INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
Vol. 10 No. 1 (2019) 23-33

IJSCET

http://penerbit.uthm.edu.my/ojs/index.php/ijscet
ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Building Design Effect on Indoor Natural Ventilation of Tropical Houses

Izudinshah Abd Wahab[1*], Hazri Abd Aziz[1], Nur Nasuha Abd Salam[1]

[1]Department of Architecture, Faculty of Civil and Environmental Engineering,
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2019.10.01.003
Received 16 November 2018; Accepted 21 May 2019; Available online 01 June 2019

Abstract: Air movement is one of the important parameter to establish a good indoor thermal condition. Due to the public environmental concern, people are becoming more interested on turning to the natural sources in achieving the parameters. With a good design approach considering the matters, building is expected to be able to provide good indoor natural ventilation flow inside, hence keeping comfort to its habitable spaces. As being studied before, there are type of houses that contribute to its indoor natural ventilation. However, a proper design solution may still required in determining the design elements to be used. This research defined the significant elements as a proper specified attributes which were observed in case studies. Three categories of tropical houses were studied under the category of vernacular house, contemporary house with vernacular element and contemporary house. Spaces of the houses that indicate good indoor natural ventilation performance were observed on the presence of the specified attributes. Based on the analysis, wind catcher element was found to be the most significant attribute to contribute the maximum to indoor natural ventilation. Wide opening was also found to be significant especially with those with louvers. It is also interesting to find how indoor layout design also significantly giving impact on the performance. Therefore, besides concerning on how to extract the outdoor air flow into building, it is also important to manage the indoor air flow effectively to benefit the occupants.

Keywords: natural ventilation, indoor natural ventilation performance

1. Introduction

The housing demand growth is common in developing countries. While there are ups and down of the economic demand towards the supply throughout years, housing development is generally growing. One of the priority aspect considered when buying house is indoor thermal comfort. In tropical region, where the climate is hot and humid, concern on the house is about the ability to keep the indoor thermal cool and comfort. Generally the outdoor tropical air temperature is around 28°C to 30°C (Ahmed, 2003) whereas the comfort level of tropical climate indoor spaces is around 26°C to 29°C (Nicol, 2004; Zain, Taib & Baki, 2007; Candido *et al.*, 2010).

Several factors determined indoor thermal comfort. One of the highly contributing factor is air movement. There is no specific standard of air movement velocity required for house indoor due to variety of activities that may held at home, thus requiring variety level of air movement to cool the occupant. However, based on previous research, 2m/sec air velocity is accepted as the common required air movement to gain comfort (Zain *et al.*, 2007; Candido *et al.*, 2010; Jamaludin *et al.*, 2015). This may achieved naturally or using mechanical devices. Nowadays, due to unpredictable increasing price of electricity and petrol, people have become more environmentally responsive (Wahab *et al.*, 2018).

**Corresponding author: izudin@uthm.edu.my*

Therefore users are becoming more concern in considering natural ventilation as the source of indoor air movement rather than depending on Heating, Ventilation and Air Conditioning (HVAC) system. In previous researches, several building elements were found closely associating the natural ventilation flow in a building (Wahab, *et al*., 2018; Wahab & Ismail, 2014; Ramli & Hassan, 2010; Nguyen *et al*., 2011; Antarikananda *et al*., 2006). However, unpredictable natural ventilation effect on building may not bring the desired thermal condition to the interiors when applied to other building. Therefore, this paper presents a research finding on significant priorities of the building elements in general that contribute the best to a good indoor natural ventilation.

2. Research Background

Ventilation is important in supplying fresh air and removing heat and air pollution inside building to provide acceptable indoor air quality (IAQ). Towards sustainable living, buildings nowadays are expected to be less depending on mechanical system to generate the ventilation. With a good design approach on the matters, building is expected to be able to allow comfort ventilation flow inside, hence keeping comfort to its habitable spaces. Basically, natural ventilation relies on two principles of air movement which are cross and stack ventilation. In order to drive cross ventilation and stack ventilation naturally, there should be air pressure difference between any two points inside a room.

