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Indoor Environmental Comfort in Malaysian Urban Housing

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ABSTRACT

In Malaysia, terraced houses have been rapidly constructed since 50 years ago and account for 44% of the existing urban housings. However, these houses have very limited use of natural ventilation and daylighting due to openings with small window-to-floor ratio. The deep plan design causes gloomy indoor spaces, low air change rate and poor indoor air quality. Studies showed that indoor environments have major impact on occupants' well-being. Thereby this study evaluates the effects of indoor comforts on occupants' perceived health in Malaysian typical terraced houses. Survey of terraced houses in Johor Bahru, Malaysia was conducted using questionnaire. Various terraced houses were studied to identify the critical comfort and health issues in terraced housing. The relationships among occupants' perceived comforts, health and behavior were studied. The variance of types of terraced house was also analyzed. The findings demonstrated significant linear relationships between indoor comfort and health. However, occupants' behavior did not give significant impact on thermal comfort. This study concludes that it is very essential to improve indoor comfort in Malaysian typical terraced houses through tropical design strategies to enhance occupants' well-being.

Keywords: Thermal Comfort, Visual Comfort, Natural Ventilation, Daylighting, Health, Tropical

1. INTRODUCTION

Terraced houses have been rapidly constructed in Malaysia since 1960's due to the increasing demands for housing. It accounts for 44% of the existing housing stocks in urban areas in Malaysia as of year 2000 (MDS, 2000). This housing typology is adopted from the British terraced house design which is also known as "row house" (Omar *et al*., 2010). This type of house has relatively narrow and deep plan with limited fenestration at the front and rear facades (**Fig. 1**). The housing layout is planned repetitively and monotonously in rows of rectangular lots with clear boundaries (Hashim and Rahim, 2008). The typical spatial characteristics of the terraced house in Malaysia have been remained the same for decades. Hence, the sustainability of these terraced houses in tropical climate needs to be further investigated.

In Malaysia, the annual maximum intensities of solar radiation falling on horizontal and vertical surfaces are about 1000 and 850 W/m^2 respectively for east and west facing surfaces (Ossen, 2005). The major building envelopes of terraced houses that are exposed directly to solar radiation are the roofs. The openings at the façades are the very limited sources for daylighting although the external illuminance in tropical climate is as high as 130 klx (Lim *et al*., 2012a). Besides, natural ventilation is also constrained by the small Window-to-Floor Ratio (WFR). Tropical climate has very low wind speeds, thus the range of indoor air velocity in low rise buildings in Malaysia is only between 0.04 m/s and 0.47 m sec^{-1}, which is inadequate for indoor air movement (Hui, 1998).

Sadafi *et al*. (2011) had evaluated the thermal effects of internal courtyard in a tropical terrace house in Malaysia. Internal courtyard allows better natural ventilation but increases the radiation heat gain. Therefore, efficient openings and shading devices are needed.

Kubota *et al*. (2009) investigated the effects of night ventilation technique on indoor thermal environment for terrace houses in Malaysia. The findings concluded that indoor humidity control during the daytime such as by dehumidification would be needed when the night ventilation technique is applied to Malaysian terraced houses. Otherwise, full-day ventilation would be a better option compared with night ventilation.

Fig. 1. Example of typical Malaysian terraced house

Zakaria (2007) had studied sustainable housing for residential-industrial neighbourhoods in Malaysia by looking into several indoor environmental quality (IEQ) aspects. Questionniare surveys, physical measurements and interviews were conducted for housing area in Pasir Gudang, Johor, Malaysia. The findings recommended sustainable housing strategy for residential-industrial neighbourhoods. However, the focus of the study was on the IEQ especially air quality due to pollution from industries. The reseacher did not emphasize the impact of other IEQ aspects on occupants' health.

