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Opening Design and Position Effect on Building Natural Stack Effect and Cross Ventilation

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***Abstract*—Stack effect ventilation in building occurs due to the movement of the cold and warm air into and out of the building driven by buoyancy. Buoyancy force can be increased by increasing the thermal difference and the height of the shaft where stack effect ventilation may happens. Thermal different is less controllable, leaving the shaft and openings design of a building as the best option in exploring the potential of stack effect ventilation. This paper presents a finding of a study on ventilation openings positioning effect towards stack effect neutral plane. A house in Batu Pahat, Johore of Malaysia called *Kebun Angin* was chose as the subject based on its internal space layout that consists of a central atrium acting as the shaft. Using neutral plane calculation, the level of the plane was determine to understand the character of the ventilation flow theoretically. While using CFD simulation, equal size of indoor and outdoor openings was found to be the best design in optimizing natural ventilation in the building. However, the presence of several windows between inlet and outlet was disturbed the air movement in atrium throat, thus reducing the potential of stack effect.**

***Index Terms*— Natural ventilation, stack effect, openings, neutral plane**

I. INTRODUCTION

Ventilation in building is necessary in providing an acceptable indoor air quality (IAQ) which is essentially based on the supply of fresh air and the removal of indoor pollution concentration, and providing thermal comfort by providing a heat transport mechanism [1]. Ventilation can be provided either by natural or mechanical. Houses with sustainable construction concept relies more on natural ventilation to give better indoor air quality (IAQ) and thermal comfort to their occupants. Natural ventilation is a process of changing by supplying and removing air through an indoor space by natural passive means. Natural ventilation is based on two different principles which are cross and stack ventilation. Cross ventilation is the common way to obtain natural air supply in the buildings [2].

However, in order to drive the system, this natural ventilating system relies on natural forces such as wind availability and direction. The building design should be integrated and oriented to these factors to gain excellent cross air ventilation or otherwise, these factors become somewhat unreliable natural resources to achieve excellent air flow and thermal comfort [3].

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In urban surrounding, where there is not much of air movement due to the dense surrounding, stack effect ventilation may contribute significantly to generate building natural ventilation. Stack effect relies on thermal buoyancy as the driving force to create the airflow. Thermal buoyancy occurs when there is density differences between the internal and external air, which caused by temperature difference between the inside and outside or height difference.
When the indoor temperature is higher than the outdoor temperature, the positive pressure is built up in the upper part of the building while negative pressure is formed at the lower part. Between these two pressures, at certain height neutral plane is formed where at this point the pressure equals to each other [1]. At neutral plane level, no horizontal flow occurs due to zero pressure difference between inside and outside of a building. Determination of the location of neutral plane is important to evaluate the flow due to stack effect [4]. However, when there is another opening between the inlet and outlet openings, the cooperation should be intensified in order to avoid the air flow short-circuits phenomenon [5].

A. Indoor air quality

Indoor air quality is referring to the air quality that qualifies the occupants comfort in the building. Ventilation in the building is designed to provide an acceptable indoor air quality (IAQ), which essentially is based on the supply of fresh air and the removal or dilution of indoor pollution concentration [6,7]. Acceptable indoor air quality is defined as the air in which there are no known contaminants at harmful concentrations and with which a substantial majority of people exposed do not dissatisfaction [8]. Good indoor air quality is required for a healthy indoor environment [9]. Poor indoor air quality may cause variety of short and long term health problems. Inadequate ventilation can increase indoor pollutant levels by not bringing in enough outdoor air to dilute emissions from indoor sources and by not carrying indoor air pollutants out of the building. Without adequate ventilation and cooling, an excessive increase in the efficient use of given space may reduce the quality of its indoor climate to the extent that it affects the people using it, leading to reduced performance and even to an increase in morbidity. Besides air temperature, relative humidity and air velocity are identified as major factors affecting the indoor air quality [10].

B. Thermal comfort

Thermal comfort gives a huge influence to satisfaction of indoor building occupants. Thermal comfort can be defined as that condition of mind which expresses satisfaction with thermal environment. Human thermal comfort is defined as the state of mind that expresses satisfaction with the surrounding environment [8]. This definition describe to us that thermal comfort is evaluated on two vital factors; the personal factor and the environmental factor. Personal factor relates to users opinion where involves their physical body condition and activities. Whereas the environmental factor is based on measurable air relative humidity and temperature along with the velocity of the air movement.

Relative humidity can be defined as the ratio of the partial pressure of the water vapor in moist air at a given temperature to the partial pressure of water vapor in saturated air at the same temperature [11]. Mean monthly relative humidity in Malaysia is between 70 – 90%, which different from one place to another place and one month to another month [12]. Recommended relative humidity by Malaysian Energy Efficient Guideline is 70% [13]. Increase of relative humidity will cause uncomfortable surrounding as body sweat unable to evaporate to cool the body.