Generally cross ventilation moves horizontally and depends on wind blow. Wind blow occurs by air pressure difference between points in larger scale where the wind travel in distance. Therefore the direction may depends on seasonal monsoon but is also highly influential by physical obstruction along the way. In smaller scale, air pressure difference also happened between the walls of the building design. Air pressure in front of windward wall that faces the wind direction will be higher than at the leeward wall which against the wind direction. This may create the air flow pattern surrounding the building. In any scenario, good building design should be able to allow the flow inside to desired areas (Mohamed *et al*., 2013).

Meanwhile stack effect commonly moves vertically. It is still a phenomenon of air movement which relies on air pressure difference. In tropical areas, due to temperature difference, the air inside the building is either more or less dense than the air outside. The process of balancing the pressure may cause the air either to rise up or settling down. The effect is greater in building which allow a space for the vertical air movement. In situation where the building has an atrium, a natural air flow will be caused if there are openings at high and low level of the atrium. In tropical climate countries, where normally the air inside is cooler than that outside, the air will drain out the low opening, being replaced with a fresher air from outside through the high opening. Stack effect works best when the air intakes are as low as possible and the height of building spaces is as great as possible (Narenda *et al*., 2001).

Ironically, the physic of air movement in both principles may contradict with each other [Ramli & Hassan, 2010; Narenda *et al*., 2001). Most previous researches are only focusing on either one is the aspect of design effect prediction and simulation due to the situation [Ramli & Hassan, 2010; Lomas, 2007). Throughout years, there are many approaches introduced to deal with the matter. Based on builders' experience, various types of openings are designed to enhance the air flow into building. However, in tropical climate area, excessive openings may also allow heat penetration into building which cause indoor overheating. Along with immature ventilation opening that fails to enhance the air flow, indoor layout may also influences indoor air movement. Without proper planning and understanding on the science of air movement, such openings may not contribute to thermal comfort effectively. Due to that, typical terrace houses indoors nowadays are recorded to be hotter than outside (Davis *et al*., 2005). This demand a proper design solution on how to preserve and improve the temperature level of indoor air while at the same time encouraging the air movement in order to balance the humidity level.

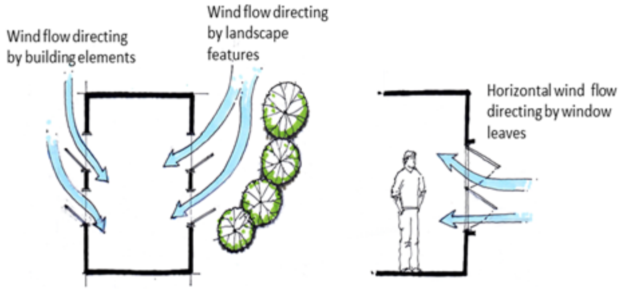
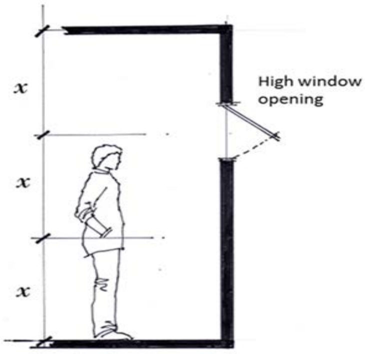
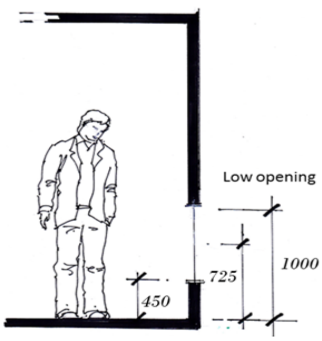
3. Methodology

In the process of identifying the building elements, nine building attributes were defined with proper specifications in order to objectively differentiate the elements. The attributes were defined based on previous research findings on elements that may influence good air flow in buildings. As shown in Table 1, the nine attributes were defined specifically for the purpose of the research analysis. With proper specifications, the attributes presence may objectively identified in the case studies of this research.

