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Occupants' Utilization of Natural Ventilation: A Study of Selected Terrace House Designs in Hot-humid Climate

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ABSTRACT

With increased time spent indoors and demand for enhanced comfort levels, energy consumption in homes is rising mostly for cooling, particularly in hot-humid regions. Natural ventilation is seen as an alternative to mechanical cooling as it is totally independent on energy and has been reported to be of high potential. However, little information is available on the utilization of natural ventilation in individual living spaces in different house designs. Therefore, this paper aims to investigate occupants' utilization of natural ventilation in living spaces under different terrace house designs in hot-humid climate and also the relationship between the openings and occupants' satisfaction with natural ventilation. Five (5) different terrace house types in Putrajaya, Malaysia with different opening design characteristics were selected for the study. A total of 298 households from these house types were surveyed and results show that occupants mostly open their windows during the daytime to capture breeze from outside despite the fact that they owned air-conditioners. In terms of occupants' level of satisfaction with indoor ventilation when utilizing natural ventilation, majority rated neither satisfied nor unsatisfied. Further regression analysis reveals that this level of satisfaction is significantly related to opening sizes that are in accordance with the law, duration of opening windows and AC ownership. Findings from this study will shed more light on behavioural pattern of occupants of residential buildings towards natural ventilation provisions and highlight the importance of conforming to the law governing them.

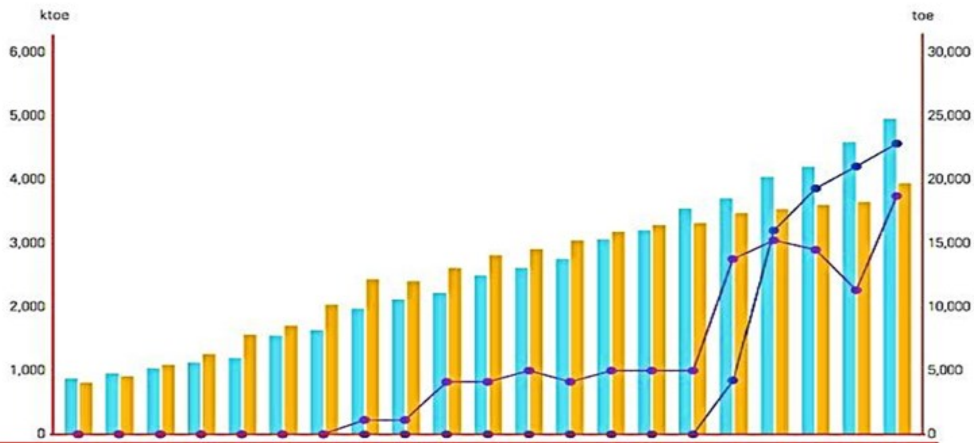
1. Introduction

The rate of the world's energy consumption is on the increase. According to the US Energy Information Administration (EIA) (Smith et al., 2011), world energy consumption will increase by 53% from 2008 to 2035, which will on average increase continually by 2% annually. Consuming about 40% of total world energy, the largest percentage of energy use all over the world can be accounted for in buildings (Santamouris, 2005; Chan et al., 2009). Energy used in buildings is mostly for heating, cooling, lighting and operating electrical equipment (Santamouris, 2005) with ventilation and air-conditioning contributing highly to this total consumption (Chan et al., 2009). The impact of air conditioner (AC) usage on energy demand in terms of electricity has posed a serious problem in almost all countries (Santamouris, 2005), since 68% of electricity is generated from the burning of fossil fuels (Smith et al., 2011) which is the primary source of greenhouse gases emissions.

Southeast Asian countries such as Malaysia, is characterized with high temperature and humidity all year round, therefore cooling is required in order to achieve the required thermal comfort. Due to this, buildings normally opt for mechanical cooling strategies that inevitably use considerably large amount of electricity. Presently, the rate of electricity consumption in Malaysia increases as the year progresses. As shown in Figure 1, the 'residential and commercial' sector in Malaysia consumes the highest amount of electricity compared to 'industrial', 'transport' and 'agricultural' sectors.

An uncontrollable increase in the demand for energy in the future can also be expected as a result of increased growth in population, demand for enhanced comfort levels, and the amount of time spent indoors (Iwaro and Mwasha, 2010). As such, energy consumption needs to be controlled and energy sustainability needs to be embraced by all, putting into consideration the indoor air quality, thermal comfort of occupants and more importantly, reduction in greenhouse gas emissions. Although, energy efficient cooling strategies to reduce dependency on non-renewable energy have been implemented, these strategies cannot totally eliminate carbon emissions. Therefore, natural ventilation should be considered, as it has been revealed to have a good potential in delivering acceptable thermal comfort for both tropical and temperate climates (Haase and Amato, 2009). It is also a natural means of saving energy and an effective passive strategy to improve indoor air quality (Bangalee et al., 2012; Haw et al. 2012; Hooff and Blocken, 2010; Saadatian et al. 2012).

Due to the potential of natural ventilation, numerous studies on occupants' ventilation behavior in residential buildings had been executed (Johnson and Long, 2005; Fabi et al., 2012; Frontczak et al., 2012; Lee et al., 2012). For example, a survey of Danish residents by Frontczak et al. (2012) revealed that occupants preferred natural



YEAR	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Resid. & Comm (ktoe)	885	988	1,081	1,147	1,365	1,549	1,747	1,961	2,165	2,220	2,453	2,660	2,859	3,066	3,298	3,567	3,792	4,065	4,268	4,536	4,957
Industrial (ktoe)	830	937	1,137	1,303	1,567	1,826	2,029	2,422	2,411	2,591	2,805	2,930	3,059	3,242	3,340	3,371	3,475	3,587	3,687	3,719	3,994
Transport* (toe)	0	0	0	0	0	0	0	1,000	1,000	4,000	4,000	5,000	4,000	5,000	5,000	5,000	14,117	15,295	14,862	11,358	18,439
Agriculture** (toe)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4,886	15,991	19,393	21,080	23,920

Figure 1: *Electricity consumption by sectors in Malaysia (Suruhanjaya Tenaga Malaysia - Malaysian Energy Commission, 2010)*

ventilation above mechanical ventilation in delivering indoor fresh air by utilizing window openings more often. Similarly, Lee et al. (2012) found that most kitchen spaces of residential buildings had inadequate ventilation and the frequency and periods of opening windows by occupants were determined by indoor activities. Also, Fabi et al. (2012) summarized those factors that influence the opening of windows by occupants as: physiological (age and gender), psychological (preference in temperature and perceived illumination), social (smoking behavior and presence at home), physical environmental (climatic conditions) and contextual (building type and orientation, ventilation system and time of the day). These studies however, are limited to occupants' ventilation behavior in temperate climate hence, may not be applicable to residential buildings in hot-humid climatic conditions.