As a tropical country, hot and humid climate give Malaysia almost uniform temperature throughout the year with the average temperature of 26°C to 37°C [14]. However, a study on air temperature from natural ventilation during office hours (0800-1700) and non-working hours (1800-0700) in Subang found that it is hard to achieve 26°C [15].

Meanwhile, air movement in building is provided by ventilation either naturally or mechanically. Air movement will affect the thermal comfort of occupants depending on environmental temperature and humidity. When the air temperature is above the skin temperature, the effect of the air movement will be as same as other climatic factors and the increase of air movement will raise the skin temperature [16]. Thus, good indoor air quality (IAQ) and thermally comfortable buildings usually are designed within concern of proper air movement through sustainable approach of construction and development [17].

C. *Natural ventilation*

A good dwelling design can always provide the occupants with favorable and comfortable indoor environment during most of the years without assisting by mechanical devices [19]. Nowadays, many of building use mechanical system to assist the air movement of their house or building. However, most of these technologies may cause an increase of electricity usage. Due to increasing of awareness of the environment and cost effect, people nowadays are tend to opt for natural sources, so do the ventilation system.

Besides relying on cross ventilation, stack effect ventilation is also seen to be potentially exploited in giving benefit for building occupants. As it is generated by the means to equalize the air pressure between two points, the location of neutral plane should be considered properly to create the natural air flow from outside into the building before the contaminant air inside the building can be expelled. Stack ventilation carry the warm air during summer into the building through the top opening, and then drain it out by the lower opening. Whereas, when the outside temperature is lower than the inside temperature, the warmer air will float out the top opening, and replacing by the cooler air from outside through the lower opening.

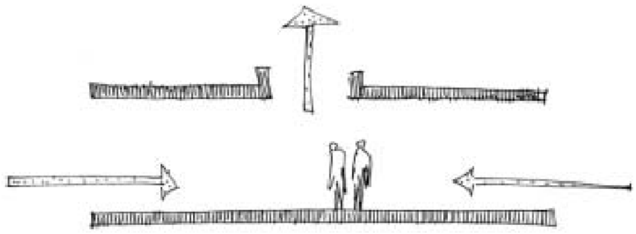

Fig 1. Stack ventilation process through the building [1].

Air movement into and out of the buildings is driven by buoyancy [1]. Buoyancy occurred resulting from the different of air density due to temperature and moisture differences from internal and external the buildings. Over-pressure will be built up in the upper part of the building and under pressure is created in the lower part of opening when the outdoor air temperature is less than the indoor air temperature. In hot and humid climatic condition country like Malaysia has made the stack ventilation inefficient due to the lower air temperature difference between the inside and outside of naturally ventilated [20]. Therefore, several elements should be considered to enhance the effectiveness of stack effect

D. *Stack height*

In order to enhance stack effect ventilation, the potential of stack effect can be estimated during the design process through use of the following equation [21].

V = 60 K A [g h (Ti-To)/Ti]1/2

Where:-
V is the estimated air flow rate (cfm)
K is a factor that accounts for orifice characteristics (assumed = 0.65)
A is the smallest value of inlet. Stack “throat”, or outlet areas (sq ft)
g is the gravitational constant (32.2 ft/sec2)
h is the stack height
Ti (inside is the higher of two differential air temperatures (° R).
To (outside) is the lower of two differential air temperatures (° R).

Therefore, it can be determined that the potential of stack effect ventilation is depending on three main variables from the equations which are the size of openings, the difference of height between the inlet and outlet, and the difference in dry-bulb air temperature between the stack inlet and outlet [22]. As air movement create by stack effect is usually inadequate for physiological cooling, the best method to keep the air flowing is by increasing the air volume or stack height or increasing the air temperature difference [19]. The density of dry air varies with air temperature [18]. Thus, by increasing the stack height, the difference in pressure may also increase if the air in the stack column remain their differences. During stack effect processes, the pressure at the base of the building will be reduced as the warm air rose. Thus, the pressure will draw the cold air through the high level ventilation openings such as windows, open doors or any other openings and leakages.

E. Openings in building

In building, there could be more than two different size and locations of the openings which could interrupt the air flow thus reducing the pressure of the air. The maximum number of openings in building produces high air intakes outside the house to give poor performance of stack effect [3]. There are two different types openings in building which will be affected the flow of the air which are purposed-provided and adventitious openings [23].

Openings of building however, might be combined in parallel or series based on its other function. The configurations and design types are usually specified by architects [24]. This will give different effect on the building wind flow. If designed appropriately based on the wind flow character, building ventilation may be enhanced, hence increase the indoor thermal comfort level significantly.