Previous research on Malaysian terraced houses had been focusing on building physical performances. However, studies have shown that indoor environmental performances, including thermal and visual, have major impact on occupants' well-being (Salnikov and Karatayev, 2011; Bluyssen, 2010; Choi *et al*., 2012; Todorovic and Kim, 2012; Zamani *et al*., 2013). According to the Rio Declaration, the Principle 1 stated, "Human beings are at the center of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature". Thereby, this study presents the impacts of indoor environments on occupants' comfort and health in existing Malaysian typical terraced houses. It is important to understand the relationship between the occupants' comfort and health.

2. MATERIALS AND METHODS

Study of occupants' perceived comfort and health in Malaysian terraced houses was conducted. Drop-off and pick-up questionnaire method was employed to conduct survey in twelve terraced housing estates in Johor Bahru, Malaysia on 23-30 May 2013. Random purposeful sampling method was employed in order to cover various types of terraced houses including intermediate, corner and end units (**Table 1**). Due to the limited time and manpower to collect the data, the total number of samples collected was only 31 houses among the housing estates. However, it fulfilled the minimum need of samples for statistical analysis (Roscoe, 1975).

The questionnaire was divided into 5 major sections. Section 1 was intended to evaluate the occupants' comfort in relation to natural ventilation, indoor temperature and air quality. Section 2 was to obtain feedbacks from occupants regarding to the use of daylighting for task performance and visual comfort. Section 3 investigated the behaviour of the occupants to use and control natural ventilation and lighting. Section 4 aimed to evaluate the occupants' psychological and physical health. Finally, Section 5 was to collect opinions from occupants regarding to the elements of their houses which need to be improved. All the questions were using 1 (lowest) to 5 (highest) scales.

The data collected were analysed using statistical methods. First of all, the mean of each question in Section 1, 2 and 4 were computed in order to identify the most critical comfort and health issues. Then, the correlations among Sections 1 to 4 were analysed. Spearman's rho correlation was employed for this analysis since the data was qualitative in nature and fell under the category of non-parametric test. The correlation tests were important to understand the significant relationships among the variables.

The variance of types of terraced house (intermediate, corner and end units) was also studied using Mann-Whitney U test. It was a non-parametric test as well as data were qualitative in nature. It was to find out the impact of different types of terraced house on occupants' perceived comforts. Since the designs of corner unit and end unit are identical with similar openings at the sides, these 2 types of terraced house were combined as 'corner unit' for the statistical analysis. All the tests were analysed at a default confidence level of 95%. Finally, the mean of each question in Section 5 were calculated to distinguish the most significant things to improve in terraced houses according to occupants' perceptions.

3. RESULTS

With the total of 22 questions regarding to thermal comfort and visual comfort, there were 7 questions scored mean below 3.00 (average) as shown in **Fig. 2**. The lowest score was Air movement in Toilet with mean 2.58. This indicated that most of the respondents were unsatisfied with the natural ventilation in toilet which is very essential to assure fresh air and hygiene. Meanwhile, the second and third lowest scores were yielded by indoor temperature comfort during afternoon and noon times.

Table 1. Summary of respondents according to types of terraced house

No.	Type	No. of house(s)	Percentage
1	Intermediate Unit	20	64.50
2	Corner Unit	6	19.40
3	End Unit	5	16.10
	Total	31	100.0%