Among building types, vernacular houses is commonly agreed to have a good indoor thermal environment. Previous research also proven the type of house to reflect positively to their surrounding in providing good indoor natural ventilation [Ramli & Hassan, 2010; Nguyen *et al*., 2011). Therefore, in determining the categories of houses for this research case studies, vernacular house stands its own category. Whereas other categories representing contemporary houses with vernacular elements and contemporary houses. Selection of the houses are as in Table 2.

Indoor natural ventilation measurement in each of the houses were done as the case studies. Measurement were done in almost every spaces inside the houses and as well outside surrounding the building. The measurement were done hourly during the studies period. The outside mean reading were to determine the hourly outdoor air movement velocity. Whereas the indoor measurement stand as the spaces indoor air movement velocity particularly.

Table 1 - Specification of natural ventilation attributes

	Natural Ventilation Attributes	Specifications
1	Wide Windows and Door Opening	Opening with size of 20% of the space floor area
2	Wind Driven Windows / Doors Design.	Elements to direct wind flow 
3	Louver blades at openings	Having louvers at any angle which allow air to sip between the blades.
4	High Openings	Central level of high window opening at 2/3 of the floor to ceiling height. 
5	Interior Layout	Open plan concept design where spaces are adjoined without wall or barrier to allow ventilation free flow
6	Low Opening	Opening with central height at 450mm from floor level or less 

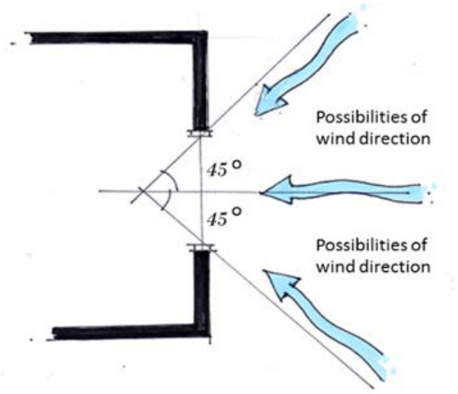
7	Wind Catcher element	Openings with 45° or less angle from the direction of wind flow. The openings height also shall not be blocked by any obstruction. 
8	High Ceiling	Ceiling height from floor to be minimum 4000m.
9	Raised Floor	Floor to be raised at minimum 300mm from the Ground Level.

Table 2 - Categories of houses and the case studies

Categories	Case Studies
Vernacular House	Tok Su House of Penang, Malaysia
	Sri Banai House of Kedah, Malaysia
	Batak Toba House of Indonesia
	Kalimantan Tengah House of Indonesia
Contemporary House with Vernacular Elements	Sri Merlong House of Rengit, Malaysia
	Sri Penggaram House of Batu Pahat, Malaysia
Contemporary House	Skudai Box Johor, Malaysia
	Sekeping Seapark of Selangor, Malaysia

Portable Anemometers were used in the process of measuring the air movement velocity. Spaces in the case studies were numbered as the indoor points, whereas outdoor points were also determined surrounding the house. Air movement velocity of each points were measured in a same hourly time frame. 10 minutes limitation period was set to be the allowable period to cover all indoor and outdoor location points for each hourly data measurement.

Fig. 1 - Vernacular house case studies (Clockwise from top: Batak Toba House, North Sumatera House, Tok Su House & Sri Banai House)

Fig. 2 - Contemporary house with vernacular elements (From left: Sri Merlong House, Sri Penggaram House)

Fig. 3 - Contemporary house case studies (From left: Sekeping Seapark, Skudai Box)

The indoor natural ventilation performance of each spaces in the case studies building was determined by the ratio of;

$$\frac{\text{The mean indoor air movement velocity}}{\text{The mean outdoor air movement velocity}}$$

This indicates how capable the spaces in allowing outdoor air flow into the building. However, theoretically, air movement may not only influenced by the outdoor cross ventilation. There are other factor like stack effect which depends on the air buoyancy effect to move the surrounding air. Therefore an over 1 unit ratio of indoor natural ventilation is also expected.

