Kitchen		*LP1BC10E.CF2*								
Cooking, Food Preparation, Whistling Kettle, etc	80.0	**Frequency**	125	250	500	1000	2000	4000	8000	96.9
		dB	80.5	84.6	85.8	84.4	87.6	89.7	94.5	
Bedrooms		*BB93_RAISED_NATURAL.SO8*								
Children's noise e.g. playing, crying, laughing etc.	78.0	**Frequency**	125	250	500	1000	2000	4000	8000	78.0
		dB	59.0	69.5	74.9	71.9	63.8	57.3	48.3	

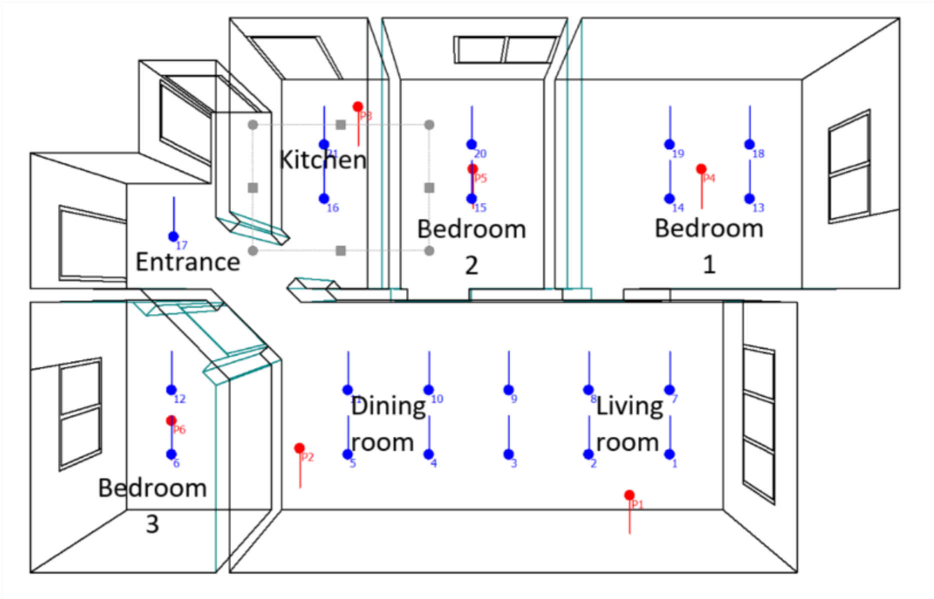


Figure 6: The locations of sources and receivers in the ODEON model.

