EVALUATING NATURAL VENTILATION PROVISIONS AND OCCUPANTS' VENTILATION BEHAVIOR IN FIVE TERRACE HOUSING TYPES IN PUTRAJAYA, MALAYSIA

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Abstract

This study investigates the natural ventilation provisions of residential buildings in the hot-humid climate of Putrajaya as well as the occupants' utilization and overall satisfaction of these provisions. Five terrace house design types were selected for the study and natural ventilation (NV) provisions were identified through acquired building documents. Computer simulations were carried out on all house types to determine the ventilation rates delivered by the NV provisions. Furthermore, a total of 298 households from the selected house types were surveyed. Two house types were found not to comply with the Uniform Building By-Law (UBBL) governing NV provisions in Malaysia and those house types that complied were found to exhibit higher ventilation rates. Occupants' level of satisfaction when utilising NV was found to be significantly related to opening sizes complying with UBBL, longer duration of opening windows, and occupants' means of achieving comfort. This paper informs designers on the importance of complying with the required law governing NV in residential buildings. It also highlights the need for a strict effective enforcement of UBBL compliance for the purpose of building approvals.

Keywords: *Hot-humid climate; indoor air quality; occupants' satisfaction; residential buildings; Uniform Building By-Law; ventilation rates*

INTRODUCTION

Adequate ventilation is needed in order to achieve the desired thermal comfort for occupants. This is particularly necessary in regions characterized by high temperature and humidity all year round. In a hot-humid climatic region such as Malaysia, occupants of residential buildings are reported to depend highly on mechanical cooling technologies to achieve this aim (Kubota et al, 2009; Toe and Kubota, 2015). However, numerous studies have revealed that people in hot-humid climatic regions can accommodate high temperatures and, in fact, adequate comfort can be achieved through natural ventilation (Cândido et al, 2010; Wei et al, 2011; Yau et al, 2011; Nguyen et al, 2012). Although these studies were able to prove the adaptive ability of people in hot-humid regions to high temperatures, their dependence on mechanical cooling is still very high. For example, in Malaysia, residential is among the largest electricity consuming sectors, mainly due to the use of air-conditioning (Chan et al, 2009; Energy Commission Malaysia, 2010).

Attempts to improve the energy efficiency of residential buildings have led to houses being built to be air tight to prevent leakage of cool draft through the building's skin (Nielsen and Drivsholm, 2010; Lee et al, 2012). This air tightness in buildings leads to limitation in the passage of air in and out of the indoor environment thereby causing a reduction in ventilation rates (Nantka, 2006). Studies have shown that reduction in ventilation rates could result in the poor indoor air quality (IAQ) which has been reported to lead to various health related issues such as sick building syndrome, occurrence of asthma, and other respiratory diseases (Aizat et al, 2009; Fisk et al, 2009; Lee et al, 2012; Mentese et al, 2015).

In Malaysia, studies have shown that naturally ventilated residential buildings are found to exhibit indoor climatic (temperature and humidity) conditions and contaminant levels that are not acceptable within the recommended range for acceptable IAQ (Ahmed et al, 2004; Muhamad-darus et al, 2011; Jamaludin et al, 2015; Kubota and Toe, 2015). Consequently, less satisfaction levels on the part of occupants were recorded despite the fact that most of them opened their windows to ventilate their homes (Kubota and Ahmad, 2005; Kubota, 2006; Kubota et al, 2009). These studies indicate that, despite the benefits of natural ventilation, naturally ventilated buildings in Malaysia are still in poor IAQ conditions and the fact that occupants' regular practices of opening their windows have yet to be translated into improved satisfaction levels on their indoor conditions. This raises the questions of whether the provided natural ventilation provisions are actually adequate and whether they are fully utilized by the occupants.

This study therefore aims to address these uncertainties. The specific objectives of this study are as follows: 1) to identify natural ventilation provisions in selected residential houses in Malaysia, 2) to determine the ventilation rates delivered by the natural ventilation provisions, and 3) to assess occupants' utilization of those provisions and their level of satisfaction with indoor ventilation while utilizing these provisions. It is anticipated that findings from this study will inform designers on the importance of the required law governing the natural ventilations in residential buildings. Such law is stipulated in the Uniform Building By-Law (UBBL) 1984 Law 39 (1) that says, "Every room designed, adapted, or used for residential [purposes]...shall be provided with natural lighting and ventilation by means of one or more windows, having a 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" (Laws of Malaysia, 2008).

The paper first explains the key theories and research in this area, followed by the stages of methods used in the study. It then presents and discusses the results of the study before concluding with some recommendations for future research.

LITERATURE REVIEW

The necessity of introducing outdoor air for ventilation to ensure good IAQ in buildings has been acknowledged for more than 150 years (Janssen and Hill, 1982). The overall measure of the rate of outdoor air being supplied for ventilation in an indoor space, which is referred to as the air exchange rate (ACH) or ventilation rate (ASHRAE, 2007), includes intake of air through intentional or unintentional openings. Marr et al (2012) argued that this ventilation rate is influenced by natural ventilation through window openings, the total area of window opening provided, as well as the frequency of opening the windows. Ahmed et al (2004), Yamamoto et al (2010), and Muhamad-darus et al (2011) also expressed similar views. Yamamoto et al (2010) asserted that natural ventilation through window openings and doors was more likely to increase the ACH in residential buildings. Ahmed et al (2004), on the other hand, revealed that the most significant parameters that influence IAQ and ACH of a home were room sizes, existence of ventilation outlets, and occupancy rate, whereas Muhamad-darus et al (2011) indicated these factors as household activities, ventilation system, and the location of a house. However, Yamamoto et al (2010) asserted that ACH could be reduced when air-conditioning was used as a means of attaining comfort.

In relation to ACH and air-conditioning usage, a study conducted by Guo et al (2008) found that the highest ACH value was recorded when the air-conditioner and fan were turned on and all windows were left opened in a mechanically ventilated classroom. The study was conducted to find out the influence of ACH on a particular contaminant. At the end of the study, a relationship was found between ACH and the indoor concentration of the measured contaminant. It was revealed that the higher the ACH value, the lower the concentration level of indoor contaminant, the same conclusion reached by Zuraimi and Tham (2008) in their study on indoor pollutants concentrations in child care centers.

To achieve adequate ACH for ventilation and contaminant control, Hassan and Ramli (2010) stated that the maximum openings on the building walls should be considered, as this will create a high air intake into the house, hence, causing an increase in the indoor ventilation rates. This could be achieved when the provided opening area on the building walls is not less than 40% of the total floor area (Tantasavasdi et al, 2001). Although an opening area is essential for outdoor air intake, occupants' usage of the provided opening (known as occupants' ventilation behavior) is more important (Lee et al, 2012). Lee et al (2012) described the occupants' ventilation behavior as the relationship between occupants and their window openings in relation to the frequency and duration of which they are utilized to admit outdoor air.

In summary, these studies have revealed that insufficient ventilation can result in the deterioration of IAQ. Consequently, a large opening area is necessary for adequate ventilation for easy exchange of air from the outdoor to the internal environment. It is therefore evident from the literature that, for effective natural ventilation, acceptable IAQ and thermal comfort levels, occupants' satisfaction, adequate openings that provide sufficient ACH, and proper occupants' ventilation behaviour are highly important. The theoretical framework of the study is illustrated in Figure 1.