In order to generate the air flow in building through stack effect, the design of the building must providing as much height differences as possible between the two different openings as the wind is not reliable. This is essentials to create the air movement by buoyancy. This buoyant air whenever confined within the shaft will create a pressure by gravity acting on the difference in air densities over the height of shaft [26]. The warmer air with greater pressure will reduce the pressure in the lower opening in building, thus drawing cold air in through open doors, windows, or other openings and leakage. However, despite increasing the stack height, the area and location of openings in building should also being considered as these parameters will directly influence the pressure distribution created. The pressure had been created at certain height will equal to each other where at this level is referred as neutral plane. At neutral plane, there is no pressure created. The neutral plane or the level of zero pressure difference with regard to the building exterior will occur at the height in the stack at which the cumulative resistance to the airflow balances the cumulative resistance to outflow [26]. Neutral plane is the horizontal plane at which the pressure equals to the outdoor pressure it is known as Neutral Pressure Plane (NPP) [16]. The area of inlet openings should be not less than the outlet openings if the neutral plane needs to be play down [5].

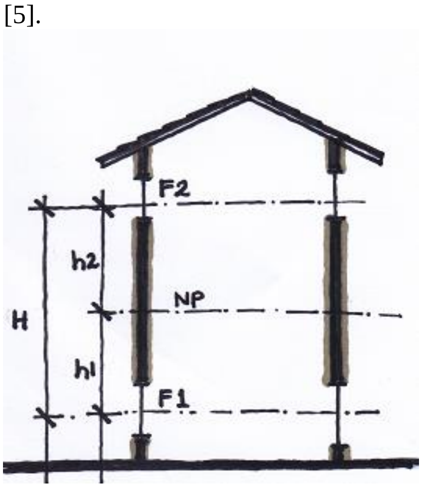

Fig 2. The pressure when at inlet and outlet are same is known as neutral plane.

II. RESEARCH APPROACH

This research was done based on objectives; to identify the effect of window position and size towards the stack effect neutral plane; and to determine the influence of multi openings at various height on the stack effect potential.

The research was conducted based on an actual residential building named *Kebun Angin*, located in Batu Pahat, Johor. The determination of the suitable openings size that will greatly influence the neutral plane location and give significant impact to stack effect for the house are tested by CFD simulation. In reality, stack ventilation will also influenced by wind driven air from outside of the building. Therefore, the setting of surrounding environment was done based on the actual surrounding data. Thus, it may not represent on stack ventilation solely.

Due to consideration on actual case, the surrounding environmental data was also referred on actual site. Data collection was done in three phases to find the mean reading for air temperature, relative humidity and air movement. The construction of the building was just started during the data collection process. No physical obstruction was there on site as the construction was at the stage of preparing the ground beam at the time. However determination on the point for data collection using data logger E-Sampler had to be done properly so that the process did not cause problems to the construction work as shown in Fig. 3. The findings on environmental data gathered were recorded based on the maximum reading and the minimum reading. The mean was set to be used in CFD simulation study. Average daytime air movement was 1.32-1.33m/sec. with 34.6°C average surrounding air temperature. Indoor air temperature was based on average tropical air temperature at 30°C. Meanwhile average night time air movement was 0.7-0.71m/sec. with average surrounding air temperature at 27.7°C. Indoor air temperature remains at 30°C.

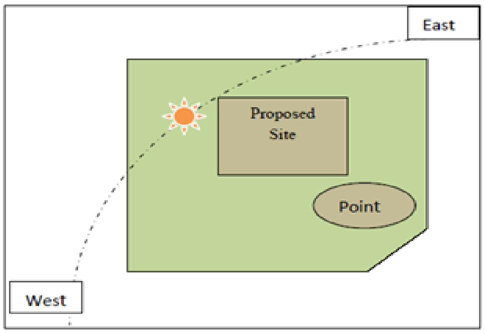

Fig 3. Proposed set point for measuring parameters

Fig 4. Proposed site during on field data collection

Table (i):
Environmental Data of the Site

		AT, °C	WS, (m/s)	RH, (%)	Pressure, Pa
Day time	Maximum	39.3	2.8	66	100916
	Minimum	27.6	0.3	37	100388
	Average	34.6	1.3	47.7	100678
Night time	Maximum	28.8	0.8	53	100877
	Minimum	26.9	0.3	48	100623
	Average	27.7	0.7	49.9	100750.6

Based on the house actual design, the neutral plane level was determine based on following formula [25]:

$h1 = (HF2^2)/(F1^2 + F2^2)$
$h2 = (HF1^2)/(F1^2 + F2^2)$

where:
h1=height of inlet to the neutral plane (m)
h2=height of neutral plane to outlet (m)
H=total height between inlet and outlet (m)
F1=area of inlet (m2)
F2=area of outlet (m2)

This study concentrated on area which directly connected to the house atrium. The atrium was designed to be the house stack throat. Besides the clerestory window being the side lit vent opening for the atrium, only two types of windows are directly attached to the area which are W4 and W11 as shown in Fig. 5. These windows design come in three segments; the openable window itself, the upper adjustable louvers on top of the window and the lower adjustable louvers below the window. The sizes of the windows and louvers are shown in Table (ii). Due to the scenario, there are three comparable conditions which may happened which cause three different levels of neutral plane.