There have been numerous studies conducted to find ways of improving the ventilation effectiveness in hot and humid climate (Nugroho and Ahmad, 2005; Mohamed et al. 2008; Sadafi et al. 2008; Tahir et al. 2010) but previous studies on occupants' ventilation behavior in this context are still very limited (Wong et al., 2002; Kubota and Ahmad, 2005; Kubota, 2006; Kubota et al., 2009). Wong et al. (2002) studied occupants' ventilation behavior in Singapore public housing and revealed the occupants' adaptive measures during periods of different thermal conditions. In Malaysia, Kubota and Ahmad (2005); Kubota (2006) and Kubota et al. (2009) reported the results of a survey carried out to determine the rate at which occupants utilized air-conditioning to the detriment of natural ventilation in residential buildings. The results showed that 80% of occupants utilized window openings mostly during the daytime although AC ownership was high among households. These studies however disregard the followings: (1) ventilation in individual living space; (2) the influence of occupants' behaviour upon window opening; (3) the effectiveness of natural ventilation under different terrace house design types; and (4) occupants' level of satisfaction. The authors acknowledge that Mohit et al. (2010); Talib (2011); Teck-Hong (2012) and Zainal et al. (2012) had considered the level of occupants' satisfaction but it was only studied in relation to provided building design, indoor environment, amenities and other social economic characteristics but not in relation to natural ventilation achieved through the provided openings in the buildings.

Another important aspect is that natural ventilation provisions in Malaysian residential buildings are governed by the Uniform Building By-Laws (UBBL), 1984, issued to set a standardized building regulation for the whole of Malaysia and applicable to all local authorities and building professionals (Laws of Malaysia, 2008). UBBL law 39 (1) states that "Every room designed, adapted or used for residential…shall be provided with natural lighting and ventilation by means of one or more windows having total area of not less than 10% of the clear floor area of such room and shall have openings capable of allowing a free uninterrupted passage of air not less than 5% of such floor area." However, studies (Hanafiah, 2005; Ahmad et al., 2011) have shown that this law was sometimes ignored, meaning there were certain cases where residential buildings built in Malaysia were designed with inadequate openings for effective day lighting and natural ventilation.

This paper aims to investigate natural ventilation provisions and the extent to which occupants utilize these provisions in residential buildings in hot-humid climate, taking into account window openings in all living spaces under different house design types. The specific objectives of this paper are: (1) to identify natural ventilation provisions in different house design types in accordance to the UBBL requirement; (2) to examine occupants' ventilation behaviour in terms of window opening in all living spaces; (3) to find out occupants' reasons for utilizing window openings; and (4) to identify the factors that contribute to the level of occupants' satisfaction with indoor ventilation when utilizing natural ventilation.

This study focuses on terrace houses in Malaysia as statistics indicate that terrace houses are the largest housing type built in Malaysia (Figure 2). Furthermore, terraces houses have openings limited to two external walls (with the exception of end units), thus making natural ventilation more restricted compared to other house types. The living spaces included in the study are living/dining room, kitchen and bedrooms as they are considered as the main occupancy areas in a house.

This paper intends to reveal the implication of the non-conformity to natural ventilation provisions stipulated in the UBBL on occupants' level of satisfaction. It is envisioned that the results would facilitate the followings: (1) awareness among designers on the importance of

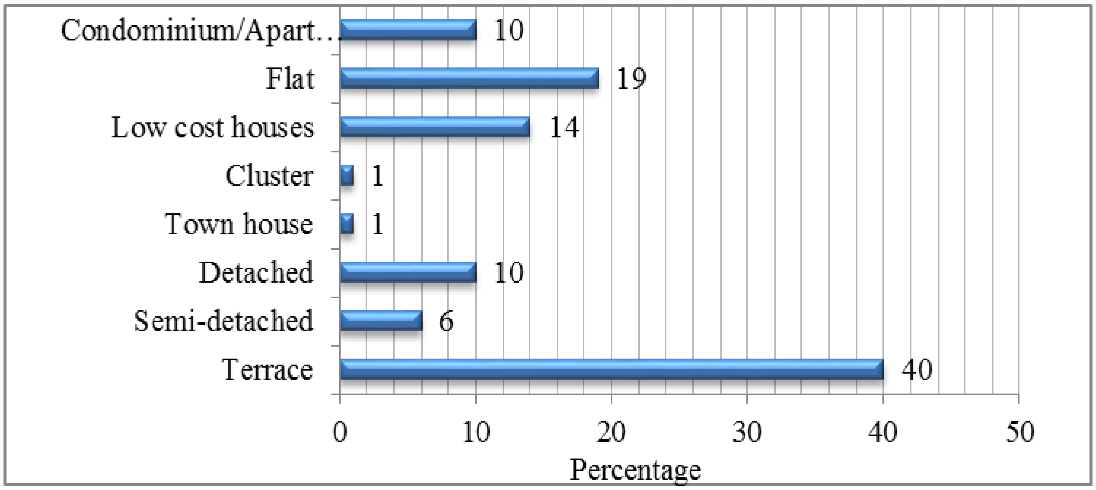


Figure 2: *Malaysian housing stock (SeoRyungJu and Bin Omar, 2011).*

conforming to the law governing natural ventilation; and (2) necessary modifications to, and enforcement on, minimum natural ventilation requirements in the UBBL. The paper first explains the method used in the study. It then presents and discusses the results of the survey. The paper concludes with some thoughts on the importance of proper ventilation behavior and UBBL natural ventilation requirements as well as some recommendations for future research.

2. Methodology

2.1 Study area

Being the new Federal Capital Territory of Malaysia, Putrajaya has residential zones which constitute as the second largest major land use, thus making it suitable as the case study area. Furthermore, houses in Putrajaya are mainly in their as-built condition as the local authority places restrictions on renovating the properties for the purpose of maintaining the uniformity of the overall designs. This ensures that all units under each design type that were selected for the study have similar characteristics. Amongst the fourteen residential precincts in Putrajaya, Precincts 11 and 14 are among those with the largest number of terrace housing units and designs. Terrace houses from these two precincts were therefore selected for the purpose of this study.

2.2 Sample selection

Site visits were conducted in both Precincts 11 and 14 with the objective of identifying different terrace house designs with varying window types, sizes, patterns and locations. During the visit, five distinct designs were identified and these were P11A2 and P11A5 in Precinct 11and P14B, P14E and, P14F in Precinct 14, with a total of 649 units of terrace houses. The selected house design types, their classification and total units are shown in Table 1.