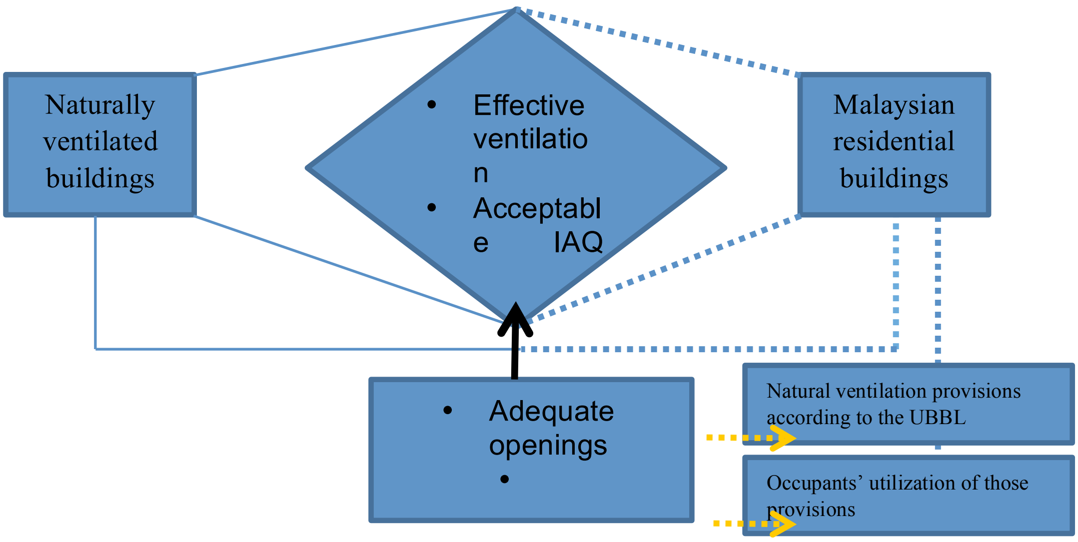

Figure 1. Theoretical framework (Source: Authors)

Based on the aforementioned discussion, it is hypothesized that the window opening area, the occupants' means of achieving comfort (AC ownership), the occupants' demographic characteristic (total number of occupants, years of occupancy), and the duration of opening windows contributes to the occupants' level of satisfaction with indoor ventilation when utilizing natural ventilation.

However, to understand natural ventilation in Malaysian residential homes, the provided natural ventilation provisions (openings) need to be viewed with respect to the Malaysian UBBL, a standardized building regulation that governs all Malaysian residential buildings. Two studies (Hanafiah, 2005 and Ahmad et al, 2011) have been conducted to investigate the adequacy of natural ventilation provisions in Malaysian terraced houses in accordance with the UBBL. However, the studies were carried out on renovated houses; hence, the conformity of the houses' original opening design (sizes and types) to the UBBL cannot be ascertained since the original design has been altered.

This highlights the need for natural ventilation and natural ventilation provisions in Malaysian residential buildings to be further investigated. Studies have been conducted on Malaysian residential buildings in relation to natural ventilation and occupant satisfaction (Kubota and

Ahmad, 2005; Kubota, 2006; Kubota et al, 2009; Mohit et al, 2010; Talib, 2011; Teck-Hong, 2012; Zainal et al, 2012). However, the question of whether or not the provided natural ventilation provisions are adequate remains unanswered. As a result, the link between regulatory compliant provisions and improved natural ventilation in residential buildings has not been successfully established, especially within a hot-humid climatic condition.

Also, these studies failed to consider the relationships that may exist among all the above-mentioned three issues as a whole (i.e. natural ventilation provisions, occupants' ventilation behaviour, and occupants' satisfaction). Nor was there any effort to look into other factors that may particularly influence occupants' satisfaction than the one focused in Kubota and Ahmad (2005), Kubota (2006), and Kubota et al (2009), i.e. the length of time of which windows were left open. This study therefore aims to fill these gaps by investigating the present condition of natural ventilation provisions in Malaysian residential buildings. By doing this, their adequacy with respect to the UBBL requirements will be confirmed. Furthermore, by considering UBBL compliant natural ventilation provisions as an influencing factor alongside occupants' ventilation behavior, occupants' satisfaction with indoor ventilation will be clearly understood.

METHODOLOGY

This study adopted a case study approach with multiple sources of data to achieve its objectives. The first objective was fulfilled through document analysis and observations, whereas the second objective was achieved by conducting computer simulations. Lastly, a questionnaire survey was conducted to achieve the third objective. The document analysis and observation was needed in order to identify the natural ventilation provisions (for this study, these provisions are limited to window openings and other unobstructed openings within the living spaces as specified by the UBBL) in existing residential buildings. Computer simulations were carried out to reveal the influence of UBBL compliant openings on the ACH, and subsequently, establishing the link between regulatory compliant provisions and improved natural ventilation. On the other hand, the roles that these provisions play in increasing occupant satisfaction were examined through a questionnaire survey. The survey was also conducted to reveal the occupants' utilization of these provisions, which is necessary to understand the relationship that exists between occupants and these provisions. This study is limited to these three data collection processes.

Description of selected house types

Statistics indicate that terrace houses are the largest housing type built in Malaysia (National Property Information Centre, 2013); hence, this housing type was chosen for the study. Specifically, five terrace house design types in Putrajaya precincts 11 and 14 were selected after site visits were conducted to identify different terraced house designs with varying window types, sizes, patterns, and locations. Putrajaya (Federal Capital Territory of Malaysia) has residential zones constituting the second largest major land use, thus making it suitable as the study area. Precincts 11 and 14 were chosen as they contain the largest number of terraced housing units with a variety of designs compared to other twelve precincts available in Putrajaya. Moreover, houses in Putrajaya are fundamentally kept in their original conditions as the local authority places constraints on renovations to maintain the consistency of the general designs. This guarantees that all units under each house type chosen for the study have comparable qualities.

Figure 2 (Figure 2a - 2e) shows the perspectives and floor plans of the selected house types. They were all double-storey terraced houses, constructed with veneer brick wall, concrete frames, and roof tiles. Each unit of house types 1, 2, 3, 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. All house types had a floor-to-ceiling height of 3.30 m for the ground floor and 3.10 m for the first floor. The ground floor accommodated a living/ dining area, a kitchen, and bedroom 3, whereas the upper floor contained three bedrooms i.e. master bedroom, bedroom 1, and bedroom 2. Among all of the house types, only type 5 had an internal courtyard. The living spaces of all house types were provided with casement window types of varying sizes; in some cases, awning window types were installed at the top of each casement window. 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.

Figure 2a. House type 1

Figure 2b. House type 2

Figure 2c. House type 3

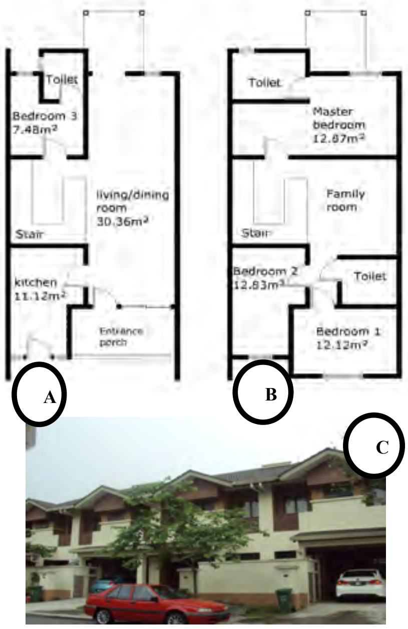

Figure 2d. House type 4

Figure 2e. House type 5

Figure 2. Perspectives and floor plans of selected house types (A represents the ground floor; B, the first floor; and C, the perspective view) (Source: Authors).