First condition is where all three segments are open allowing the wind flow to go through the window and the upper and lower louvers. Second condition is where the louvers are all closed leaving only the window open. Third condition is where only the lower louvers are open. As the clerestory windows at top of the stack throat is open in all conditions, all three conditions will determine three different neutral plane level due to the stack height and lower opening size difference.

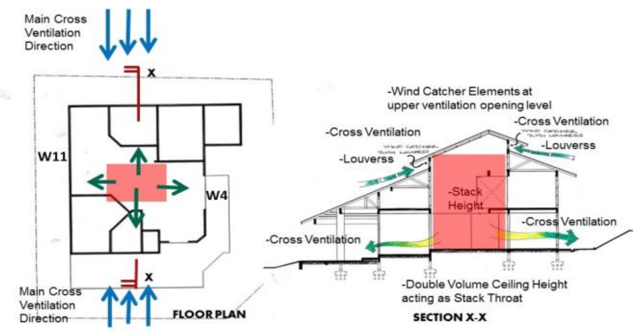

Fig.5. *Kebun Angin* layout design and cross ventilation.

Table (ii):
Area of Openings in Kebun Angin House

Opening type	No	Window area(m^2)	Louvers area (upper)(m^2)	Louvers area (bottom)(m^2)
W4	1	0.93	0.54	1.35
W11	2	0.93	0.54	1.35
W5	1	0.47	0.27	0.68
W6	1	0.93	0.54	1.35
W12	1	1.95	1.95	2.84
Clerestory	2	-	1.6	-

Table (iii):
Three Condition Tested in Simulation

Condition	Opening	Opening size	Description
When the lowest opening and upper opening size is almost same	W4	1.2m x 1.125m	The lowest opening involving lower louvers area only.
	W11	1.2m x 1.125m	
	Clerestory	3.2m x 0.5m	
When the lowest opening size bigger than upper	W4	1.2m x 2.350m	The lowest opening involving the window and the louvers area.
	w11	1.2m x 2.350m	
	Clerestory	3.2m x 0.5m	
When the lowest opening size smaller than upper	W4	1.2m x 0.775m	The lowest opening accounted for the window area only.
	W11	1.2m x .775m	
	Clerestory	3.2m x 0.5m	

III. RESEARCH FINDINGS

Based on the three conditions of openings, the neutral plane level was determined. Theoretically the balance air flow of air inlet and air outlet led by an almost similar size of top openings which are the clerestory windows and lowest openings will cause a good stack ventilation flow. The determination of the neutral plane level are shown in Table (iv), Table (v) and Table (vi).

A. Neutral plane when the inlet and outlet opening area is almost same.

Table (iv)
The Opening Size for Condition 1

Condition	Opening	Opening size	Description
When the lowest opening and upper opening size is almost same	W4	1.2m x 1.125m	The lowest opening involving lower louvers area only.
	W11	1.2m x 1.125m	
	Clerestory	3.2m x 0.5m	

$h1 = (HF2^2)/(F1^2 + F2^2)$
$= (8.6 \times 3.202) / (2.702 + 3.202)$

$= 5.00m$

$h2 = (HF1^2)/(F1^2 + F2^2)$
$= (8.6 \times 2.702) / (3.202 + 2.702)$
$= 3.60m$

h1 and h2 differs by only 1.4m

B. Neutral plane when the inlet area is bigger than outlet area

Table (vi):
The Opening Size for Condition 2

Condition	Opening	Opening size	Description
When the lowest opening size bigger than upper	W4	1.2m x 2.35m	The lowest opening involving the window and the louvers area.
	w11	1.2m x 2.35m	
	Clerestory	3.2m x 0.5m	

$h1 = (HF2^2)/(F1^2 + F2^2)$
$= (7.6 \times 3.202) / (5.642 + 3.202)$
$= 1.85m$

$h2 = (HF1^2)/(F1^2 + F2^2)$
$= (7.6 \times 5.642) / (3.202 + 5.642)$
$= 5.75m$
h1 and h2 differs by 3.9m

C. Neutral plane when the inlet area is smaller than outlet area

Table (vii):
The Opening Size for Condition 3

Condition	Opening	Opening size	Description
When the lowest opening size smaller than upper	W4	1.2m x 0.775m	The lowest opening accounted for the window area only.
	W11	1.2m x .775m	
	Clerestory	3.2m x 0.5m	

$h1 = (HF2^2)/(F1^2 + F2^2)$
$= (7.6 \times 3.202) / (1.862 + 3.202)$
$= 5.68m$

$h2 = (HF1^2)/(F1^2 + F2^2)$
$= (7.6 \times 1.862) / (3.202 + 1.862)$
$= 1.92m$

h1 and h2 differs by 3.76m

III. RESEARCH ANALYSIS

Based on the determination of the opening size at specified height, the natural ventilation potential were determined. By using three different size and position of opening to the house as comparison, the air flow pattern in the house were investigated using simulation. Simulation was conducted based on the surrounding environmental condition where there was also cross ventilation influence around. This was used as the air movement setting. Two sets of environmental condition were used representing the daytime condition and the night time condition. FloVENT was used to predict the 3D airflow effect into the building. The air flow in the house were tested according to the area of inlet and outlet determined. Each condition is presented by the location of neutral plane as calculated before.