As for the analysis, the presence of the natural ventilation attributes specified earlier was identified in the spaces studied. Frequency of the attribute to present at spaces with good indoor natural ventilation performance may remark its significance.

4. Result and Discussion

As for the findings, all spaces with points measured more than 0.2m/sec of indoor air movement were listed. Compared to each outdoor air movement velocity, the spaces were ranked as in Table 3, based on their indoor natural ventilation performance ratio towards the natural ventilation attributes presence in the spaces..

Table 3 - Significant spaces with good indoor natural ventilation performance matrix to the natural ventilation attributes presence

No.	Spaces Studied (Point)	Indoor Natural Ventilation Performance Ratio	Natural Ventilation Attributes								
			Wide Opening	Wind Catcher	Wind Driven	High Vent Opening	Low Vent Opening	Space Layout	High Ceiling (Stack Effect)	Opening with Louvers	Raised Floor
1	SM (3)	0.854		/				/			
2	SB (9)	0.843	/	/		/	/		/	/	/
3	SB (11)	0.797	/	/		/	/		/	/	/
4	TS (2)	0.775	/	/				/		/	/
5	SM (4)	0.746	/	/		/	/		/	/	
6	SB (8)	0.661	/	/	/	/	/		/	/	/
7	SS (7)	0.652		/				/			
8	SB (13)	0.638	/	/			/	/		/	/
9	SM (7)	0.636	/	/	/					/	
10	BT (5)	0.607		/		/	/	/	/		
11	SM (8)	0.600	/	/	/					/	
12	SKBX (5)	0.600	/	/				/			
13	SB (14)	0.592	/	/			/	/		/	/
14	SM (2)	0.582	/	/	/			/		/	
15	SB (1)	0.570	/	/	/	/			/	/	/
16	SB (10)	0.547	/	/	/	/			/	/	/
17	SB (2)	0.501	/	/	/	/			/	/	/
18	SB (5)	0.501	/	/	/	/			/	/	/
19	BT (6)	0.467		/		/	/	/	/		
20	BT (9)	0.467		/		/	/	/	/		
21	BT (12)	0.467		/		/	/	/	/		
22	KT (1)	0.462		/	/	/	/		/	/	/
23	KT(10)	0.462	/	/		/	/	/	/	/	/
24	SM (6)	0.450		/				/			
25	SM (1)	0.436	/	/	/	/				/	
26	SS (2)	0.435	/	/				/		/	
27	SS (5)	0.435	/	/				/			
28	SS (12)	0.435	/		/	/		/		/	
29	SS (14)	0.435	/		/	/		/		/	
30	BT (10)	0.420		/		/	/	/	/		
31	BT (4)	0.414		/		/	/	/	/		
32	SKBX (3)	0.400	/	/	/			/			
33	SKBX (4)	0.400	/	/	/			/			
34	SKBX (6)	0.400	/	/	/			/			
35	BT (7)	0.367		/		/	/	/	/		
	TOTAL		**24**	**33**	**15**	**20**	**15**	**23**	**17**	**20**	**12**

- SM=Sri Merlong, SB=Sri Banai, TS=Tok Su, SS=Sekeping Seapark, BT=Batak Toba, SKBX=Skudai Box, KT=Kalimantan Tengah

Sri Banai, a vernacular house, indicates its significance by dominating nine out of 18 indoor spaces with ability to bring in 50% or more outdoor air movement into its spaces. While, it was Sri Merlong house that recorded the highest percentage of indoor air movement performance at Point 3 which located at the *Serambi* (open lobby). Being partly open, its performance was very well expected. However it is also interesting to see Point 9 and 11 of Sri Banai house which located at its Family Area to record a high performance. Both Sri Merlong and Sri Banai covers 14 out of the 18 indoor spaces within the criteria, hence remark their design significance on enhancing indoor natural ventilation.

Based on the result, only Sri Penggaram house failed to be in the list. Figure 4 to Figure 10, showed all the rest of the case studies with red marked spaces indicating the significant spaces with good indoor natural ventilation performance.