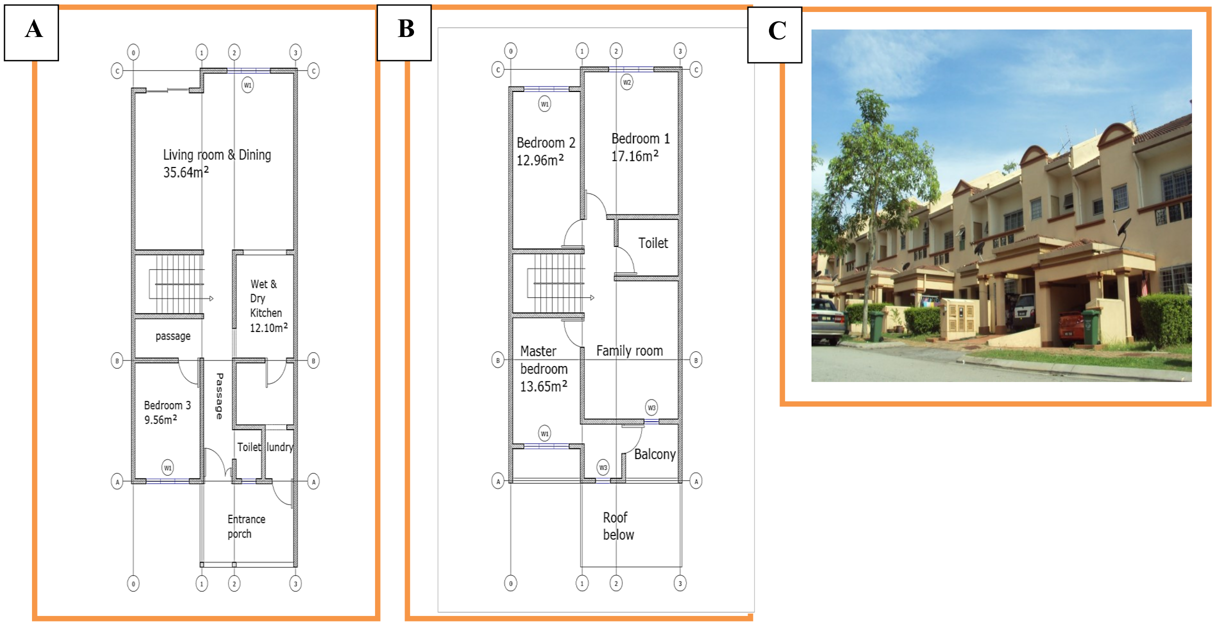
In order to give a representation of the selected house types, house units were randomly selected from the total units of 649. Bartlett et al. (2001) suggested a sample size of 235 for a population of 600 for categorical data. However, due to the variation in the total units of each selected house type, a number of 60 intermediate units were randomly selected from each house type, giving a total number of 300 house units included in the study. At the end of the survey, a total of 298 questionnaires were realized, amounting to 46.0% of the total house units in all five house design types (see Table 1).

2.3 Description of the selected house types

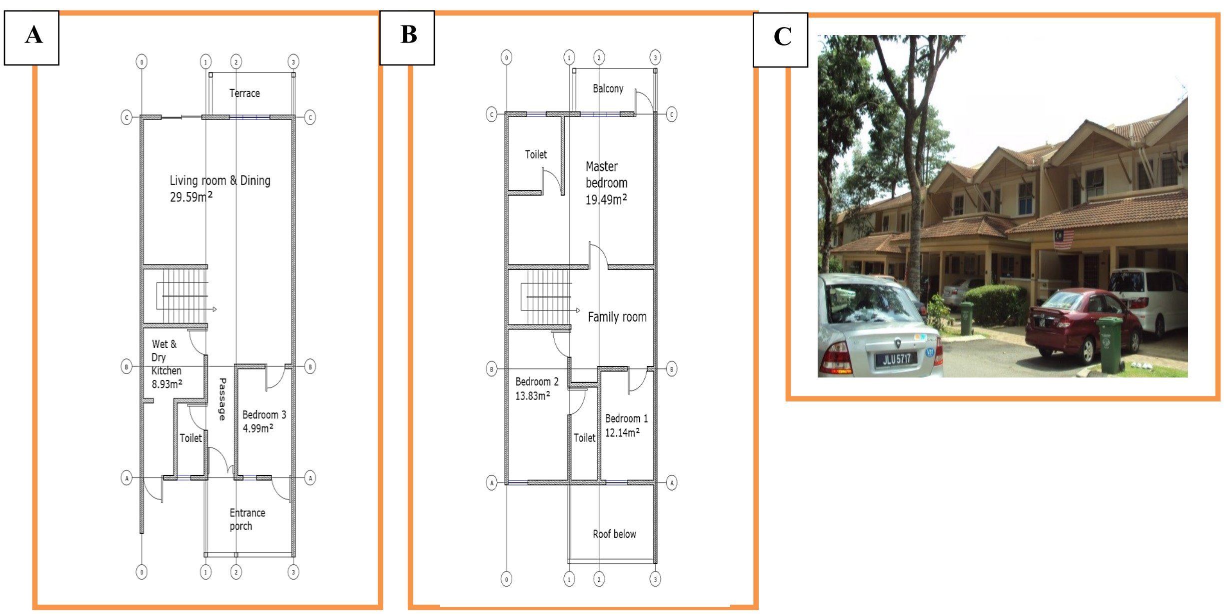
All selected house types were double-storey terrace houses, built using brick veneer construction with concrete frames and roof tiles. Typically, the housing blocks are arranged in rows separated by two lanes of driveway around 2.4m-3.0m each in width both at the front and back. Each house unit is provided with a small green space at the front of the unit (See Figure 3) whereas a communal green area is provided in each neighborhood. All of the selected house types had a total number of four bedrooms with living/dining room (with no partition separating the living and dining rooms), kitchen and bedroom 3 located on the ground floor, while on the first floor were master bedroom, bedroom 1 and bedroom 2. Each unit of house types 1, 2, 3,

Table 1: *Classification of the house types and their total units*

Precinct	Precinct 11		Precinct 14			Total
Design type	P11A2	P11A5	P14B	P14E	P14F	
Design classification	Type 1	Type 2	Type 3	Type 4	Type 5	
Total units	136	215	94	120	84	649
Questionnaire distributed	60	60	60	60	60	300
Questionnaire collected	60	60	58	60	60	298