As for the simulations, several points were determined inside and outside of the house design to study the flow. The points are shown in Table (viii) whereas Figure 6 shows the location of the points in floor plan of *Kebun Angin*.

Table (viii):
Points determined for data collection

Point Number	Location of the point
Point 1	Family Hall
Point 2	Living Room
Point 3	Void
Point 4	Clerestory Window
Point 5	Outside

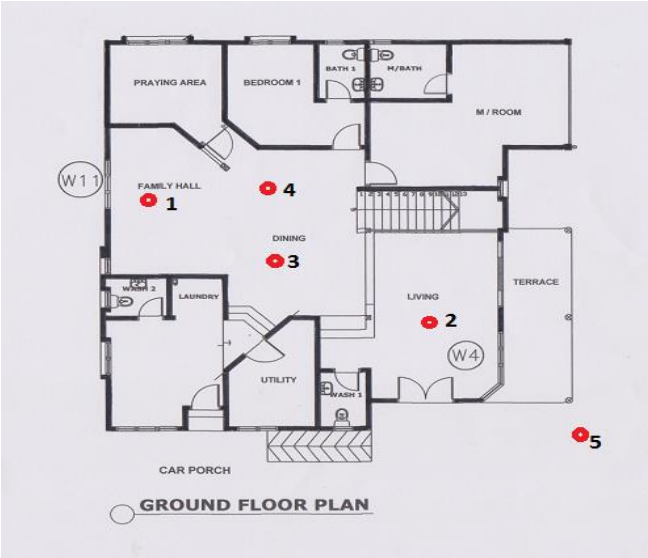

Fig. 6. Building space layout showing the studied points.

Simulation on Condition 1 during daytime was based on surrounding airflow at 1.33m/sec. The flow was found increased up to 1.78m/sec at the clerestory windows at top high of the building. The shaped of the roof may direct the flow towards the opening before moving in through louvers. Shallow path between louvers may cause the air to go faster thus may create a turbulence jet at the clerestory windows.

Inside the building, the air flow was found slowing down to 0.32m/sec as it flows down the void area which act as the stack throat. The slow moving air kept its pace at the Living area but there was a higher pace of movement at the Family Hall besides W11 at 1.54m/sec. This may be due to the central neutral plane level in this condition where the speed of air moving in and out were about the same. However the rapid movement was only found at Family Hall but not at Living area.

Table (ix):
Predicted air movement for Condition 1 during daytime.

Monitor Point	Void	Living	Rear clerestory	Family hall	Outside
Wind speed (m/s)	0.32	0.13	1.78	1.54	1.33

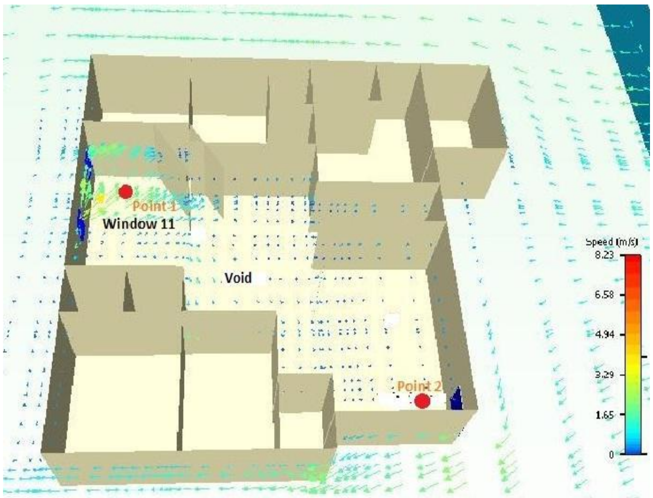

Fig. 7. Predicted wind vector in the house at Ground Floor in Condition 1, daytime.