Based on the spaces analysis in Sri Merlong house and Sri Banai house, both houses are using high pitched roof which provide high ceiling for the indoors. Both also provides openings below the roof which may act as the wind catcher elements and high windows that may allow stack effect process. Direct flow through ventilation openings at small spaces such as at Point 13 and 14 do contribute to the scenario as expected.

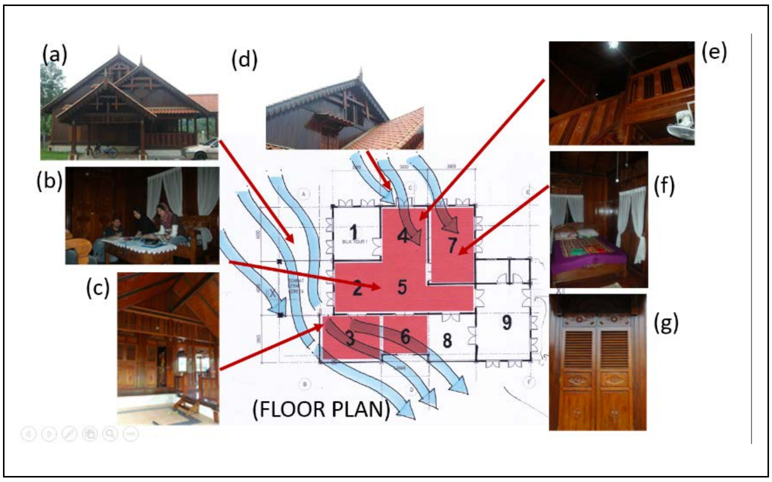


Fig. 4 - Sri Merlong house with significant spaces layout and the photos. Point 3 and 6 as the serambi (open lobby), point 2 and 5 as the living hall, point 4 as the family area and point 7 as the bedroom

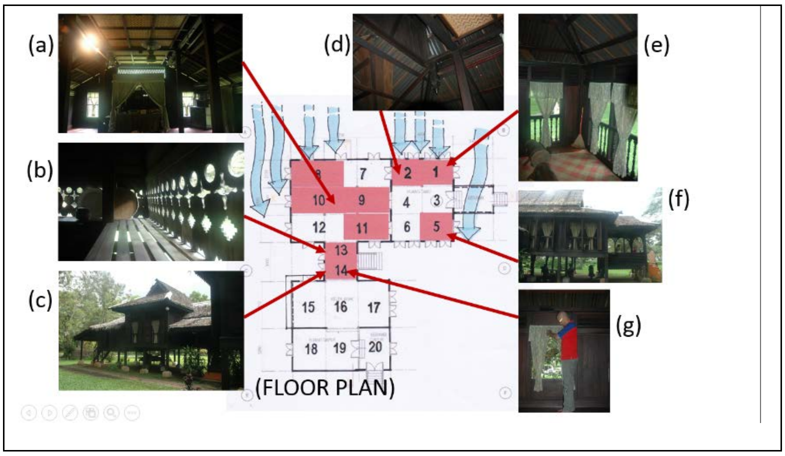


Fig. 5 - Sri Banai house with significant spaces layout and the photos. Point 1, 2 and 5 as the living hall, point 8, 9, 10 and 11 as the family area and point 13 and 14 as the rest area

Ironically, vernacular elements in Tok Su house do not show obvious significant effect on good indoor natural ventilation performance. Being a small Guest Area with ample size of openings contribute to the result as expected. Meanwhile, Indonesian vernacular houses were found not to have such a wide window openings when compared to Malaysian. However high openings on both houses show possibility of the wind catcher attribute towards their indoor natural ventilation performance.