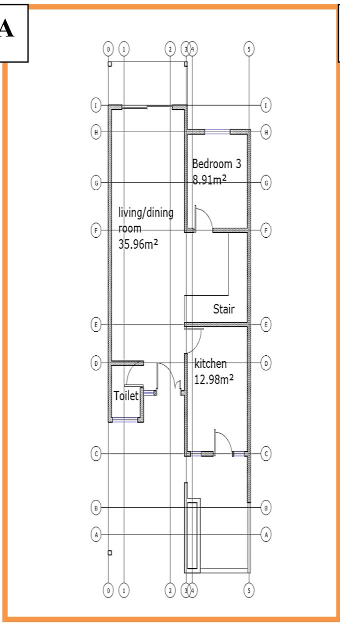


(a) House Type 1

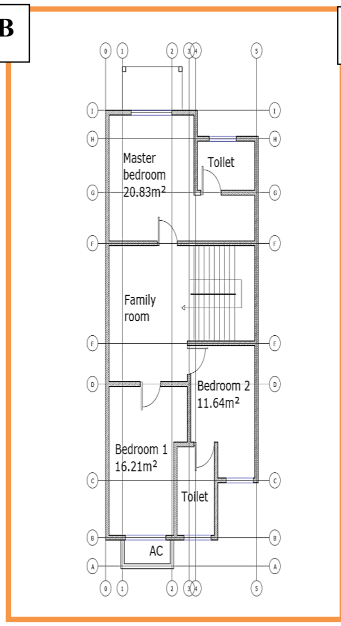


(b) House Type 2

A



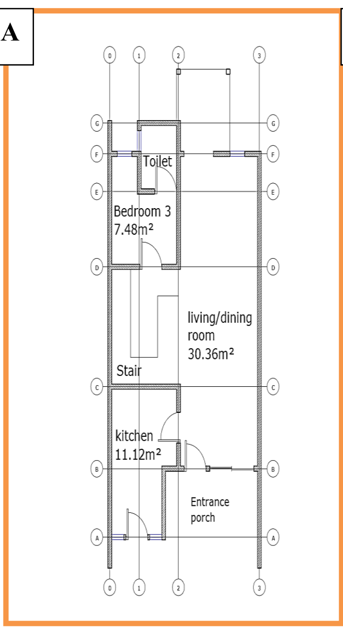
B



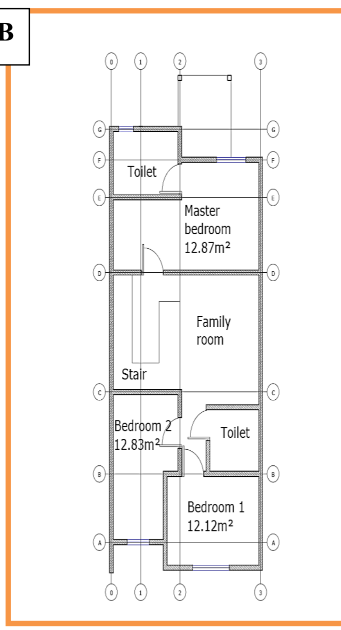
C

(c) House Type 3

A



B



C

(d) House Type 4

(e) House Type 5

Figure 3: *Perspectives and floor plans of selected terrace house types (A represents Ground floor, B, First floor and C, perspective view)*

4, and 5 had a built up area of 105.16 m^2, 93.94 m^2, 153.30 m^2, 129.93 m^2 and 166.44 m^2 respectively. Among all of the house types, only type 5 had an internal courtyard. The inclusion of internal courtyard helps to improve the ventilation effectiveness of terrace houses because window openings facing the courtyard facilitate temperature differences between indoor and outdoor (Sadafi et al., 2008). The perspectives and floor plans of all five selected terrace houses design types are shown in Figure 3.

The living spaces of all house types had casement window type of varying sizes and in some cases, there were awning window type at the top of each casement. Apart from architectural design, the difference between these house types was in the ratio of their operable openings for ventilation provisions and wall area, as required by the UBBL, law 39(1). Table 2 represents the percentage of operable openings to the floor area in all five selected terrace house types.

Table 2 shows that only three house types (house types 1, 3 and 5) provided at least 10% operable window area in accordance with the UBBL requirement. By the same token, all house types did not have the 5% uninterrupted opening as required by the UBBL, except house type 5 where 1.41% (1.44m^2) of the total living space area was provided.

2.4 Instrumentation

Questionnaire survey provides an easy and straightforward way of gathering data due to its highly structured format (de Vaus, 2002; Gillham, 2008). Among the advantages of questionnaire are low cost, lack of interviewer bias and above all, it provides data for hypothesis testing (Gillham, 2008). Besides, previous studies on occupants' ventilation behavior (Kubota and Ahmad, 2005; Kubota, 2006; Andersen et al., 2009; Frontczak et al., 2012; Lee et al., 2012) were carried out through questionnaire surveys. Among the aspects considered in these studies include general information of occupants, means of achieving comfort, ventilation behavior, and reasons for opening and not opening windows. In order to achieve the objectives of this study, it was also considered relevant for the study to include the following two aspects: 1) occupants' level of satisfaction with window openings for natural ventilation; and 2) occupants' evaluation of natural ventilation in respect to indoor temperature, humidity, and perceived

Table 2: *Percentage of operable openings to the floor area*

House type	Total floor area of living spaces (m^2)	Operable window, m^2 (%)	Uninterrupted opening, m^2 (%)
Type 1	101.07	16.20 (16.03)	Nil
Type 2	88.97	7.56 (8.50)	Nil
Type 3	106.53	11.0 (10.33)	Nil
Type 4	86.78	7.86 (9.06)	Nil
Type 5	102.21	11.52 (11.27)	1.44 (1.41)

air quality. As such, the questionnaire used for this study was divided into four parts, as explained below.

2.4.1 General questions

Questions under this part were to obtain information about occupants' demographic characteristics including number of occupants, period of occupancy, and number of people occupying each room.

2.4.2 Means of achieving comfort

This part aimed to recognize the occupants' means of achieving comfort. Specifically, respondents were requested to indicate whether or not they were using AC and/or electric fan in each of their living spaces. Answers to these questions were useful to facilitate the examination of whether these variables had correlation with respondents' preferences and expectations.

2.4.3 Occupants' ventilation behavior

Questions under this part were those formulated to establish the survey respondents' ventilation behavior. Specifically, respondents were requested to select the period(s) in which windows were normally opened, and also the period in which AC were normally operated. These two questions were applied to each and every living space namely living/dining room, kitchen and bedrooms with the following options to choose from: 'morning', 'afternoon', 'evening', 'night', 'all the time' or 'never'. For respondents who utilized window openings, they were also asked to indicate the duration of which windows were left opened. The options given for this question were 'less than 1 hour', '1 to 5 hours', '6 to 10 hours', '11 to 15 hours', 'more than 16 hours but less than 24 hours', and '24 hours'. Furthermore, occupants were asked to choose the manner ('fully' or 'partially') in which they opened their windows. The final question under this category sought to understand the respondents' main reason(s) for opening and not opening their windows.