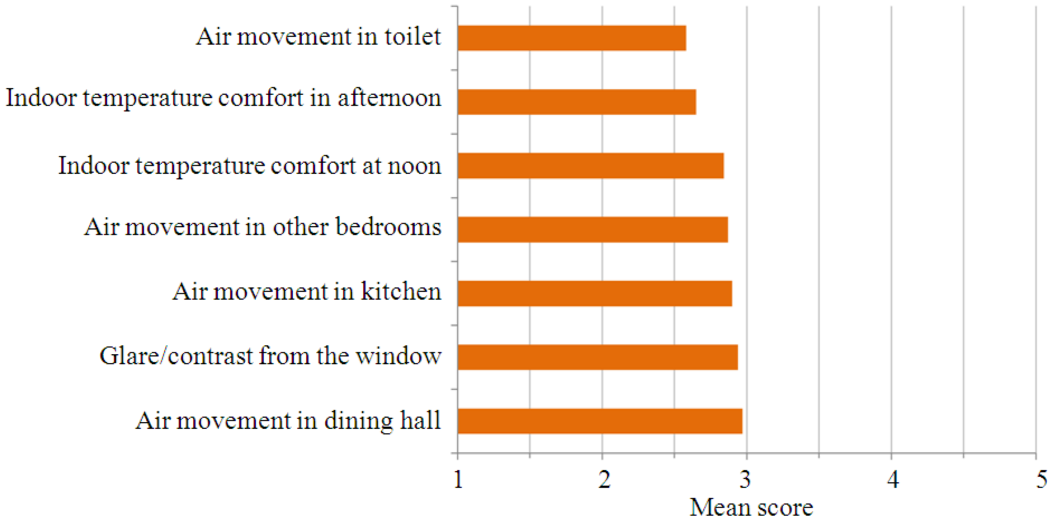

Fig. 2. Critical comfort issues with mean < 3.00

Among all the 7 lowest scores, only 1 of them was related to visual discomfort, thus thermal comfort issues were more significant than visual comfort issues in the terraced houses. Air movement and indoor temperature were the major thermal comfort issues.

Figure 3 indicates 5 health issues with the lowest mean scores. The mean scores for health issues ranged higher than the mean scores for comfort issues. Even the lowest score for health issue which was related to quality of sleep without air-conditioning yielded 3.23 (slightly above average). Therefore, most of the respondents were satisfied with their health conditions. Among the 5 lowest scores, 3 of them were related to psychological health which influenced their minds and emotions. Among all the physical health issues, blocked or runny nose symptom obtained the lowest score. This issue can be related to poor ventilation and air quality as well as discomfort indoor temperature. Meanwhile, the physical health issue with the second lowest score (lethargy and tiredness) can be caused by poor ventilation, insufficient indoor lighting level and lack of daylighting.

Table 2 shows the correlations among Section 1 to 4. The correlations between Natural Ventilation and Thermal Comfort (Section 1) and Daylighting and Visual Comfort (Section 2) were analysed. The results showed that there was a positive linear relationship between these 2 variables. The value of 'sig. (2-tailed)' (0.052) was more than the predetermined alpha value (.05/2 = 0.025), thus the stated null hypothesis was accepted. There existed inadequate evidence to show that there was significant positives linear relationship between them.

The correlations between comfort and behaviour were analysed. The results show that there was a positive linear relationship between Natural Ventilation and Thermal Comfort (Section 1) and Occupants' Behaviour (Section 3). The value of 'sig. (2-tailed)' (0.084) was more than the predetermined alpha value (0.05/2 = 0.025), thus the stated null hypothesis was accepted. There existed inadequate evidence to show that there was significant positive linear relationship between these 2 variables.

The correlations between Daylighting and Visual Comfort (Section 2) and Occupants' Behaviour (Section 3) demonstrated significant positives linear relationship. The value of 'sig. (2-tailed)' (0.029) was close to the predetermined alpha value (0.05/2 = 0.025), thus the stated null hypothesis was rejected. This conclusion was made at the significance level of 0.05.