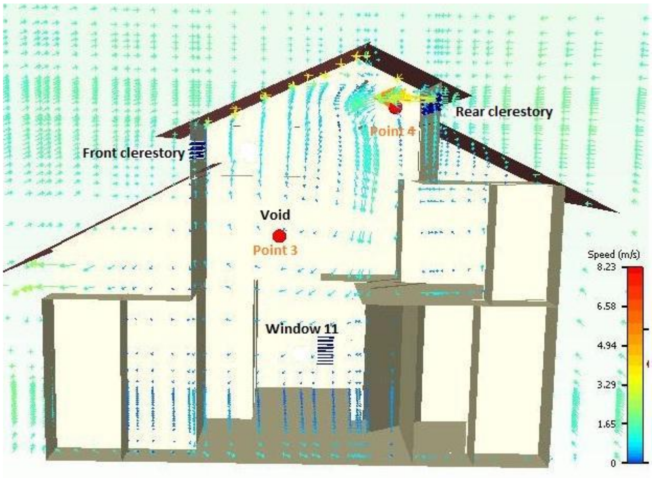

Fig. 8. Predicted air movement through the atrium acting as the stack throat in Condition 1, daytime.

Table (x):
Predicted air movement for Condition 2 during daytime.

Monitor Point	Void	Living	Rear clerestory	Family hall	Outside
Wind speed (m/s)	0.30	0.32	1.82	1.43	1.32

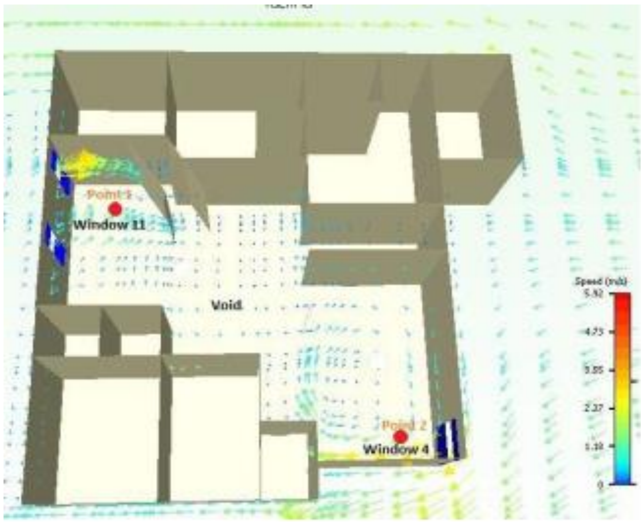

Fig. 9. Predicted wind vector in the house at Ground Floor in Condition 2, daytime.

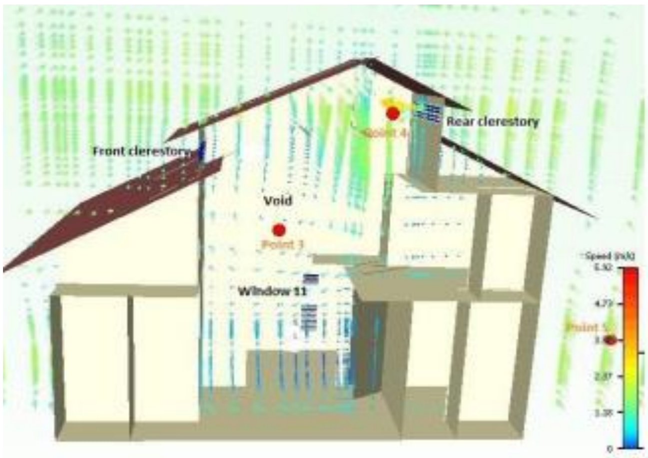

Fig. 10. Predicted air movement through the atrium acting as the stack throat in Condition 2, daytime.

Simulation on Condition 2 during daytime was based on surrounding airflow at 1.32m/sec. In this scenario, the windows of the house was opened to full size. The monitor point showed there was an increasing of wind speed in the house. Record showed the air speed at the clerestory window remain high at 1.82m/sec. Again, the shape of the roof and the shallow path between louvers blade at that level may direct the flow to move fast at that particular openings. .

In the void atrium apace, the air movement was found to be slowing down. In this condition the neutral plane level was at 1.82m height from center of the window level. Hence, the air movement at human level which is slightly below the neutral plane level was found flowing slow at only 0.30m/sec. As what happened in Condition 1, the air movement at Family Hall was recorded moving more rapid than at the Living area. The air movement at the Family Hall was recorded at 1.43m/sec whereas at the Living area was recorded at 0.32m/sec. Despite of the difference, the level of air movement at both areas were considered good enough for indoor building natural ventilation.

In Condition 3 during daytime, the Neutral Plane Level was at higher position due to smaller low windows openings compared to the clerestory high openings. The flow was still found high at the upper clerestory windows. Inside the building, the air flow was found slowing down to 0.27m/sec as it flows down the void area which act as the stack throat. Despite higher Neutral Plane Level may cause the air to move faster downward due to the release of air through lower windows, the result showed contrast. Even the air movement in Living area and Family Hall showed slower movement compared to what happened in Condition 1 and Condition 2.

Table (xi):
Predicted air movement for Condition 3 during daytime.