2.4.4 Occupants' evaluation of natural ventilation

The last part of the questionnaire consisted of two sets of questions. The first set of questions required the respondents to determine the adequacy of their homes' natural ventilation provisions in terms of the number and sizes of openings. In the second set, respondents were asked to rate their level of satisfaction in respect to indoor air temperature, humidity and the perceived air quality, as well as the overall ventilation in their homes. Responses in this set of questions were scored using the Likert scale. Not only is the Likert scale easy to construct, it also gives room for respondents to answer questions in accordance to their degree of feelings (Barnett, 1991). Indoor temperature was scored using the seven-point ASHRAE thermal sensation scale of -3 to 3 (ASHRAE Standard, 2010), where a score of "-3" represents "cold"; "-2" represents "cool"; "-1" represents "slightly cool"; "0" represents "OK"; "1" represents "slightly warm"; "2" represents "warm"; and "3" represents "hot". With regard to humidity level, respondents were requested to rate on a scale of -2 to 2 where a score of "-2" represents "humid"; "-1" represents "slightly humid"; "0" represents "neutral"; "1" represents "slightly dry"; and "2" represents "dry". Similar way was also used to rate the perceived air quality where "-2" represents "stuffy" and "2" represents "fresh". The level of satisfaction, on the other hand, was scored on a five-point scale, where a score of "1" represents "very unsatisfactory" and "5" represents "very satisfactory". Since the climatic conditions in Malaysia are relatively uniform all year round, respondents were asked to provide their evaluations in general i.e. not based on any specific climatic condition. The last question in this part was an open-ended question which provided respondents the opportunity to express additional opinions and comments regarding the openings provided in their homes.

Before the main survey, a pilot study of 30 questionnaires was conducted and 19 (63.3%) of the distributed questionnaires were recovered. All questions were well understood as they were answered without any problem; however, the assumption for validity was not met (Cronbach alpha < 0.7). Therefore, the question under 'occupants' ventilation behaviour' which addressed the manner of which occupants opened their windows (fully or partially) was dropped in order for the assumption for validity to be met (the final Cronbach alpha is 0.78). Altogether, the final questionnaire consisted of thirteen questions written in English and Malay considering the fact that not all local residents speak English. The main survey was carried out throughout October 2012. House units were chosen at random and all questionnaires were self-administered. A representative (mostly housewives) from each house unit acts as the respondent (i.e. one house unit was represented by a single occupant). The respondents were requested to give their answers based on the time when their house is occupied. The completed questionnaires were analyzed with SPSS statistical analysis program (version 16) using relevant statistical analysis, which includes: simple statistical analysis, descriptive analysis, cross-analysis, and regression analysis.

3. Results

3.1 Demographic characteristics

The period of occupancy and household size in each house type were investigated to analyze their demographic characteristics. Table 3 represents the demographic characteristics of the 298 respondents grouped under the five house design types. The average period of

Table 3: *Occupants' demographic characteristics (N = 298)*

House types	Mean	Standard deviation	Mean	Standard deviation
Type 1	4.668	2.715	4.733	1.603
Type 2	6.341	3.234	5.116	1.678
Type 3	2.788	1.036	4.396	1.632
Type 4	3.109	1.874	4.866	1.630
Type 5	0.373	0.123	3.450	1.281
(n= 298)	3.460	2.908	4.513	1.666

occupancy of the total respondents is 3.46 years while the average household size is 4.51 persons.

3.2 Occupants' means of achieving comfort

The survey reveals that majority 52.7% (or 157 out of 298) of the respondents owned at least one AC unit (see Figure 4). The remaining 47.3% (or 141 out of 298) relied solely on natural ventilation and utilised electric fan as a means of achieving comfort. Figure 5 shows that the two house types with the highest percentage of AC ownership were types 1 (56.7%) and 3 (56.9%). This means, respondents from house types 2, 4 and 5 mostly used electric fans to achieve the required comfort. Figure 6 presents the distribution of AC ownership in all living spaces. It shows that more than half (51.2%) of the respondents installed AC in their master bedroom. It is worth noting that none of the respondents installed AC in their kitchen.

Frequent distribution of the means of achieving comfort in different living spaces amongst respondents who owned AC (n=157), as shown in Table 4, indicates that almost all of them (97.5%) had AC installed in their master bedroom, whilst the remaining 2.5% had it installed in other living space(s). It is also important to note that all of these respondents who owned AC also used electric fans in all of their living spaces but fans were mostly preferred to achieve comfort in living/ dining and bedrooms 1, 2 and 3 (Table 4).

3.3 Occupants' ventilation behavior

Figure 7 provides the distribution of respondents by opening windows in different living spaces. It shows that majority of respondents opened their windows in living/dining room (93.0%) and kitchen (86.2%). In relation to windows in master bedrooms, 72.5% of the total respondents opened these windows although 51.2% of them had AC installed in this space, as indicated in Figure 6. Hence, it is apparent that master bedrooms, living/dining rooms and kitchens were among the three most naturally ventilated spaces.

Unlike master bedrooms, windows in other three bedrooms were infrequently opened despite the small percentages of respondents installed AC in these three bedrooms (refer to both Figures 6 and 7). Amongst the three bedrooms, bedroom 1 is recorded as having the most percentage of respondents (62.4%) utilising window openings while, bedroom 3 recorded the least (27.9%). Table 5 shows the percentage of respondents in respect to their period/frequency of opening windows in spaces where majority of the respondents utilised window openings (i.e. living/dining room, master bedroom, bedroom 1, and kitchen). The table reveals that most of them (44.0, 38.6, 33.2 and 42.3% respectively) opened their windows in all of these spaces during the

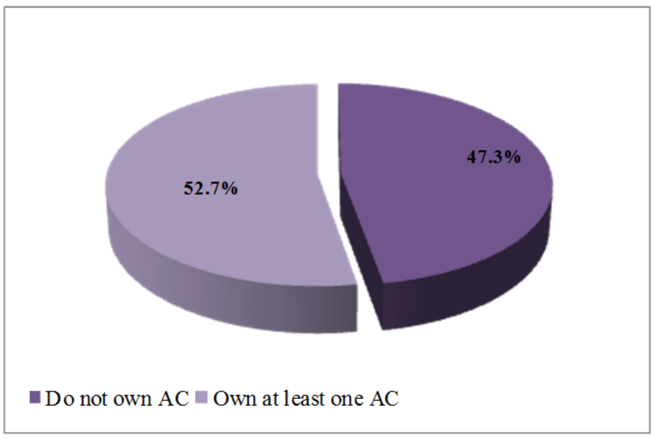


Figure 4: *Distribution of respondents by AC ownership*

Table 4: *Frequent distribution of the means of achieving comfort in living spaces among respondents who owned AC (n = 157)*

Living spaces	AC Frequency (Percent)	Fan Frequency (Percent)
Living/dining	30 (19.1)	127 (80.9)
Master bedroom	153 (97.5)	4 (2.5)
Bedroom 1	39 (24.8)	118 (75.2)
Bedroom 2	21 (13.4)	136 (86.6)
Bedroom 3	4 (2.5)	153 (97.5)