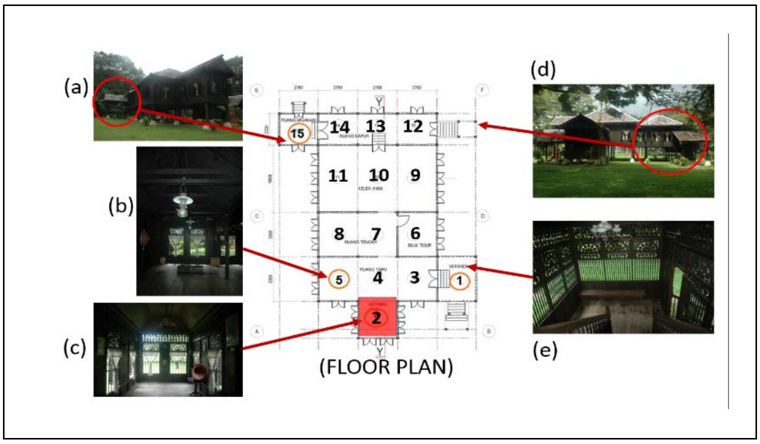


Fig. 6 - Tok Su house with significant space layout and the photos. Point 2 as the guest area

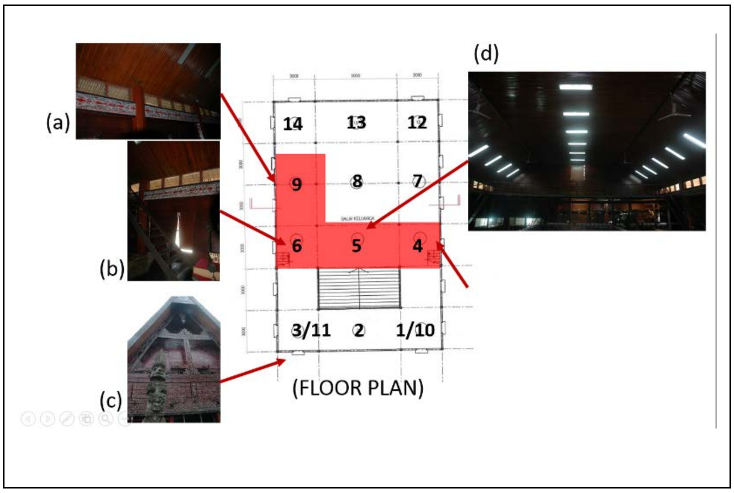


Fig. 7 - Batak Toba house with significant spaces layout and the photos. Point 3 and 6 as the serambi (open lobby), point 2 and 5 as the living hall, point 4 as the family area and point 7 as the bedroom

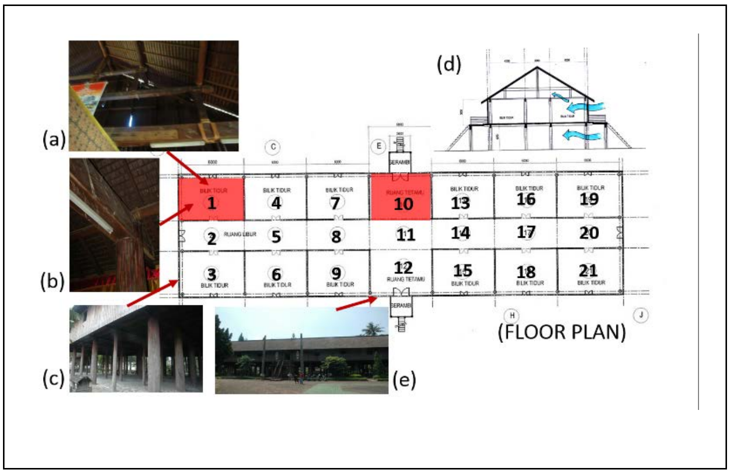


Fig. 8 - Kalimantan Tengah house with significant spaces layout and the photos. Point 1 as the bedroom and point 10 as the guest hall

Meanwhile, besides of having open concept layout design, contemporary design houses, Sekeping Seapark and Skudai Box do show limitation on the indoor natural ventilation effect. As to protect the occupants privacy, solid fencing wall were used as the site boundary, hence may block the crossing ventilation from reaching the house at certain level.