RESULTS AND FINDINGS

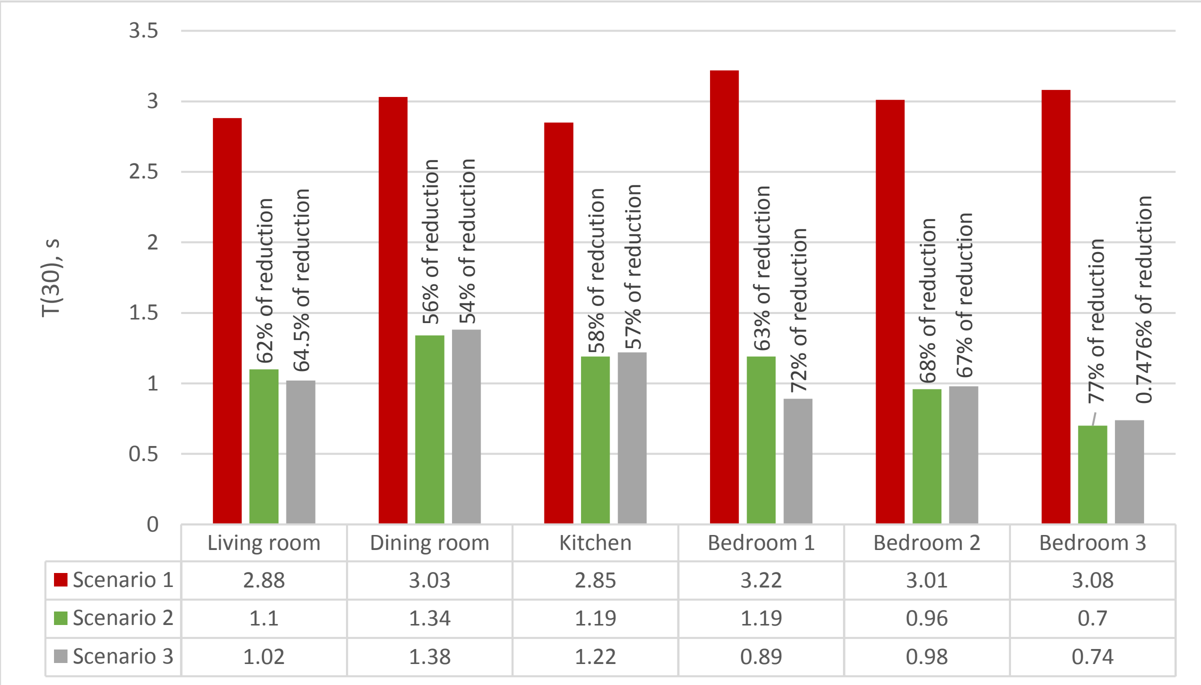
Reverberation Time

Three Scenarios of different PPR indoor furnishing condition were used to evaluate the relationship between furnishings and Reverberation time (RT) by using ODEON Room Acoustic Software 13.0 Industrial. The results were compared in the parameter of reverberation time (T30) at 1000 Hz because it is generally the most critical where the human ear is most sensitive and, in the range, where speech is produced. The RT of all rooms were being simulated. Figure 7 shows is the result of the simulation for RT in the statistic form.

Based on the Figure 7, there was a significant difference between the RT values of Scenario 1 in comparison to Scenario 2 and 3. This was due to the increased total area of absorption after furniture and additional furnishings were introduced. The highest difference was shown in bedroom 3 with a value of 2.38s (77%) between Scenario 1 and 2 caused by the addition of mattress. Meanwhile, the lowest difference was found in kitchen, 1.66s (58%) between Scenario 1 and 2 because the only furniture being added into kitchen was a kitchen cabinet with low absorption coefficient.

Besides that, it was also observed that there was minimal difference between the RT of Scenario 2 and 3, ranging from the lowest of 0.02s (2%) for bedroom 2 and the highest of 0.3s (25%) for bedroom 1. Theoretically, according to Sabine's formula T = 0.161 (V/A), any increase on total sound absorption area will reduce the reverberation time as demonstrated in the difference between Scenario 1 and 2. The increase of total absorption area in Scenario 2 was 24.37m^2.

However, only living room and bedroom 1 showed a decrease in RT value after additional furnishings were introduced in Scenario 3 as compared to Scenario 2. The total increase of absorption area due to the additional furnishings i.e. carpet and curtains, was 8.74m^2. It can be deduced that this increase of absorption area was too small to cause significant impact to the reverberation time. In all scenarios, none of the RT achieved the good housing standard of having 0.9s for living area and 0.5s for bedrooms. There can be complementary aspects that can explain this phenomenon: (i) the main building materials used mainly reflective properties; (ii) the total area of absorptive materials provided by additional furnishings was smaller than total area of building materials used in this study.



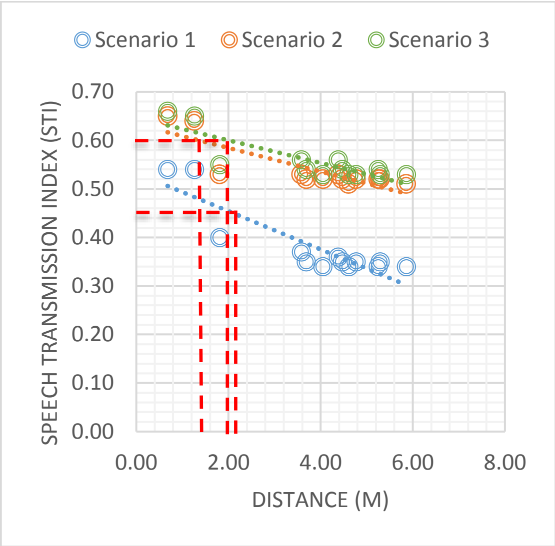
	Living room	Dining room	Kitchen	Bedroom 1	Bedroom 2	Bedroom 3
Scenario 1	2.88	3.03	2.85	3.22	3.01	3.08
Scenario 2	1.1	1.34	1.19	1.19	0.96	0.7
Scenario 3	1.02	1.38	1.22	0.89	0.98	0.74