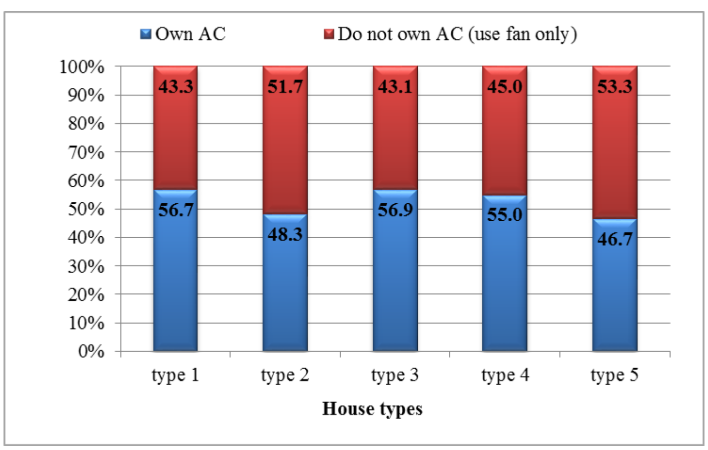


Figure 5: *Distribution of respondents by AC ownership in house types (N= 298)*

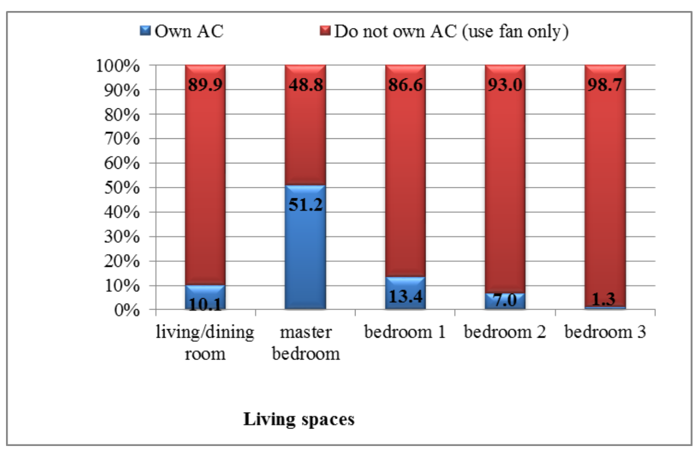


Figure 6: *Distribution of AC ownership in living spaces (N= 298)*

Table 5: *Percentage of respondents in respect to their period/frequency of opening windows in the most naturally ventilated spaces.*

	Living/dining room	Master bedroom	Bedroom1	Kitchen
Morning only	23.8	20.5	17.8	17.8
Afternoon only	4.0	1.0	0.7	3.0
Evening only	2.7	1.3	1.0	1.7
Night only	0.7	1.0	1.0	0.7
Morning & afternoon only	13.8	7.7	7.0	15.8
Morning & evening only	2.0	1.0	0.7	0.7
Morning & night only	0.3	0.0	0.0	0.0
Afternoon & evening only	1.0	0.3	0.0	0.3
Afternoon & night only	0.0	0.0	0.0	0.0
Evening & night only	0.3	0.0	0.0	0.7
Morning, afternoon & evening	44.0	38.6	33.2	42.3
Morning, afternoon & night	0.0	0.0	0.0	0.3
Morning, evening & night	0.0	0.0	0.0	0.0
Afternoon, evening. & night	0.0	0.0	0.3	0.0
Always	0.3	1.0	1.0	3.0

daytime (i.e. from morning till evening) and very small percentage (0.3, 1.0, 1.0 and 3.0% respectively) of the respondents left their windows opened for the whole day (Table 5). Furthermore, the results reveal that respondents who opened their windows, left their windows opened within the mean duration of 6-10 hours per day.

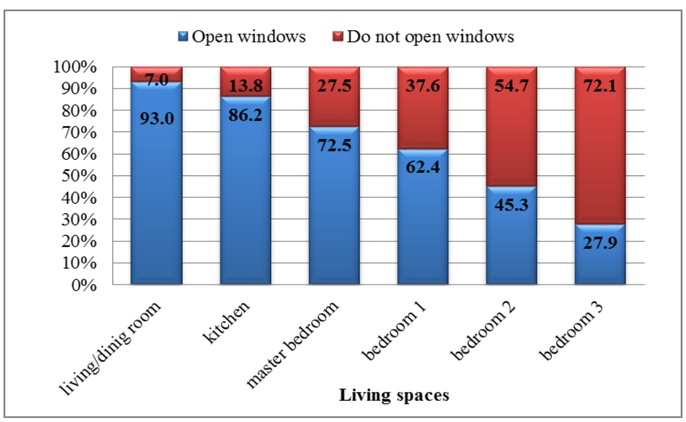


Figure 7: *Distribution of respondents by opening windows in the living spaces (N = 298)*

3.4 Reasons for opening and not opening windows

Figure 8 shows that respondents rated 'capture breeze' (29.4%), 'capture daylight' (23%), and 'release heat' (22%) as the three major reasons for opening their windows. 'Security' (27.8%), 'insects' (21.6%) and 'dust' (20.5%) were chosen as the three major reasons for not opening windows (Figure 9).

3.5 Evaluation of natural ventilation

During the analysis, responses under this category were recoded as follows: occupants' perception of indoor humidity and perceived air quality with the scale of -2 to 2 (see section '*Occupants' evaluation of natural ventilation*') was recoded as scale 1 to 5 with 3 being the middle value. While indoor temperature with scale -3 to 3 (see section '*Occupants' evaluation of natural ventilation*') was recoded as scale 1 to 7 with 4 being the middle value. This is represented in Table 6. The result shows that majority of the respondents (76.2% and 77.6%) believed that

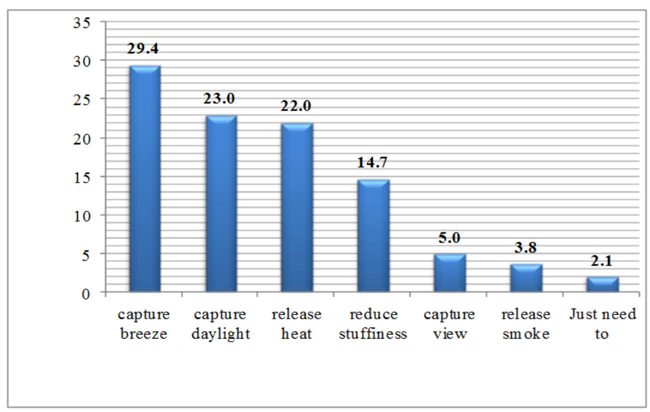


Figure 8: *Reasons for opening windows*

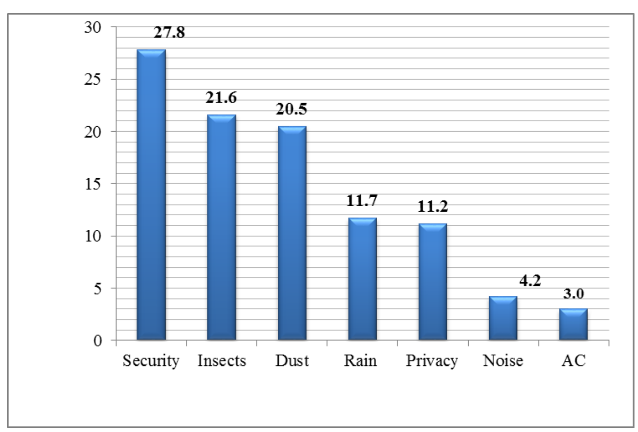


Figure 9: *Reasons for not opening window*

the provided openings in their houses were sufficient in terms of numbers and sizes respectively. In addition, majority of the respondents felt “neutral” with respect to the temperature (Mean = 4.20), humidity (Mean = 3.18) and perceived air (Mean = 3.00) in their house whenever they utilized natural ventilation. When asked about their level of satisfaction with indoor ventilation when utilising natural ventilation in their homes, majority (57.7%) of the respondents were neither satisfied nor unsatisfied i.e. just felt “OK” (Mean = 2.95).