Identifying natural ventilation provisions

Since natural ventilation provisions in Malaysian residential buildings are governed by the UBBL, this study identifies ventilation provisions in the selected house types in accordance with this law. Relevant drawings were sought from relevant organizations and these include: site and location plans, floor plans, roof plans, elevations, sections, and schedules. Subsequently, the sizes of window openings in all living spaces (living/ dining, kitchen, and all bedrooms) as well as the total floor area of all living spaces of each house design type were recorded. Then the total area of window openings was calculated for each living space. This calculation includes both operable window openings and unobstructed openings that allow uninterrupted passage of air as required by the UBBL. The window/ floor area percentage was then calculated using the following formula:

Percentage of window/ floor area (%) = $\frac{window\ area\ (m^2)}{floor\ area\ (m^2)}\ X\ 100$ ………………………. (1)

Determining the ventilation rates delivered by the natural ventilation provisions

This stage involved a computer simulation process to determine the ventilation rates delivered by the existing natural ventilation provisions (window opening area) in each living space of all the studied house types. The modeling tool chosen for this purpose was Integrated Environmental Solution (IES<VE>) software version 2012. A comparison of available simulation softwares revealed IES<VE> as the most acceptable environmental simulation software (Attia et al, 2009; Attia and De Herde, 2011; Behrendt et al, 2011). The validity of using IES<VE> for different building simulations has been widely studied (Azhar et al, 2008; Crawley et al, 2008; Leng et al, 2012) and IES<VE> has been widely adopted in numerous building and environmental studies (for example, Mohammadi et al, 2010; Chinnayeluka, 2011; Sadrzadehrafiei et al, 2011; Nikpour et al, 2013a; Nikpour et al, 2013b). Furthermore, it has been declared that IES<VE> meets relevant standards such as: ASHRAE 140: 2001, 2004 and 2007, BEST TEST, CIBSE TM33 (Integrated Environmental Solutions Limited, 2014). To ensure the reliability of the simulation results, three sequential stages of procedures were completed, namely:

1. Geometry generation: This requires all building components (e.g. openings, floors, partitions, and roofs) to be drawn using "ModelIT" IES<VE> interface. Furthermore, information such as site orientation, site location, and weather data were entered into the system. For the purpose of this study, weather data from the Kuala Lumpur/ Subang weather station was selected as it is the closest weather station to the study area.
2. Natural ventilation analysis: This was performed using the Macroflo IES<VE> module. It involved specifying relevant opening characteristics such as opening types, opening angle, duration, and direction in the MacroFlo 'opening types manager' interface.
3. Running the simulation: At this stage, the mode and required space for simulation, output parameters, and simulation duration (1st January to 31st December) were assigned and the simulation was run using the IES<VE> ApacheSim.

One intermediate house unit of each house type was selected for the simulation as it perfectly represents a terrace house unit. Surveys conducted by Kubota and his co-researchers (Kubota and Ahmad, 2005; Kubota, 2006; Kubota et al, 2009) revealed that the majority of Malaysia's residential building occupants left their windows opened mostly during the daytime (from morning to evening) and very few occupants left their windows opened for 24 hours a day. Therefore, the two scenarios simulated in this study were the times when: 1) the windows were left opened during the daytime only (6:00 AM to 10:00 PM every day), and 2) all windows were left opened at all times (24 hours every day). Thus, the difference in air flow introduced by the openings under these two different scenarios was discovered.

Assessing the occupants' utilization of the natural ventilation provisions

In order to understand a building's indoor performance, the building occupants are definitely the major source of information as they can independently share their comfort and satisfaction levels, as well as the overall building performance (Peretti and Stefano, 2011). As such, surveys, questionnaires, and observations are among the methods often used to seek these kinds of information. These methods could either be used independently or in combination with physical measurements, as there are currently no standardized methods to survey building occupants (Peretti and Stefano, 2011). Questionnaire surveys have been used to gather responses in related studies (such as Kubota and Ahmad, 2005; Kubota, 2006; Andersen et al, 2009; Frontczak et al, 2012; Lee et al, 2012) and the main issues addressed were the occupants' means of achieving comfort, their ventilation behaviour, and reasons for opening or not opening their windows. Therefore, the questions set in the questionnaire form for this study were based on these main issues. Also, it was considered relevant to include the occupants' level of satisfaction with the natural ventilation in their homes.

A questionnaire survey was conducted among 300 occupants who lived in 300 intermediate units. These 300 intermediate units were randomly selected from the total units of 649 and they made up 60 representative units of each of five house types. At the end of the survey, responses from 298 house units were realized, representing 46.0% of the total house units in all five house types.

Overall, this part of the study sought to test the study's hypothesis stated in the Literature Review section. Hence, the questionnaire form is divided into four parts and was designed to efficiently allow for the hypothesis to be tested. The first part consists of questions designed to obtain occupants' demographic information as well as the number of occupants and the period of occupancy. The second section includes questions formulated to understand their means of achieving comfort. Specifically, occupants were requested to indicate whether or not they were using AC and/ or an electric fan in each of their living spaces. Responses to this particular question are appropriate to facilitate the examination of whether these variables have any possible influence on occupants' satisfaction with the ventilation in their homes while utilizing natural ventilation.

In the third section, which was based on occupants' ventilation behavior, occupants were asked to select the period(s) in which they normally opened their windows, and also the period in which AC in each living space was normally operated. Occupants who opened their windows were further asked to choose the duration for which their windows were left opened based on six options: 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. Responses to this question provide a better understanding on the usage pattern of the natural ventilated provisions. The final question in this part sought information on the respondents' main reason(s) for opening and not opening their windows.

In the last part of the questionnaire, occupants were asked to rate their level of satisfaction with ventilation in their homes while utilizing natural ventilation. This section was scored on a five-point Likert scale, where a score of 1 represents "very unsatisfactory" and 5 represents "very satisfactory". Responses from this section act as a dependent variable (DV) for the tested hypothesis and also provide the avenue for respondents' preferences and expectations to be understood. Since the climatic conditions in Malaysia are relatively uniform all year round, respondents were asked to provide a general evaluation.

A pilot study was conducted on similar house types before the main survey in order to test the validity of the survey questionnaire. Since the assumption for validity was not met (Cronbach alpha < 0.7), relevant adjustments were made and final Cronbach alpha is 0.78. The main survey was conducted in October 2012. The respondents were requested to give their answers based on the time when their house was occupied. All questionnaires were self-administered.

Data analysis

The completed questionnaires were analyzed with SPSS statistical analysis program (version 21) using relevant statistical analysis i.e. descriptive analysis, cross-analyses, and regression analysis. Descriptive analysis was carried out to describe all the variables in the questionnaire, whereas cross tabulation was carried out to determine any relationships between variables. An ordinal regression analysis was completed to test the study's hypothesis; the DV identified from the hypothesis was occupants' level of satisfaction, which was scored on a five-point Likert scale (ordinal scale). The independent or explanatory variables (IVs) were window opening area, means of achieving comfort, total number of occupants, years of occupancy, and duration of opening windows in the living spaces, which are in both nominal and continuous scales. The means of measurement adopted for all the IVs (except window opening area) have been explained in the previous section. For window opening area, house types were grouped according to the adherence of their window opening area with the UBBL window/ floor area percentage for natural ventilation provision requirements. So, the window opening area could be either UBBL compliant or non-compliant.

Generally, when dealing with ordinal DVs, the modelling approach can be executed in three ways: 1) treated as a continuous variable, 2) grouped into a nominal variable, and 3) modelled as it is (in its original form) using ordinal regression analysis (Ananth and Kleinbaum, 1997; Strand et al, 2012). From among all options, only the third option allows for a model that incorporates the ordinal nature of the DV to be applied. Although the other approaches cannot be considered incorrect, they often cause the loss of information due to the ignoring or collapse of the order and categories of the responses (Ananth and Kleinbaum, 1997; Strand et al, 2012). Numerous studies have broadly employed the ordinal regression model for analysing ordinal DVs in different fields of study, some of which are Bonhomme et al (2010), Košak and Poljšak (2010), Ombui et al (2011), Citko et al (2012), Strand (2012), and Khalaf et al (2013).

RESULTS

Natural ventilation provisions in accordance with UBBL 1984 Law 39 (1)

Relevant documents were analyzed and site visitations and observations were conducted to identify the existing natural ventilation provisions in all of the studied houses. Table 1 gives the detailed information on the present provisions for natural ventilation (window opening area and window/ floor area percentage) in all of the studied house types. House type 1 was found to have the largest total window/ floor area percentage (16.03%), followed by house type 5 (11.27%), 3 (10.33%), 2 (8.50%) and lastly 4 (9.06%). It is important to note that only house types 1 and 5 were provided with window opening areas that complied with the UBBL. It was surprising to note that only house type 5 had unobstructed openings; however, its window/ floor area percentage of 1.41% was still below the 5% required by the UBBL. This highlights the fact that the UBBL requirements were not strictly adhered to in the studied house types.