Figure 7: Comparison of Reverberation Time (RT) against noise source location for each Scenario

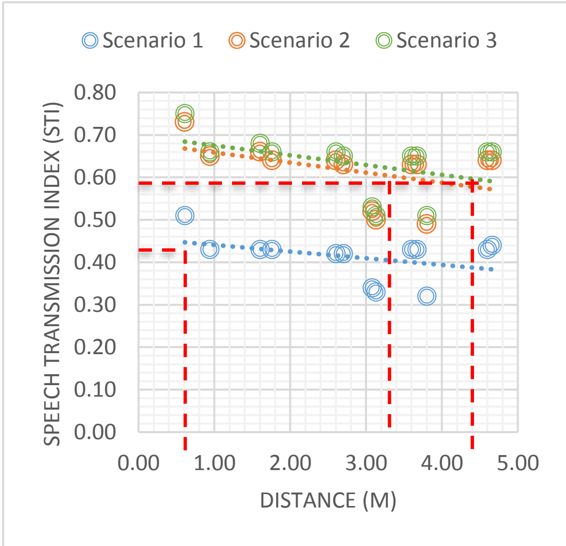
Speech Intelligibility

For this acoustic parameter, only the rooms with highest activity level in a housing unit were being simulated and compared for their results. These rooms are living room, dining room and kitchen. They are the main source of sound in daily living of the house occupants. Figure 8 shows the impact of Speech Intelligibility among the 3 scenarios for different sound sources. Generally, the STI readings dropped as the distance between sound source and receivers increased. It is observed that Scenario 1 only achieved fair STI reading at the distance between 0.6m to 2.2m. Scenario 2 achieved good STI reading at the distance between 1.7m to 3.25m. Meanwhile Scenario 3 had the best STI results, it achieved good STI reading at the distance between 2m to 4.3m.

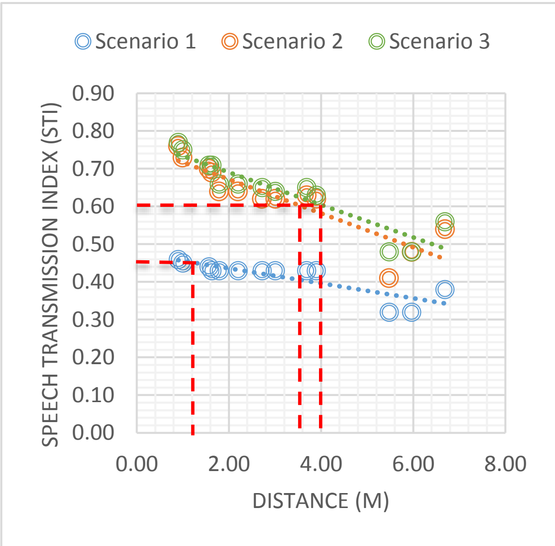
The results showed that the heavy activity zone of an unfurnished PPR low-cost flat housing unit can hardly achieved fair speech intelligibility whereas the presence of basic furniture allowed it to achieve fair to good speech intelligibility. In the scenario where extra furnishings such as carpet and curtain were applied, the speech intelligibility also improved accordingly due to the ability of material properties in shortens the duration of reflected sounds.



a) Sound source 1: Living room



b) Sound source 2: Dining room



c) Sound source 3: Kitchen

Figure 8: Comparison of STI between noise source versus scenario.

CONCLUSION

In this study, an extensive simulation of effectiveness using furnishing in improving acoustical quality at PPR housing unit has been performed onto various scenarios. A series of simulation in different scenarios of housing unit revealed that the Scenario 3 showed the best improved result in overall after evaluating the performance of acoustical criteria which include Reverberation Time (RT) and Speech Transmission Index (STI). The more the furniture and furnishings with higher absorption coefficient introduced in the housing unit, the lesser is the RT and the higher is the STI, resulting in a better indoor acoustical environment. Further simulation investigations on frequencies-based study with different type of construction materials in achieving the recommended RT standard are now being pursued intensively. The possibility of comparison between simulation and field measurement also warrants further investigation for further develop and confirm these initial findings.

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