Table 6: *Mean responses of occupants' evaluation of natural ventilation in respect to indoor humidity, perceived air, indoor temperature and level of satisfaction*

	Min.	Max.	Mean	Std. Deviation
Perception indoor humidity	1.000	5.000	3.178	0.555
Perception of indoor air	1.000	5.000	3.000	0.532
Perception of indoor temperature	1.000	7.000	4.198	0.973
Level of satisfaction with natural ventilation	1.000	5.000	2.946	0.737

3.6 General comments

Ninety seven (32.6%) of the total 298 respondents gave their complaint and opinion on how to improve natural ventilation in their homes. Larger window area was one of the major suggestions given by the respondents to improve natural ventilation in their homes. Seventy-eight (80.4%) of the 97 respondents believed a larger living area would improve natural ventilation whereas 19.6% of the 97 respondents demanded for the planting of more tress in the neighbourhood. More importantly, 34.0% of the 97 respondents complained that the first

Table 7: *Ordinal Regression for occupants' level of satisfaction*

Parameter Estimates					
Variable	Parameter	B	SE	OR	
Threshold (base= very satisfactory)	Very unsatisfactory	-1.066	0.568	-	
	Unsatisfactory	1.303	0.492	-	
	Ok	4.638	0.573	-	
	Satisfactory	8.334	0.913	-	
Number of occupants		0.093	0.078	1.097	
Years of occupancy		-0.044	0.046	0.957	
Duration of opening windows		0.852	0.131	2.344	***
Window opening area (base= non-UBBL compliant)	UBBL compliant	0.524	0.262	1.689	**
AC ownership (base= do not own AC)	Own AC	0.587	0.242	1.800	**
	Model	-2 Log Likelihood	Chi-Square	df	Sig.
Model-fitting information					
	Intercept Only	574.653			
	Final	517.265	57.388	5	0.000
Goodness-of-fit table					
	Pearson		764.447	927	1.000
	Deviance		479.672	927	1.000
Test of parallel lines					
	Null Hypothesis	517.265			
	General	498.988	18.277	15	0.248
Pseudo-R^2 measures					
	Cox and Snell	0.307			
	Nagelkerke	0.352			
	McFadden	0.179			

Note: Nagelkerke pseudo R^2 = 35.2 %. ***p< .05, ****p< .01. B= Estimate; SE= Standard error; OR= Odd ratio (exponent of B) floor was always hotter than the ground floor, and this can be due to the direct radiant heat received from the roof.

3.7 *Regression Analysis*

Ordinal regression analysis was completed to identify the factors that contribute to the level of occupants' satisfaction with indoor ventilation when utilizing natural ventilation in their home. The factors considered as the explanatory variables were: window opening area, AC ownership, total number of occupants, years of occupancy, and duration of opening windows in the living spaces. For the analysis, the five studied house types were grouped according to the adherence of their window opening area with the UBBL 10% window/floor area for natural ventilation provision requirements. Therefore, house types 1, 3, and 5 were grouped under house types that are 'UBBL compliant' while house types 2 and 4 under house types that are 'non-UBBL compliant' (See section 2.3 and Table 2). The regression model of occupants' level of satisfaction is presented in Table 7.

From the result output in an ordinal regression model for the 'Parameter estimate', the Nagelkerke R-Square and the p-value are the two values used by the model to show the measure of significance of the tested relationships (Agraz-boeneker et al., 2007). A p-value less than 0.05 signify a significant relationship between the measured variables. Table 7 shows that three explanatory variables significantly influence occupants' overall level of satisfaction, they are: window opening area (UBBL compliant and non-UBBL compliant) ($p < 0.05$), AC ownership ($p < 0.05$), and duration of opening windows ($p < 0.01$). For the approximation of the coefficient of determination (R^2), 'Nagelkerke's pseudo R-square' is commonly used. It is usually expressed as a percentage of the variability of the dependent variable explained by the model (Agraz-boeneker et al., 2007). According to Bonhomme et al. (2006) and Bonhomme et al. (2010), a Nagelkerke pseudo R^2 value between 0.2 and 0.4 can be considered satisfactory. Although, Ganguly et al. (2010) stated that there is no standard cut-off value for pseudo R^2, his study, through empirical evidence, confirms that R^2 values between 0.2 and 0.4 could also be considered. It can be observed for the result in Table 7 that the obtained Nagelkerke pseudo R^2 value 0.352 (35.2%) is still within the recommended value. This indicates that 35.2% of the variation in occupants' level of satisfaction was explained by all of the predictor variables entered into the regression model.

From Table 7, the odd ratios or 'OR' (which is derived from calculating the exponent of the estimate values) for 'duration of opening windows' is 2.344. This indicates that with a longer duration of windows being left opened, respondents were likely to be 2.344 times more satisfied with indoor ventilation when utilizing natural ventilation than those who opened less. Consequently, respondents occupying house types with windows that are UBBL compliant were 1.689 times more satisfied than those occupying houses with windows that are not UBBL compliant. Furthermore, the result shows that respondents who owned AC in their homes were 1.800 times more satisfied with indoor ventilation than occupants who did not own AC.

4. Discussion

The study has revealed the extent to which occupants utilised natural ventilation in these selected house designs by taking into account window openings in all living spaces, namely: living/dining room, master bedrooms, kitchen, and other bedrooms. The results have shown that majority of the occupants owned at least one AC in their home and AC was mostly installed in their master bedroom. Nevertheless, majority of them still utilised window openings, but rarely opened windows during night hours because most of them operated their AC in master bedroom during night hours. The study has also found that respondents mostly utilised window openings in living/dining room, master bedroom, bedroom 1, and kitchen, but rarely did so in bedrooms 2 and 3. The reason for this is that these bedrooms were most of the time unoccupied. In general, respondents opened their windows mostly during the daytime, for the mean duration of 6 to10 hours per day. This result is consistent with Kubota et al. (2009) who found that occupants of Malaysian residential buildings utilised natural ventilation more during the daytime between 10am-6pm compared to the night time. According to Rijal et al. (2007), Andersen et al. (2009) and Fabi et al. (2012), the chances of occupants opening their windows during the daytime is higher as the indoor temperature gets hot due to high outdoor temperature. Nevertheless, the release of hot indoor air during the daytime will not happen if the outdoor temperature is higher than indoor, which is normally the case in Malaysia with the exception of a few rainy months (Zain, 2007; Kubota et al., 2009). At night time, the indoor temperature of Malaysian concrete buildings can be much higher than outdoor temperature; hence, it is sensible to suggest that opening windows during night time to let in cool outdoor breeze is more effective to improve the level of occupants' thermal comfort.