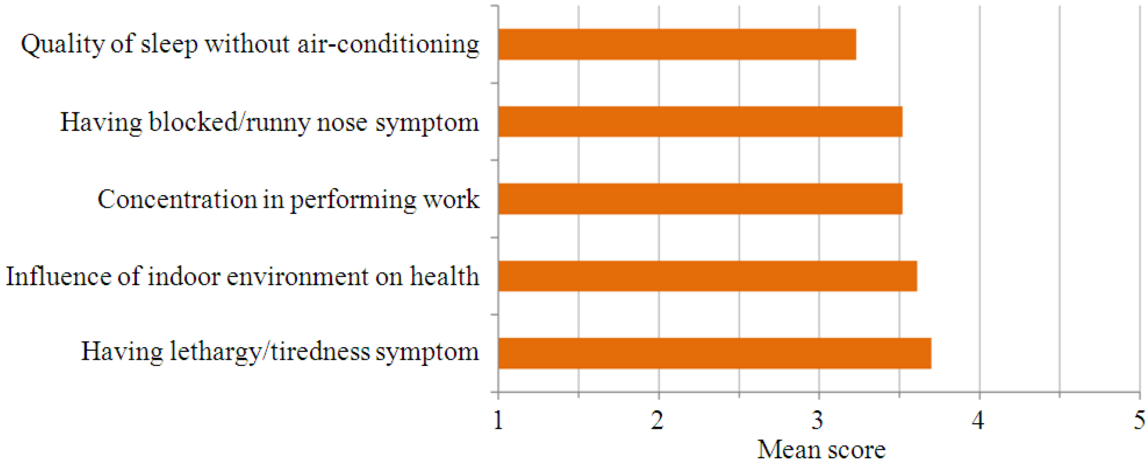

Fig. 3. Critical health issues with lowest mean scores

Table 2. Correlation among all Section 1-4

	Spearman's RHO		Section 1	2	3	4
Section	1-Natural ventilation and	Correlation coefficient	--	0.352	0.315	0.488**
	thermal comfort	Sig. (2-tailed)	--	0.052	0.084	0.005
	2-Daylighting and	Correlation coefficient	0.352	--	0.392*	0.452*
	visual comfort	Sig. (2-tailed)	0.052	--	0.029	0.011
	3-Occupants' behaviour	Correlation coefficient	0.315	0.392*	--	0.256
		Sig. (2-tailed)	0.084	0.029	--	0.164
	4-Occupants' Health	Correlation coefficient	0. 488**	0. 452*	0.256	--
		Sig. (2-tailed)	0. 005	0. 011	0.164	--

*; Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed).

The analysis showed a positive linear relationship between Natural Ventilation and Thermal Comfort (Section 1) and Occupants' Health (Section 4). The value of 'sig. (2-tailed)' (.005) was less than the predetermined alpha value (.01/2 = .025), thus the stated null hypothesis was rejected. There existed adequate evidence to show that there was significant positives linear relationship between Natural Ventilation and Thermal Comfort and Occupants' Health. The better the Natural Ventilation adn Thermal Comfort in the household, the healthier they would become. This conclusion was made at the significance level of 0.01.

The analysis also indicated that there was a positive linear relationship between Daylighting and Visual Comfort (Section 2) and Occupants' Health (Section 4). The value of 'sig. (2-tailed)' (.011) was less than the predetermined alpha value (.05/2 = .025), thus the stated null hypothesis was rejected. Hence, there was adequate evidence to show significant positives linear relationship between Daylighting and Visual Comfort and Occupants' Health. The better the Daylighting and Visual Comfort in the terraced houses, the healthier the occupants would become. This conclusion was made at the significance level of 0.05.

Variance of 'intermediate' units and 'corner' units (including end units) was studied using Mann-Whitney U test. **Table 3** summarises 12 items which showed significant differences between intermediate and corner units. All these items had values of 'Asymp.Sig (2-tailed)' which were smaller than the predetermined alpha value (0.05/2 = 0.025), thus the stated null hypothesis was rejected. There existed adequate evidence to show that there was significant differences between intermediate and corner house on these items. Among the 12 items, 6 of them were related to health while 4 of them were related to daylighting and visual comfort.