Table 1. Window/floor area percentage of the studied living spaces in each house types (Source: Authors).

House types	Total living spaces (m^2)	Provided opening area m^2 (%)	Living/dining room m^2 (%)	Master bedroom m^2 (%)	Bedroom 1 m^2 (%)	Bedroom 2 m^2 (%)	Bedroom 3 m^2 (%)	Kitchen m^2 (%)	Total m^2 (%)	UBBL compliant
1	101.07	Provided window opening	3.78 (10.60)	3.78 (23.74)	2.16 (12.59)	2.70 (20.83)	3.78 (39.54)	-	16.20 (16.03)	Yes
		Unobstructed opening	-	-	-	-	-	-	-	No
2	88.97	Provided window opening	1.44 (5.00)	1.80 (9.24)	1.44 (11.86)	1.44 (10.41)	1.44 (28.85)	0.36 (4.03)	7.56 (8.50)	No
		Unobstructed opening	-	-	-	-	-	-	-	No
3	106.53	Provided window opening	0.72 (2.00)	2.7 (12.96)	2.7 (16.66)	1.8 (15.46)	1.44 (16.16)	1.44 (11.09)	11.00 (10.33)	Yes
		Unobstructed opening	-	-	-	-	-	-	-	No
4	86.78	Provided window opening	1.08 (3.56)	1.80 (13.98)	1.44 (11.88)	1.44 (11.22)	0.90 (12.03)	1.2 (11.09)	7.86 (9.06)	No
		Unobstructed opening	-	-	-	-	-	-	-	No
5	102.21	Provided window opening	3.60 (11.51)	2.70 (14.48)	1.80 (11.39)	2.16 (13.04)	0.36 (4.88)	0.90 (7.17)	11.52 (11.27)	Yes
		Unobstructed opening	1.44 (4.61)	-	-	-	-	-	1.44 (1.41)	No

Table 2. Ventilation rates delivered by Openings in all living spaces (Source: Authors).

				Windows left open at all times (24 hrs)		Windows opened only between 6AM to 10PM	
		Room volume (m3)	Total opening Area (m2)	Airflow in (m3/h)	ACH	Airflow in (m3/h)	ACH
HOUSE TYPE 1	Living room	117.61	3.78	936.32	7.96	615.38	5.23
	Master bedroom	42.32	3.78	766.58	18.12	530.42	12.54
	Bedroom 1	53.20	2.16	419.65	7.89	283.00	5.32
	Bedroom 2	40.18	2.70	543.74	13.53	368.24	9.17
	Bedroom 3	31.55	3.78	733.82	23.26	511.27	16.21
	Kitchen	39.93	-	0.50	0.01	0.36	0.01
	Total	324.78	16.20	3400.63	10.47	2308.68	7.11
HOUSE TYPE 2	Living room	97.65	1.44	161.17	1.65	104.364	1.07
	Master bedroom	60.42	1.80	358.45	5.93	233.676	3.87
	Bedroom 1	37.63	1.44	262.62	6.98	173.34	4.61
	Bedroom 2	42.87	1.44	264.20	6.16	174.168	4.06
	Bedroom 3	16.47	1.44	235.19	14.28	158.868	9.65
	Kitchen	29.47	0.36	149.22	5.06	98.208	3.33
	Total	284.51	7.56	1430.86	5.03	942.62	3.31
HOUSE TYPE 3	Living room	118.67	0.72	165.42	1.39	107.53	0.91
	Master bedroom	64.57	2.70	525.42	8.14	347.33	5.38
	Bedroom 1	50.25	2.70	508.61	10.12	339.05	6.75
	Bedroom 2	36.08	1.80	360.43	9.99	237.56	6.58
	Bedroom 3	29.4	1.44	254.95	8.67	170.68	5.81
	Kitchen	42.83	1.44	286.52	6.69	190.98	4.46
	Total	341.81	11.00	2101.36	6.15	1393.13	4.08
HOUSE TYPE 4	Living room	100.19	1.08	279.65	2.79	179.68	1.79
	Master bedroom	39.90	1.80	334.94	8.40	221.98	5.56
	Bedroom 1	37.57	1.44	253.48	6.75	168.52	4.49
	Bedroom 2	39.77	1.44	253.44	6.37	168.59	4.24
	Bedroom 3	24.68	0.90	195.34	7.91	128.34	5.20
	Kitchen	36.70	1.20	239.94	6.54	158.94	4.33
	Total	278.81	7.86	1556.78	5.58	1026.04	3.68
HOUSE TYPE 5	Living room	103.19	5.04	1190.74	11.54	900.14	8.72
	Master bedroom	57.82	2.70	919.69	15.91	690.01	11.93
	Bedroom 1	48.98	1.80	785.74	16.04	589.18	12.03
	Bedroom 2	51.34	2.16	387.11	7.54	255.92	4.99
	Bedroom 3	24.35	0.36	62.57	2.57	41.94	1.72
	Kitchen	41.42	0.90	198.22	4.79	130.00	3.14
	Total	327.091	12.96	3544.06	10.84	2607.19	7.97

Ventilation rates delivered by the natural ventilation provisions

Computer simulations were carried out to reveal the influence of UBBL compliant openings on the ACH. Table 2 shows the simulated ventilation rates delivered by these openings in all living spaces. It is apparent from this table that house types 1, 3, and 5 have their total window/ floor area percentages in accordance with the UBBL (see Table 1), exhibited higher ventilation rates (10.47, 6.15 and 10.84 ACH respectively when windows were left opened at all times, and 7.11, 4.08 and 7.97 ACH respectively when windows were opened only between 6:00 AM to10:00 PM) than the remaining two house types that are non-UBBL compliant. It can also be noticed that amongst these three house types, house type 5 has the highest ventilation rate of 10.84 ACH, probably due to its inclusion of unobstructed openings, as required by the UBBL. This indicates that higher ACH values could also be recorded in other house types if unobstructed openings were included in their design. These results establish that the provisions' compliance with the regulation plays an important role in improving the natural ventilation.

It can also be noticed in Table 2 that there was a significant difference in the overall ACH values between the scenario when windows were left opened at all times (column 6) and when windows were opened only between 6:00 AM and 10:00 PM (column 8). Specifically, the ACH values obtained for house types 1, 2, 3, 4, and 5 (10.47, 5.03, 6.15, 5.58, and 10.84 ACH respectively) when the windows were left opened at all times were generally higher than when windows were opened only between 6:00 AM to10:00 PM (7.11, 3.31, 4.08, 3.68, and 7.97 ACH respectively).

Occupants' utilization of the provided natural ventilation provisions

This section presents the results from the questionnaire survey, which was conducted to understand the relationship that exists between occupants and the natural ventilation provisions. They are grouped under occupants' demographic characteristics, their means of achieving comfort, their frequency and periods of utilizing those provisions, their level of satisfaction, and factors that influence their satisfaction, as explained below.

Demographic characteristics

The household size and occupancy period in each house type were investigated to evaluate occupants' demographic characteristics. Table 3 presents the characteristics of the 289 respondents, representing 289 house units of five house types. The average occupancy period was 3.46 years while the average household size was 4.51 persons.

Table 3. Occupants' demographic characteristics (N = 298) (Source: Authors).