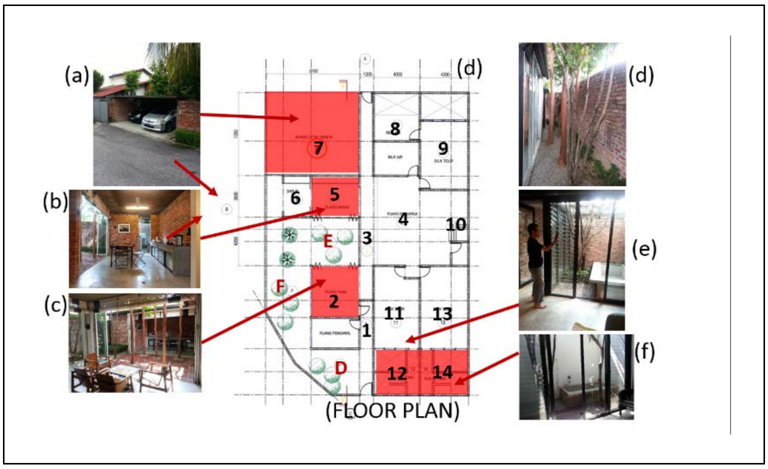


Fig. 9 - Sekeping Seapark house with significant spaces layout and the photos. Point 2 as the living hall, point 5 as the dining hall, point 7 as the car porch and point 12 and 14 as the bedrooms

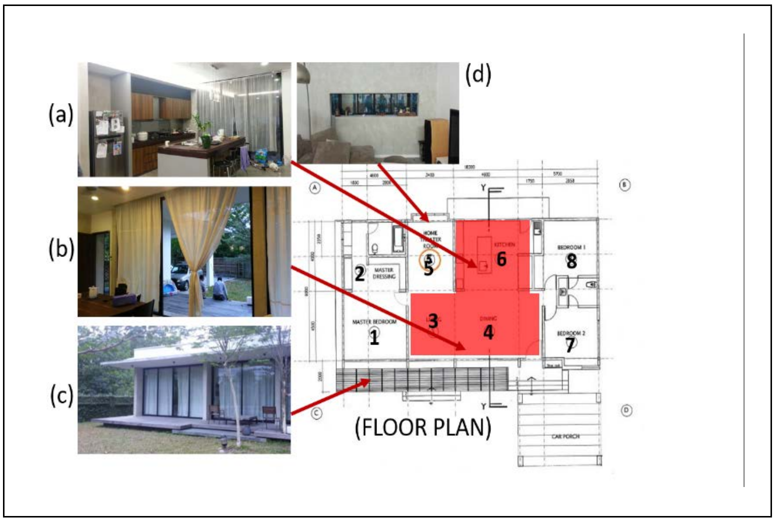


Fig. 10 - Skudai Box house with significant spaces layout and the photos. Point 3 and 4 as the dining attach living hall, point 6 as the kitchen

As a whole frequency analysis on the presence of the nine attributes in all the case studies spaces is shown in Table 4. Based on the findings, wind catcher elements facing the wind flow orientation was found to be the most significant attribute. Being at higher level, such openings may stand a better chance to collect the crossing wind flow which obviously stronger at higher level.

Wide openings was found to be significant as well. However, there was limitation especially at lower floor level, where the crossing wind may also interrupted by other surrounding objects as happened in Sekeping Seapark and Skudai Box. Besides that, it was also found that louvered openings may significantly contribute to the good air flow into the houses. Thinner valve for the flow may cause higher velocity of incoming air which is good to push air movement further inside the building. Besides acting as blind to avoid sun glare, louvres may also help in directing the flow through the louver blades angle attack.

Besides the process of catching the outside air flow into the building, it is also important to manage the indoor air movement flow inside the building. Having walls inside a house may allow winward and leeward side of wall concept to occur in a building due to the air pressure difference distributed. Therefore, a proper planning with understanding on the physic of air movement may important to design the acquired air flow inside a building.