Table 3. Summary of items which showed significant difference between house types

Section	Question	Item	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)	Exact Sig. (2 *(1-tailed Sig.))
1	4	Annoyed by bad smell	48.000	258.000	-2.649	0.008	0.009[b]
2	1a	Sufficient daylighting brightness in Living Hall	48.500	258.500	-2.623	0.009	0.009[b]
	1c	Sufficient daylighting brightness in Kitchen	51.000	261.000	-2.638	0.008	0.014[b]
	1f	Sufficient daylighting brightness in Toilet	49.000	259.000	-2.607	0.009	0.011[b]
	3b	Using daylighting to perform work with computer	56.500	266.500	-2.317	0.021	0.025[b]
3	7	Frequency to look at view through window	57.000	267.000	-2.246	0.025	0.029[b]
4	1	Influence of indoor environment on health	54.000	264.000	-2.520	0.012	0.020[b]
	5a	Having Dry/Watering Eyes symptom	47.000	257.000	-2.817	0.005	0.008[b]
	5b	Having Blocked/ Runny Nose symptom	53.500	263.500	-2.430	0.015	0.018[b]
	5c	Having Dry/Irritated Nose symptom	56.000	266.500	-2.347	0.019	0.025[b]
	5d	Having Chest Tightness symptom	52.500	262.500	-2.544	0.011	0.016[b]
	5g	Having Lethargy/ Tiredness symptom	42.000	232.000	-2.817	0.005	0.006[b]

a. Grouping Variable: TYPE
b. Not corrected for ties.

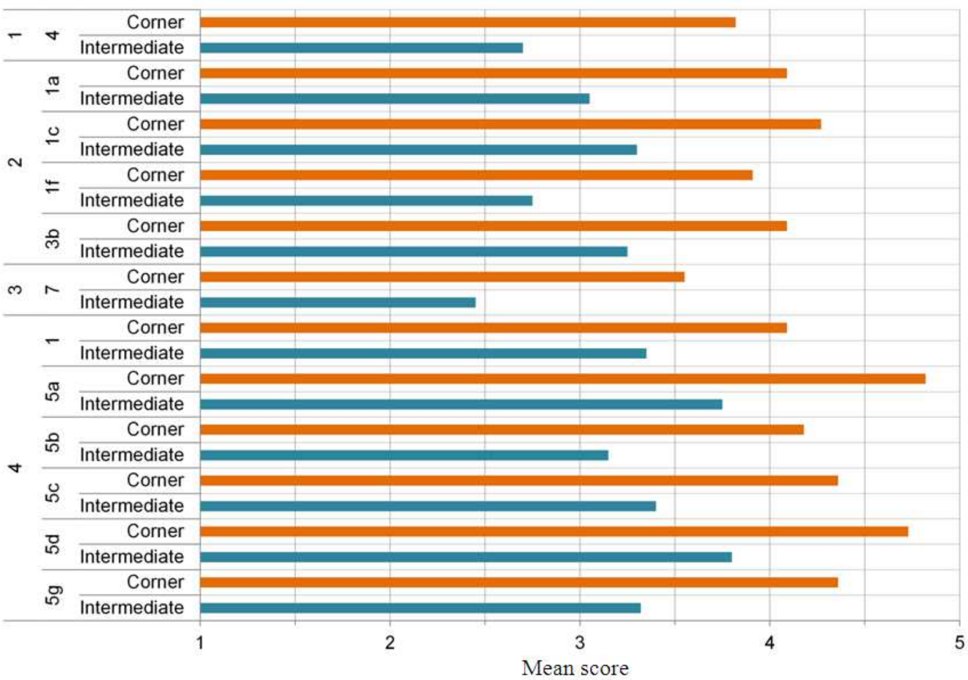

Fig. 4. Comparison of mean scores of the 12 significant items between corner and intermediate units