House types	Occupancy period (years)		Household size (person)	
	Mean	Std. deviation	Mean	Std. deviation
1	4.67	2.72	4.73	1.60
2	6.34	3.23	5.12	1.68
3	2.79	1.04	4.40	1.63
4	3.11	1.87	4.87	1.63
5	.37	.12	3.45	1.28
(n= 298)	3.46	2.91	4.51	1.67

Means of achieving comfort

This part of the survey presents other means that the occupants employed to attain comfort besides opening their windows and their pattern of usage. The survey reveals that 157 (52.7%) of the house units had at least one AC unit installed. The remaining 141 (47.3%) house units relied solely on natural ventilation and utilized electric fans as a means of achieving comfort. The study also found that all house units installed electric fans in all of the living spaces. This corresponds to the fact that those respondents who owned an AC also used electric fans in all of their living spaces. Figure 3 illustrates the distribution of AC ownership in the living spaces of all house types. It shows that the master bedroom was the most preferred space to be installed with an AC (51.2%), whereas fans were mostly preferred to achieve the desired comfort in bedrooms 1, 2, and 3. Also, house types with the highest percentages of AC ownership were type 1 (56.7%) and type 3 (56.9%), as shown in Figure 4. Surprisingly, house types with the highest percentages of AC ownership (types 1 and 3) were among those that complied with the UBBL 10% window/ floor area percentage.

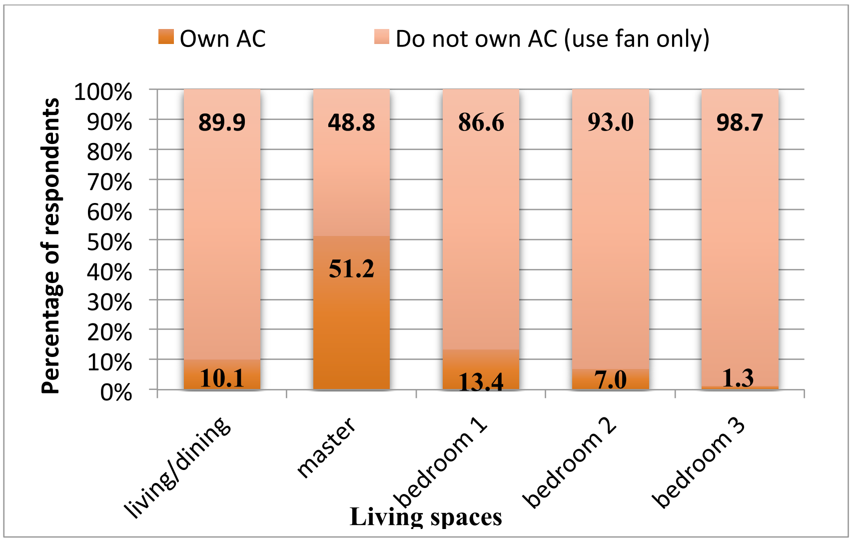

Figure 3. AC ownership in living spaces (N=298)

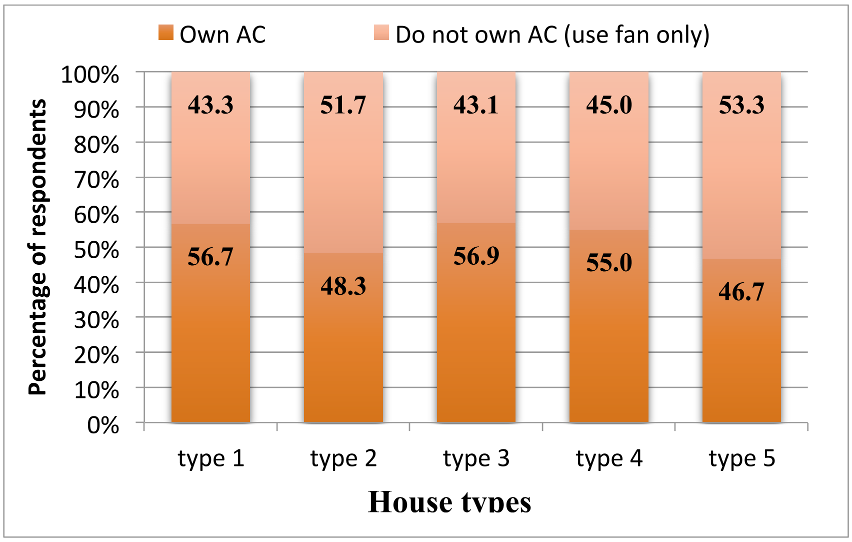

Figure 4. AC ownership in each house types (N=298) (Source: Authors).

Figure 5 shows the periods of the day in which the AC was normally operated in all living spaces. It indicates that the AC in all living spaces was mostly operated only at night. Since they were mostly installed in master bedrooms, 74.5% of the respondents who installed an AC in their master bedrooms operated it only at night, while the remaining 25.2% operated it at various times in the day. This demonstrates that the AC was mainly installed for use during sleeping hours.

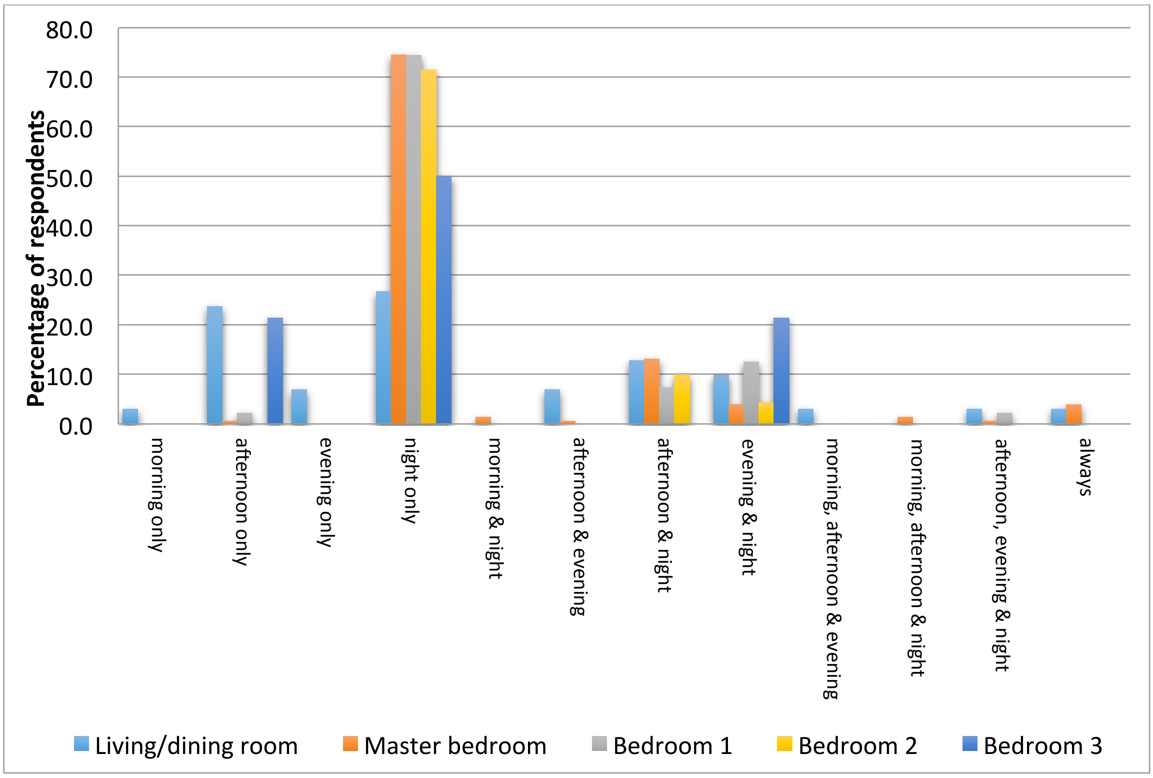

Figure 5. Periods of the day in which AC was operated in all living spaces (N=157) (Source: Authors).