Among many reasons, 'capture breeze', 'capture daylight', and 'release heat' were the three main reasons why occupants decided to open their windows. The need for occupants to capture breeze and release heat indicates that they need natural ventilation for evaporative bodily cooling and also appreciate increased ventilation rate to release indoor heat. This is quite understandable as Malaysia has a hot-humid climatic condition all year round, the need to release heat and gain fresh air from the outdoor would be necessary. Also, 'security' 'insects' and 'dust' were chosen as the three major reasons of not opening windows; however, these reasons can be controlled through the use of window grilles and insects screen. As security was the main reason for not opening windows, this explains why majority of occupants refused to open their windows during the nighttime.

Concerning the level of satisfaction with indoor ventilation while utilizing natural ventilation, majority of respondents rated neutral i.e. neither satisfied nor unsatisfied. This is unsurprising because majority of the respondents often opened their windows during the daytime when the outdoor temperature was higher than indoor, as noted earlier. This finding supports Kubota and Ahmad's (2005) findings that the frequency of operating fans in Malaysian homes was high throughout the day. Since increased air movement can be achieved by using electric fans, they were popularly used as a cooling tool in homes and the resulting air circulation gave occupants the perception of fresher indoor air (Huang, 2013). Since windows are mostly opened by respondents during the daytime, this implies that fans were normally used in conjunction with opening windows. This explains the neutrality of respondents' perception of indoor air temperature, air quality, and humidity as well as their overall level of satisfaction when utilizing natural ventilation.

The results of the study also indicate that the more window openings were utilized, the more satisfied the occupants became in relation to natural ventilation in their homes. Raja et al. (2001) explained this phenomenon by reporting that the availability of ventilation controls and their appropriate uses could improve building performance and occupants' satisfaction. The study also revealed that respondents who owned AC were more satisfied with indoor ventilation than those who did not own AC. This is so because, even though occupants owned AC they still utilizes window opening so whenever they are not satisfied with one means of comfort they have the advantage of switching over to the other. Thus, having an added advantage over those who relied solely on window openings and electric fans. Furthermore, the analysis revealed that respondents who lived in houses that complied with the UBBL 10% operable window area requirement (house types 1, 3 and 5) were more likely to be more satisfied with their indoor ventilation than those who lived in non-compliant houses (house types 2 and 4). The reason for this is that houses complied with the UBBL requirement have larger opening area compared to those that did not comply with the UBBL requirement. House type 5, which was one of the house types that complied with UBBL 10% operable area requirement, had an inclusion of internal courtyard. Hence, this study confirms that such design strategy in Malaysian terrace houses can improve the occupants' satisfaction on indoor ventilation.

However, as discussed earlier, respondents were generally 'neutral' in relation to their level of satisfaction with indoor ventilation regardless of their house types (UBBL compliant or non-compliant). In other words, although the opening sizes of their house complied with the UBBL, majority of respondents did not rate 'satisfied' or 'very satisfied'. This implies that the existing sizes of opening area in the studied houses are still inadequate to ensure satisfactory natural ventilation. Exacerbating this is the fact that none of the houses included in the study had 5% fixed openings as required in the UBBL except house type 5 where 1.41% (1.44m^2) of the total living space area was provided in the living/dining room. Although majority of the respondents believed that the opening sizes and numbers were sufficient, many of them also suggested for larger window areas to improve the natural ventilation in their homes. These contradicting results may be contributed by the fact that respondents may not be aware of the minimum requirement of opening sizes for a certain size of area.

5. Conclusion and Recommendation

This paper has drawn on quantitative research undertaken with 298 occupants of five selected terrace house design types in Precincts 11 and 14, Putrajaya by focusing on occupants' ventilation behaviour and their evaluation of natural ventilation. Out of five selected house design types, only three have opening sizes in accordance with the law requirement of 10% operable opening area and none provided the required 5% fixed opening. The purpose of this paper was to investigate the extent to which occupants utilised natural ventilation in their living spaces and their level of satisfaction with indoor ventilation while utilizing natural ventilation.

The study has found that majority of respondents opened their windows despite the fact that most of them owned at least one AC unit in their home (mostly installed in the master bedroom and mainly used during the nighttime). Respondents opened their windows mostly during the daytime and they do so mainly to capture breeze from outside. Despite this action, most of them neither satisfied nor unsatisfied (just neutral) with the indoor ventilation in their homes. The reason for this lies in the fact that outdoor temperature during daytime in Malaysia is usually much higher than indoor temperature; hence the captured breeze from outside is in fact hot breeze. Since the case is opposite during nighttime, windows should have been opened more often during nighttime to release indoor heat out. However, majority of respondents do not do so mainly due to security reasons. Clearly, the required fixed openings capable of allowing uninterrupted passage of air as stated in the UBBL (5% of floor area) must be provided, which is absent in the entire house types investigated. Operable windows on the other hand, should be designed to allow them to be opened at night without jeopardizing the security of occupants. The provision of openings for natural ventilation in accordance to the UBBL requirements is essential for the welfare of occupants. The study has revealed that respondents' level of satisfaction with natural ventilation is significantly related to opening sizes that are in accordance with the law. In relation to the respondents' level of satisfaction, the duration of opening windows and AC ownership were also found to be the contributing factors.

It can be concluded that natural ventilation, adequate openings and proper occupants' ventilation behavior are highly important to ensure good indoor air quality, acceptable levels of thermal comfort and occupants' satisfaction. Insufficient ventilation can result in the deterioration of the indoor air quality which in turn could lead to various health related issues such as sick building syndrome, occurrence of asthma and other respiratory diseases. Large opening area is necessary for adequate ventilation, therefore, the UBBL requirements for natural ventilation (both 10% operable area and 5% uninterrupted fixed area) are crucial as these provide large enough opening areas for easy exchange of air from the outdoor to the internal environment. As a result, improvements in occupants' health and satisfaction could be expected. The findings in this paper have implications for residential designers and the government/regulators. Designers need to be more concerned about the impact of their opening designs on occupants' level of comfort. It is also recommended for regulators to adequately enforce the compliance of this requirement for the purpose of building approval.

As this research is only based on a small sample in Putrajaya, a more comprehensive study is recommended to assess the general ventilation provisions in Malaysian housing sector. Further studies are also recommended to include additional behavioural factors that could influence occupants' level of satisfaction with regards to indoor ventilation and natural ventilation provisions in their homes.

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