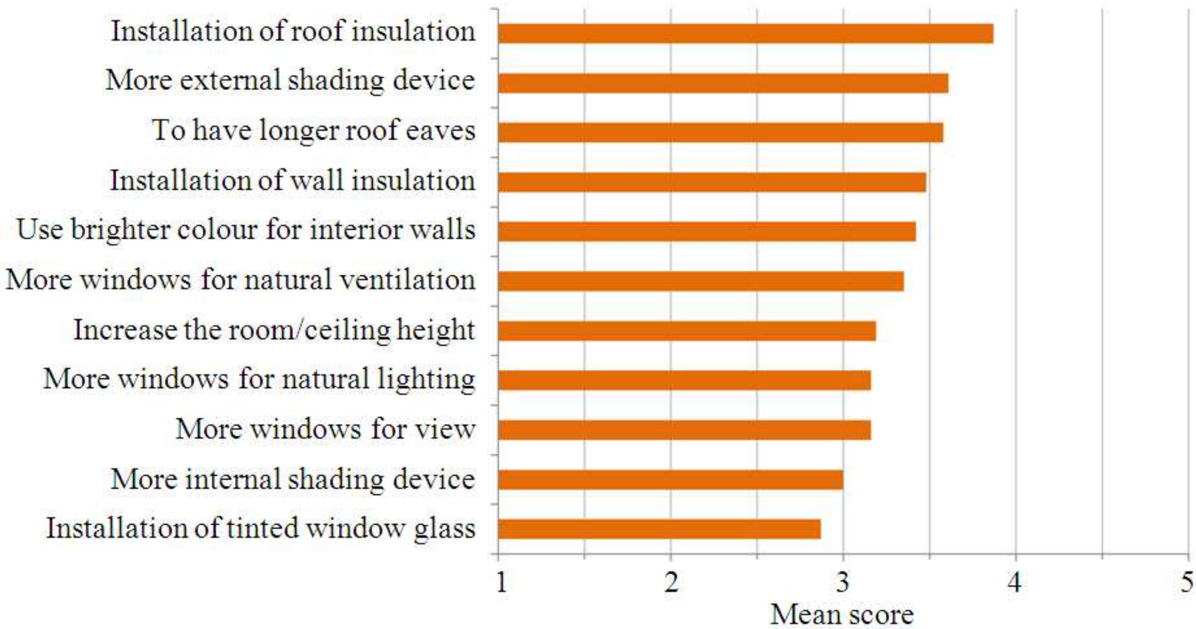

Fig. 5. Mean scores of occupants' perception on aspect to improve

Further comparison was made to investigate the mean scored by intermediate and corner units respectively in order to identify which house type obtained better performances (**Fig. 4**). Evidently, corner units consistently yielded higher scores in comparison with intermediate units for all the items. This signified that corner units with WFR higher than intermediate units performed better in both natural ventilation and lighting, thus provided healthier indoor living environment to the occupants. Having openings on the side walls also encouraged occupants in corner units to appreciate the view through windows more frequently (mean score 3.55) than the occupants in intermediate units (mean score 2.45).

Occupants' perception on the aspects that need to be improved in their terraced houses were analysed in order to identify the ranking of the items. **Figure 5** shows the mean scores of each item. Among all the 11 items, the most significant aspect to improve according to occupants' perception was the installation of roof insulation with mean score of 3.87. Besides, many respondents also agreed that having more external shading device was important as the mean score was 3.61. Meanwhile, not many respondents intended to have more windows for natural ventilation, lighting or view. The lowest mean score was 2.87 for "installation of tinted window glass".

4. DISCUSSION

From the results of critical comfort issues, it showed that natural ventilation problem was more serious than daylighting in terraced houses. This can be rationalized that most of the activities or tasks performed in terraced houses do not demand high level of brightness such as leisure, cooking and sleeping. Apart from that, most terraced houses are naturally ventilated; hence the issues of air movement and indoor temperature are very essential. Moreover, the outdoor temperature is high and air velocity is low in Malaysia (Hui, 1998).

According to Malaysian Uniform Building by-law (UBBL), every room for residential purposes shall be provided with daylighting and natural ventilation by windows having a total area of not less than 10% of the clear floor area of such room and 5% of them shall be open able. On the other hand, every bathroom or toilet shall be provided with daylighting and natural ventilation by openings having a total area of not less than 0.2 m^2 and such openings shall be open able (Lembaga Penyelidikan Undang-undang, 2013). However, the finding of this study reflects that the current natural ventilation and daylighting requirements as imposed by the authority are inadequate for occupants' well-being.