Frequency and periods of utilizing natural ventilation provisions

This subsection presents the occupants' usage pattern of the window openings. Figure 6 shows that the majority of the respondents opened their windows in the living/ dining rooms (93%), kitchens (86.2%), and master bedroom (72.5%). Hence, it is apparent that these three spaces were the most naturally ventilated spaces in the studied houses. Furthermore, a comparison between Figures 6 and 3 reveals two important results. First, 72.5% of the total respondents opened windows in the master bedroom, although 51.2% of them had AC installed in this space. This shows that the idea behind the AC installation was not to eliminate the use of windows for attaining comfort but rather to serve as a means to improve their comfort level mainly during sleeping hours. As mentioned earlier, the AC was purposely installed for achieving comfort during sleeping hours. This is apparent in Figure 7, which reveals that windows were mostly opened in all living spaces during the daytime (i.e. morning, afternoon, and evening) and they were rarely opened at night times. Second, despite the small percentages of respondents who installed an AC in bedrooms 2 and 3, windows were less frequently opened in these two rooms. This indicates that these two bedrooms were mostly not occupied.

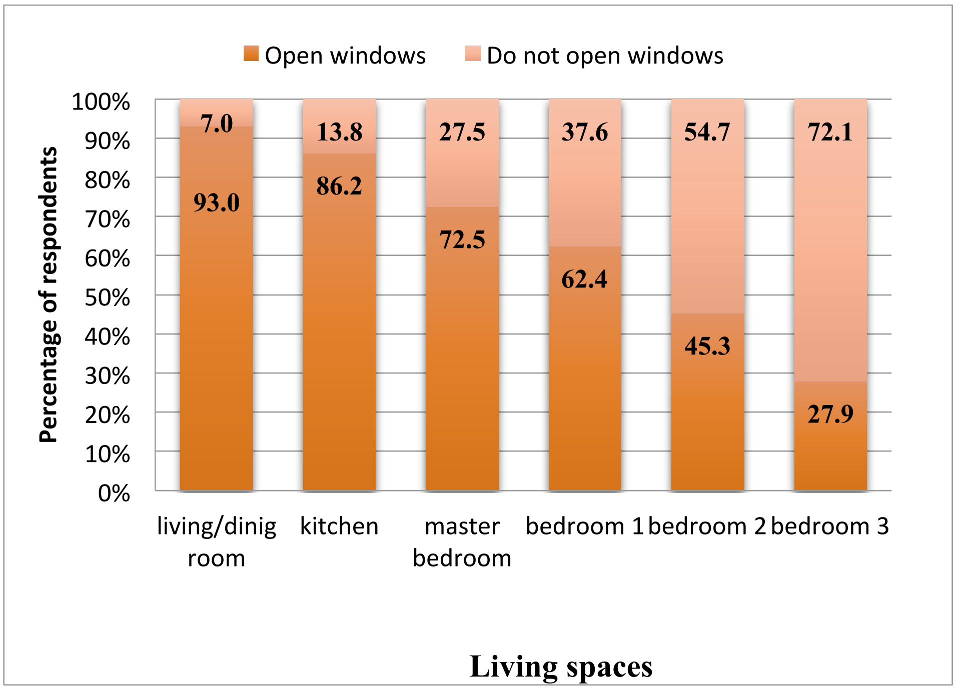

Figure 6. Percentage of respondents that open windows in all living spaces (N=298) (Source: Authors).

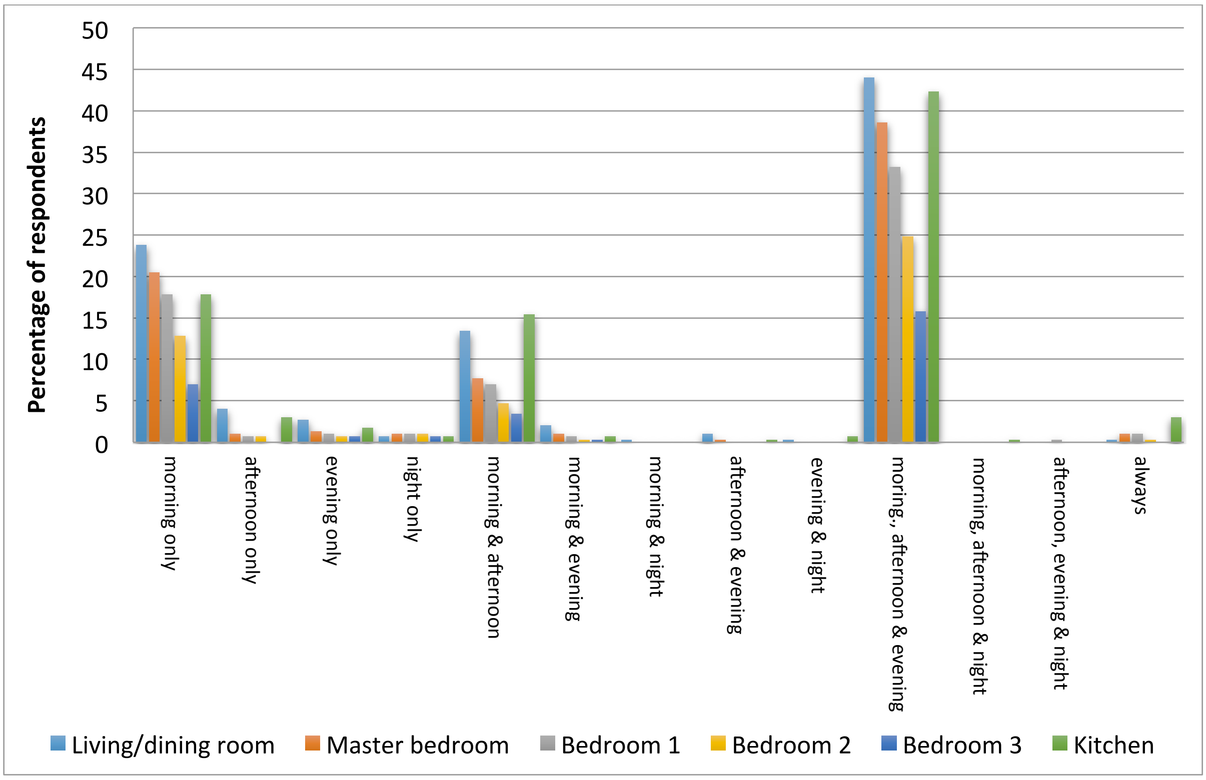

Figure 7. Periods of the day in which windows are opened in all living spaces (N=298) (Source: Authors).

Table 4 shows the duration in which windows were left opened in all living spaces. It reveals that the majority of the respondents (44.3%, 42.6% and 40.6% in living/ dining room, kitchen, and master bedroom respectively) who opened their windows left them opened within the mean duration of 6-10 hours per day. In terms of reasons for opening and not opening windows, Figure 8 shows that respondents chose capture breeze (29.4%), capture daylight (23%), and release heat (22%) as the three main reasons for opening their windows, while Figure 9 shows that security (27.8%), insects (21.6%) and dust (20.5%) were the three main reasons for not opening their windows.

Table 4. Percentage distribution of respondents by duration of opening windows in all living spaces (Source: Authors).