Monitor Point	Void	Living	Rear clerestory	Family hall	Outside
Wind speed (m/s)	0.27	0.22	1.79	1.12	1.33

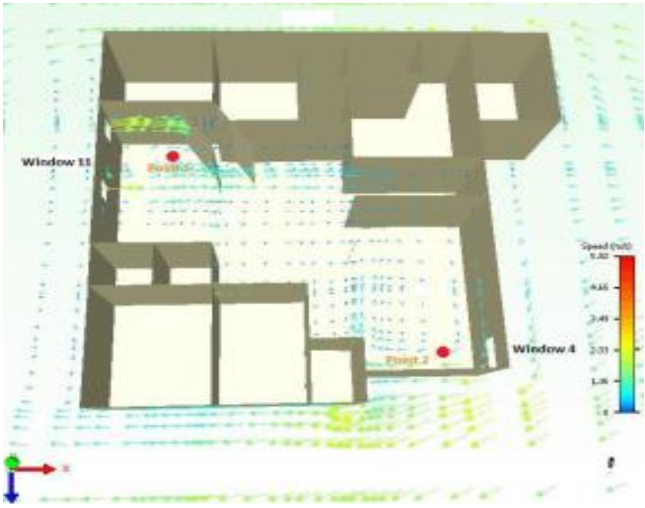

Fig. 11. Predicted wind vector in the house at Ground Floor in Condition 3, daytime.

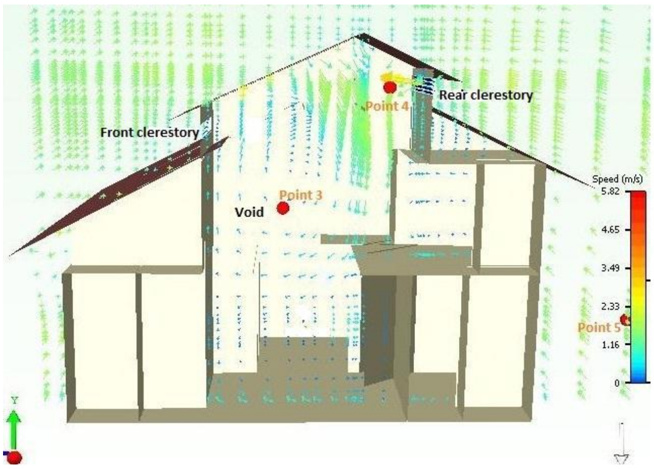

Fig. 12. Predicted air movement through the atrium acting as the stack throat in Condition 3, daytime.

As comparison, all three daytime conditions recorded the same air movement pattern in that situation. Cross ventilation was set at approximately 1.32- 1.33m/sec whereas stack ventilation may happened due to the pressure difference in the void atrium which act as the stack throat. However comparison on each wind flow performance show a better air movement in Condition 2. A lower Neutral Plane Level may cause a better air flowing out at lower windows and openings especially through W11 at Family Hall, thus creating air jet intake at the clerestory to balance the air pressure.

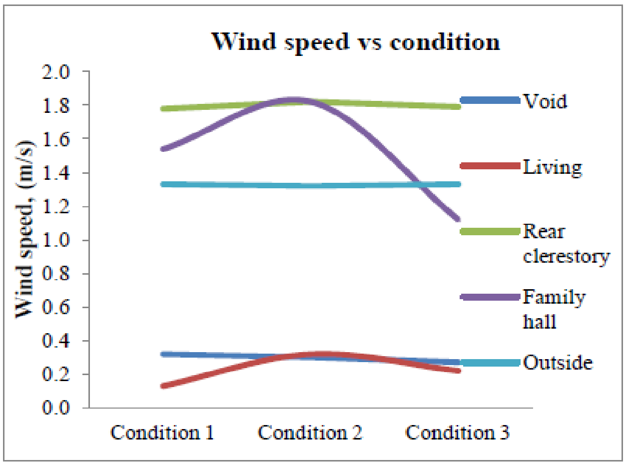

Fig.13. Comparison of wind speed for every condition during daytime.

From the graph above, the predicted wind pattern at the house shows a greater movement of air flow at the entrance of clerestory windows. However, the speed decreased as it flow down along the void atrium. This happened as not all the wind flowed into the house are driven by buoyancy alone, but also subjected to wind effect. The presence of wind forces could adversely affect the buoyancy driven flow patterns where the wind effect can assist and oppose buoyancy in the windward and leeward wings respectively [27]. The stack effect can be measured through the air movement and speed at the atrium throat. Comparison of air movement at Point 3 inside the void atrium found that Condition 1 gives the highest wind speed at 0.32 m/sec. compared to Condition 2 and Condition 3 with 0.30 m/s and 0.27 m/s respectively. Although the speed is slightly low, but still within comfortable conditions.

Table (xii):
Predicted air movement for Condition 1 during night time.