Although all the studied houses fulfilled the UBBL's requirement, most of the occupants were still dissatisfied with the use of natural ventilation. Among the 7 most critical comfort issues, 4 of them (57.1%) were related to insufficient air movement (**Fig. 2**). These results evidenced that the 5% open able WFR requirement is inadequate to achieve sufficient air movement for thermal comfort. Moreover, the air movement in toilet is the most critical issue (with the lowest mean score) despite the minimum 0.2 m^2 openings for ventilation as required by the authority.

On the contrary, the issue of daylighting was glare or contrast from the window instead of insufficient brightness. The distribution of daylighting was not uniform due to the diminishing effect. This finding is corresponding to the previous research on tropical daylighting which concluded that the challenge in utilising tropical daylighting is not insufficient quantity but is poor quality due to contrast and glare (Lim *et al*., 2010; 2012b).

Despite the mean scores of thermal and visual comfort issues were low; the mean scores of health problems were relatively high (above 3.00-average). The analysis of health issues demonstrated that indoor living environments in terraced houses affect the physiological health more than physical health. Therefore, occupants may feel unhealthy due to dissatisfaction with the indoor environments. As suggested by previous research, psycho-social effects, which relate to emotional and behavioural responses, influence how occupants perceive and behave in certain environment (Loewenstein *et al*., 2001; Bluyssen, 2009; 2010). For instance, fear of the disease can cause more damage than the disease itself. However, the factors of this scenario need to be further investigated.

By employing Spearman's rho correlation tests, the findings evidenced significant linear relationship between occupants' comfort and health. The better the comfort level in the terraced houses, the healthier the occupants feel. Thus, thermal and visual comforts give significant impact to occupants' perceived health. Nevertheless, the correlation tests proved that the relationships between behaviour and thermal comfort as well as behaviour and health are less significant. Only the relationship between behaviour and visual comfort is significant. This could be due to the control on natural ventilation in terraced houses is more limited in comparison with daylighting. Thus, thermal comfort and health levels in the terraced houses are not much affected by the occupants' behaviour such as controlling the air-conditioning, window opening.

The findings also demonstrated that different types of terraced houses give different impacts to the occupants' comfort and health. The variance of intermediate and corner units proved that the existence of openings on the side walls (for the corner or end units) affects the daylighting and visual comfort as well as occupants' health significantly. In overall, corner units performed better than intermediate units in all the significant items due to higher WFR. Therefore, increasing the opening area is important to improve natural ventilation and lighting, thus enhancing the occupants' perceived health.

5. CONCLUSION

This study presents a preliminary study of occupants' perceived comfort and health in Malaysian terraced houses. The study suggests the following conclusions:

- Thermal comfort issues are more critical than visual comfort issues in Malaysian typical terraced houses
- The requirement of 5% WFR for natural ventilation as stated in UBBL is inadequate for occupants' comfort and health, thus further review is needed
- Most of the occupants feel unhealthy psychologically instead of having physical symptoms
- There is significant linear relationship between perceived comfort and health. The better the level of comfort the healthier the occupants perceived
- The variances of intermediate unit and corner unit are substantial especially in the use of daylighting
- Proper design of the terraced houses at the first place is essential as it determines how the occupants can manage the indoor environment to achieve comfortable and healthy living environment

Although terraced houses have been increasingly developed in Malaysian urban area since decades ago, this study has signified the effect of poor natural ventilation and daylighting on occupants' perceived comfort and health. For further research, more efforts are needed to look into more specific design variables that influence the occupants' perceived comfort and health. Detailed questionnaire and more samples are needed to draw a concrete conclusion on the above matters. This is very important to provide sustainable and healthy indoor living environment in the terraced houses.

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