Duration per day	Living/dining room (%)	Kitchen (%)	Master bedroom (%)	Bedroom 1 (%)	Bedroom 2 (%)	Bedroom 3 (%)
Never open	7.0	13.8	27.5	37.6	54.7	72.1
Less than 1 hour	9.4	7.4	6.4	4.7	3.7	1.0
1-5 hours	34.6	29.9	22.1	17.8	12.8	9.4
6-10 hours	44.3	42.6	40.6	36.9	26.8	16.4
11-15 hours	2.7	2.3	1.7	1.3	1.0	.7
More than 16hr < 24hrs	1.0	1.0	.7	.7	.7	.3
24 hours	1.0	3.0	1.0	1.0	0.3	0

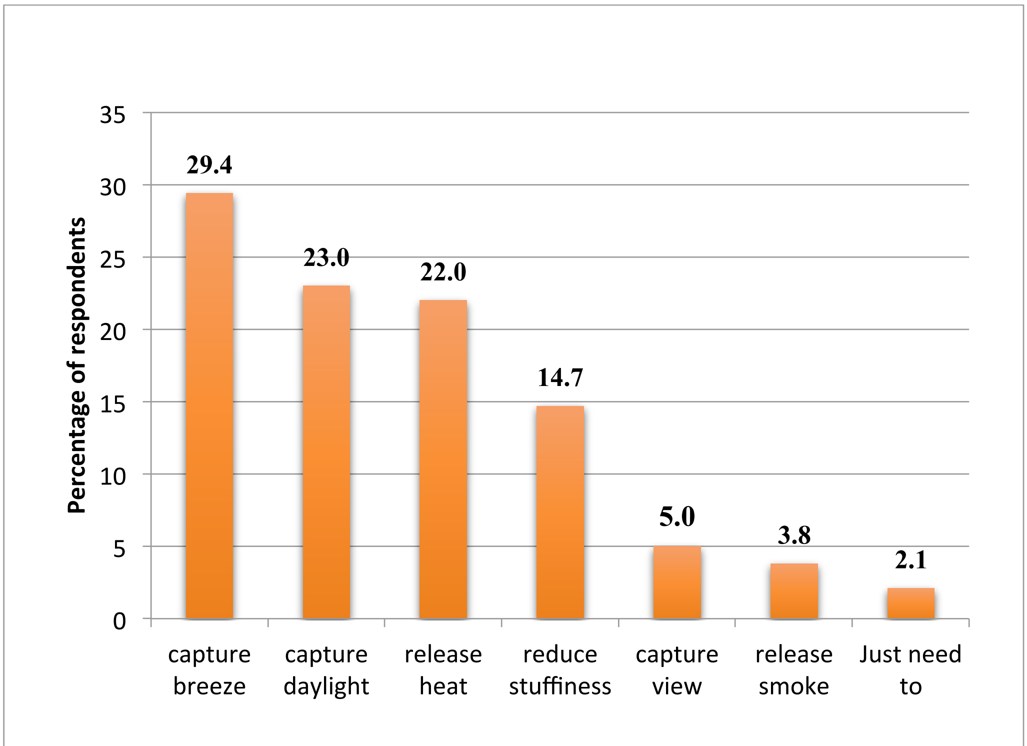

Figure 8. Reasons for opening windows (Source: Authors).

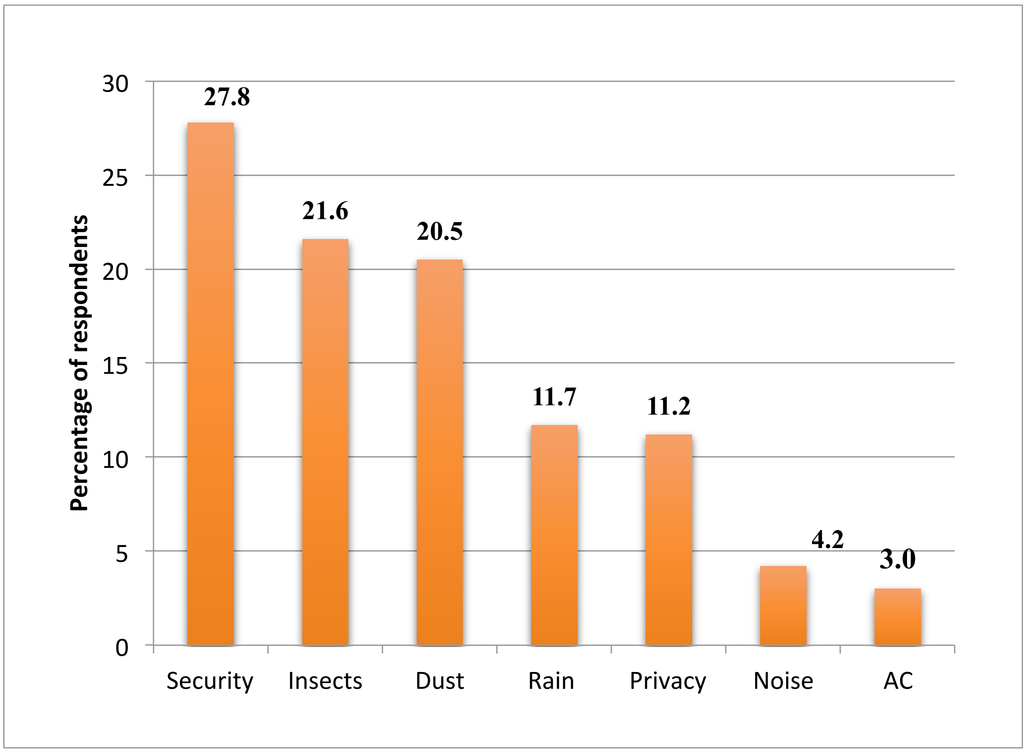

Figure 9. Reasons for not opening windows (Source: Authors).

Occupants' level of satisfaction while utilizing natural ventilation

Occupants' perception of their level of satisfaction with indoor ventilation while utilizing the provided natural ventilation provisions was scored on a five-point scale, where a score of 1 represents "very unsatisfactory" and 5 represents "very satisfactory". From the analysis, the result shows that the majority (57.7%) of the respondents were neither satisfied nor unsatisfied i.e. just felt "OK" (Mean = 2.95).

Factors that contribute to the occupants' level of satisfaction

To test the study's hypothesis that window opening area (UBBL compliant and non-UBBL compliant), occupants' means of achieving comfort (AC ownership), occupants' demographic characteristic (total number of occupants, years of occupancy), and the duration of opening windows contribute to occupants' level of satisfaction with indoor ventilation when utilizing natural ventilation. Table 5 represents the result of the regression analysis where only three IVs (duration of opening windows, UBBL compliancy and AC ownership) were found to significantly influence occupants' overall level of satisfaction. However, the other two IVs (total number of occupants and years of occupancy) showed no significance. The fifth column in Table 5 represents the odd ratios ('OR') derived from the exponent of the estimate values. The OR value for the duration of opening windows, which is 2.34, indicates that with a longer duration of windows being left opened, respondents were likely to be 2.34 times more satisfied with indoor ventilation when utilizing natural ventilation than those who opened less. Consequently, respondents who occupied house types with windows complying with the UBBL requirement were 1.69 times more satisfied than those who occupied houses with non-compliant windows. Furthermore, the result shows that respondents who owned one or more ACs in their homes were 1.80 times more satisfied with indoor ventilation than occupants who did not own any AC. Therefore, the hypothesis that the duration of opening windows, UBBL compliancy, and AC ownership influence occupants' overall level of satisfaction was supported while the hypothesis that the total number of occupants and "years of occupancy influence occupants' overall level of satisfaction was rejected.