Table 4 - Frequency of attributes presence in good natural ventilation performance spaces

No.	Natural Ventilation Attributes	Number of Presence in good indoor natural ventilation performance areas	% Frequency
1.	Wind Catcher Elements Facing Orientation of Wind Flow	33	18.4 %
2.	Wide Window / Door / Openings	24	13.4 %
3.	Ventilation Flow Through Indoor Space Layout	23	12.8 %
4.	High Opening / Clestories Windows	20	11.2 %
5.	Louvers Blades at Openings	20	11.2 %
6.	High Ceiling with Stack Effect Potential	17	9.5 %
7.	Low Openings (Ornamentals or Windows Joining the Floor)	15	8.4 %
8.	Wind Driven Windows / Doors Design	15	8.4 %
9.	Raised Floor	12	6.7 %
	Total		100 %

5. Conclusion

In this study, a list of significant attributes was developed in hierarchy based on their contribution toward a good indoor natural ventilation. While most attributes are common elements used since vernacular era, it is important to determine, which attribute do perform better than the rest. The knowledge may important to architects and designers in deciding priorities of the attributes to be applied during house design process and development.

Acknowledgement

The authors would like to thank the Department of Architecture, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia.

References

Ahmed, K. S. (2003). Comfort in urban spaces: defining the boundaries of outdoor thermal comfort for the tropical urban environments. Energy and Buildings, 35(1), 103-110.

Antarikananda, P., Douvlou, E., & McCartney, K. (2006, September). Lessons from traditional architecture: Design for a climatic responsive contemporary house in Thailand. In Proceedings of the 23rd Conference on Passive and Low Energy Architecture-PLEA2006-, Geneva, Switzerland (pp. 11-43).

Cândido, Christhina, et al. "Air movement acceptability limits and thermal comfort in Brazil's hot humid climate zone." Building and Environment 45.1 (2010): 222-229.

Davis, M.P., Nordin, N.A., Ghazali, M., Durak,M.J. & Reimann, G. (2005). Reducing Urban Heat Island Effect with Thermal Comfort Housing and Honeycomb Township. Conference on Sustainable Building South East Asia, 11-13 April 2005, Malaysia.

Jamaludin, N., Mohammed, N. I., Khamidi, M. F., & Wahab, S. N. A. (2015). Thermal comfort of residential building in Malaysia at different micro-climates. Procedia-Social and Behavioral Sciences, 170, 613-623.

Lomas, K. J. (2007). Architectural design of an advanced naturally ventilated building form. Energy and Buildings, 39(2), 166-181.

Mohamed, N., Al-Jaroodi, J., Jawhar, I., & Lazarova-Molnar, S. 2013, May. Middleware Requirements for Collaborative Unmanned Aerial Vehicles. In Unmanned Aircraft Systems (ICUAS), 2013 International Conference on IEEE. 1051-1060.

Narendra, S., De, V., Antoniadis, D., Chandrakasan, A., & Borkar, S. (2001, August). Scaling of stack effect and its application for leakage reduction. In Proceedings of the 2001 international symposium on Low power electronics and design (pp. 195-200). ACM.

Nguyen, A. T., Tran, Q. B., Tran, D. Q., & Reiter, S. (2011). An investigation on climate responsive design strategies of vernacular housing in Vietnam. Building and Environment, 46(10), 2088-2106.

Nicol, F. (2004). Adaptive thermal comfort standards in the hot–humid tropics. Energy and Buildings, 36(7), 628-637.

Ramli, M. & Hassan, A. S. (2010). Natural ventilation of indoor air temperature: A case study of the traditional Malay house in Penang. Am. J. Engg. & Applied Sci, 3(3), 521-528.

Wahab, I. A., Ismail, L.H., Abdullah, A. H., Rahmat, M. H. & Salam, N. N. A. (2018). Natural Ventilation Design Attributes Application Effect on Indoor Natural Ventilation Performance of a Double Storey Single Unit Residential Building. International Journal of Integrated Engineering, 10(2), 7-12.

Wahab, I. A., & Ismail, L.H. (2014). Natural Ventilation Performance of Kedah Vernacular House. International Journal of Sustainable Construction Engineering and Technology, 5(2), 53-65.

Zain, Z., Taib, M., & Baki, S. (2007). Hot and humid climate: prospect for thermal comfort in residential building. Desalination, 209(1), 261-268.