Table 5. Ordinal Regression for occupants' level of satisfaction

Parameter Estimates					
Variable	Parameter	B	SE	OR	
Threshold (base= very satisfactory)					
	Very unsatisfactory	-1.07	.57	-	
	unsatisfactory	1.30	.49	-	
	Ok	4.64	.57	-	
	Satisfactory	8.33	.91	-	
Household size		.09	.08	1.10	
Occupancy period		-.04	.05	0.96	
Duration of opening windows		.85	.13	2.34	***
UBBL compliancy (base= non-UBBL compliant)	UBBL compliant	.52	.26	1.69	**
AC ownership (base= do not own AC)					
	Own AC	.59	.24	1.80	**
	Model	-2 Log Likelihood	Chi-Square	df	Sig.
Model-fitting information					
	Intercept Only	574.65			
	Final	517.27	57.39	5	.00
Goodness-of-fit table					
	Pearson		764.45	927	1.00
	Deviance		479.67	927	1.00
Test of parallel lines					
	Null Hypothesis	517.27			
	General	498.99	18.28	15	.25
Pseudo-R^2 measures					
	Cox and Snell	.307			
	Nagelkerke	.352			
	McFadden	.179			

Note: Nagelkerke pseudo R^2 (.352) = 35.2 % (Ganguly et al. (2010) confirms R^2 values between 0.2 and 0.4 could be considered.) 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.
**$p< .05$, ***$p< .01$. B= Estimate; SE= Standard error; OR= Odd ratio (exponent of B)

DISCUSSION

This study has revealed the current scenario of natural ventilation provisions in five different house design types as well as occupants' usage of these provisions. The design review revealed that out of the five studied houses types, only house types 1, 3, and 5 were provided with window openings in accordance with the UBBL 10% window opening area requirement. Furthermore, none of the houses included the 5% unobstructed 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. This is unsurprising as Hanafiah (2005) and Ahmad et al (2011) reported that some Malaysian residential buildings are provided with window openings that do not fulfil the UBBL requirements. This could be due to the rising attempt at increasing energy efficiency with the use of mechanical cooling in buildings. According to Nielsen and Drivsholm (2010) and Lee et al (2012), increasing energy efficiency with the use of mechanical cooling results in houses built to be air tight to prevent leakage of cool draft. This air tightness would be an added advantage only for those occupants that rely on AC as a means of achieving comfort in their homes, whereas those who rely only on natural ventilation would be at disadvantage, as any possible avenue for air infiltration would be welcomed. Also, those windows openings that do not conform to the UBBL requirements are smaller in size compared to those that complied. And this has an implication on the ACH delivered into the indoor space, as wider window openings have been revealed to allow higher ventilation rates in naturally ventilated spaces (Hassan and Ramli, 2010). In fact, Tantasavasdi et al (2001) recommended an opening area of not less than 40% of the floor area while Mohd Firrdhaus and Cristina (2015) recommended 15% to 20% for effective ventilation in the Malaysian climate in order for occupants to attain maximum occupant satisfaction. These are in contrast to the 10% imposed in the UBBL. Mohd Firrdhaus and Cristina (2015) argued that a 10% opening is too small to allow maximum air movement under the Malaysian climate. If that is the case, then it can be argued that the 5% unobstructed openings specified in the UBBL represents an additional 5% to the provided 10% window opening/ floor area, making a total of 15% of total floor area dedicated for an opening in a specified space.

Although a larger window area contributes to a higher ACH, a high ACH would not have been achieved if window openings were not efficiently utilized. This was evident in the simulation results, which demonstrated higher ACH values when windows were left opened for a longer duration (24 hours) compared to when they were left opened for a shorter period. In addition, the regression output from the questionnaire survey responses clearly shows that respondents who opened their windows for a longer duration would be more satisfied with their indoor ventilation than those who opened less. These results support Lee et al (2012) and Marr et al (2012) who agreed that an increase in the frequency and duration of opening windows in residential buildings would lead to an increase in the rate of ventilation and thus resulting in a healthier indoor air quality. Indeed, this supports the hypothesis that the duration of opening windows, UBBL compliancy, and AC ownership influence occupants' overall level of satisfaction.

Nonetheless, the survey results also revealed that the majority of the respondents utilized window openings, despite the fact that the majority of the studied house units had at least one AC unit installed. This usage pattern was also reported by the findings from Kubota and Ahmad (2005), Kubota (2006) and Kubota et al (2009). Kubota (2006: 5) stated that "whether or not the households owned air-conditioners, they tended to open their windows…" In fact, respondents' main reasons for opening windows were capturing breeze and releasing heat. However, windows were mainly opened in the daytime while the AC was mostly operated in the night time, which is in line with the argument made by Kubota et al (2009). However, it was expected that the AC would be utilized more during daytime since the outdoor and indoor temperatures in Malaysia are usually high during the day (Zain et al, 2007; Kubota et al, 2009). Also, since Malaysia's outdoor temperature is normally lower at night, it was expected that the respondents would embrace night cooling (Kubota et al, 2009). This twist of results could be due to the fact that the houses surveyed were mostly not fully occupied during the daytime (office working hours). And, since security and insects were the two main reasons that the respondents chose for not opening their windows, this could also explain why they found it less necessary to open their windows during the night.

CONCLUSION AND RECOMMENDATIONS

In this paper, natural ventilation, openings, and occupants' ventilation behavior were studied. This was done by first investigating natural ventilation provisions of five different residential house design types in accordance with the UBBL. A further study was then carried out to reveal the effectiveness of these provisions. Finally, occupants' patterns of relationship with these provisions were investigated.

Results have shown that the majority of occupants installed an AC in their homes and the AC popularity could potentially explain the absence of the 5% unobstructed openings in all of the studied house types as air-conditioned buildings need to be air-tight to be more energy efficient. However, the UBBL non-conformity of some of the house types in relation to the 10% opening requirement is likely due to the negligence on the part of building designers. This negligence has an impact on the indoor ventilation rates. For example, house types with window/ floor area percentage less than UBBL requirement have shown to exhibit lower ACH values. Contrastingly, those with window/ floor area percentage in line with UBBL requirement exhibited higher ACH values. Not only did these house types enjoy higher ventilation rates, they also recorded higher occupants' satisfaction. Another interesting discovery is that higher satisfaction with indoor ventilation was recorded among occupants who owned an AC than those who did not. A possible explanation for this result could be that those who own an AC also utilize window openings and operate ceiling fans. In such a situation, they have the advantage of switching from one means of comfort to another, whenever they are not satisfied. Thus, these occupants have an added advantage over those who relied solely on window openings and electric ceiling fans.

In summary, although some house types conform to the UBBL 10% window opening requirement and these houses enjoy higher ventilation rates coupled with the fact that majority of the respondents frequently open their windows, occupants are generally not fully satisfied with their indoor ventilation. So, is it due to the fact that the provided natural ventilation provisions are inadequate or the occupants themselves are not really utilizing these provisions? Undoubtedly, residential buildings should strictly adhere to the UBBL requirements for natural ventilation provisions, both the 10% opening/ floor area and the 5% unobstructed opening. However, the 5% unobstructed opening is mostly ignored. Otherwise, a huge difference would have been seen in the ACH (i.e. higher values) of all the studied houses. Therefore, it is highly recommended for the 5% required unobstructed opening to be incorporated in all house designs in Malaysia. With regards to occupants' utilization of the provisions, a longer duration of opening windows is recommended. Also, occupants need to embrace night ventilation as the outside temperature is considered more favourable at this particular time of the day, and this will allow for cool breeze to be admitted into the indoor space. The combined effect of UBBL compliant openings (both 10% and 5%), frequent and longer usage of window openings, and night ventilation by occupants will eventually lead to improved natural ventilation and high occupant's satisfaction with natural ventilation in Malaysia homes.

This study highlights the need for a strict effective enforcement of UBBL compliance for the purpose of building approvals. It is recommended for local authorities to exercise such enforcement not only for approval purposes during the design and construction stages but further extended into the completion stage. Findings from this study inform designers on the importance of the required law governing the natural ventilations in residential buildings.

As this research is only based on a small house sample in Putrajaya and focuses only on terraced house types, a more comprehensive study is recommended to assess the general ventilation provisions in the Malaysian housing sector at large. Due to other limitations of this study, the following studies are also recommended:

1. Additional behavioral factors that could influence occupants' level of satisfaction with regards to natural ventilation provisions and their effectiveness,
2. Other architectural features and environmental factors (e.g. building orientation, wind flow, and directions) that could improve natural ventilation in residential buildings,
3. Review of window opening designs that incorporate devices to resolve the issue of security, insects and dust (the main reasons that prevent occupants from opening their

windows) without jeopardizing the benefits gained from utilising natural ventilation (e.g. to capture breeze and daylight and also to release heat), and
4. Considerations of the micro-climates of the study area (collecting physical environmental data), particularly the characteristic of the natural wind flow, wind directions, and wind velocity, and subsequently compare the results with those derived from this study.

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