Monitor Point	Void	Living	Rear clerestory	Family hall	Outside
Wind speed (m/s)	0.25	0.18	1.26	0.82	0.71

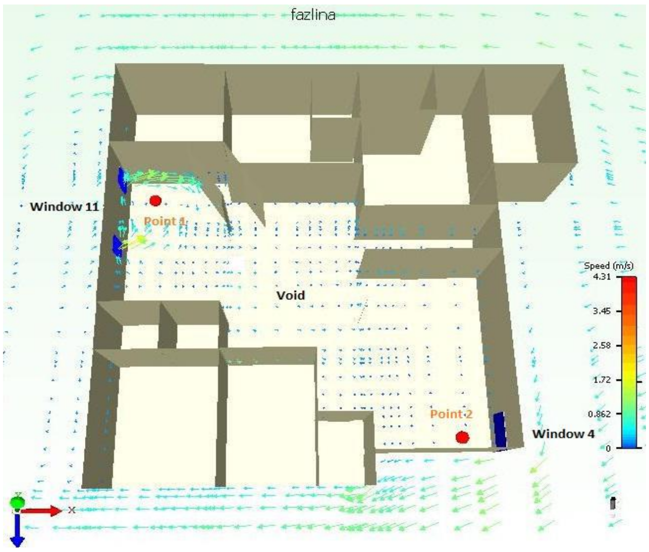

Fig. 14. Predicted wind vector in the house at Ground Floor in Condition 1, night time.

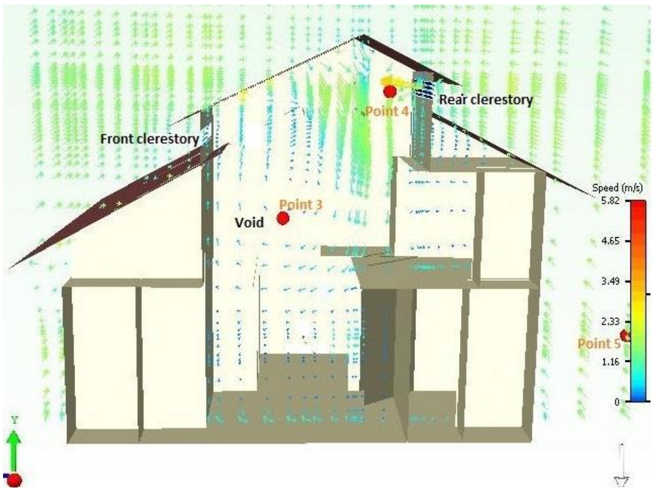

Fig. 15. Predicted air movement through the atrium acting as the stack throat in Condition 1, night time.

Through the simulation, it was found that the air flowed into the house through both of openings level. The wind flow at the clerestory was at the rate of 1.26m/s while at window 11 in family Hall at the rate of 0.82 m/s. However, as the wind spread in the house, the speed was decreased to 0.25 m/s at the atrium void. The wind speed at inlet and outlet were almost equal which may be caused by the central position of Neutral Plane Level due to almost similar size of inlet and outlet opening. In this scenario, wind effect shows dominancy due to no stack effect flow may be determined.

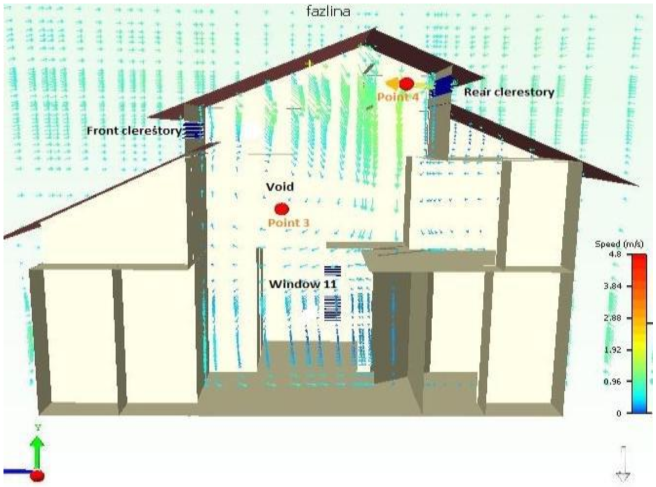

Fig. 17. Predicted air movement through the atrium acting as the stack throat in Condition 2, night time.

When the house is opened with full size of window, again, the simulation showed wind flow accessed through both level of openings at clerestory and Family Hall. The wind flow was predicted to be at 0.84 m/s and 1.38 m/s respectively. According to the principle of night stack effect ventilation, the air is supposed to flow into the house through the highest opening. However, the wind vector does not show the pattern. This may be due to the effect of wind flow upon the stack effect process which depicts the reality situation.

Table (xiii):
Predicted air movement for Condition 2 during night time.

Monitor Point	Void	Living	Rear clerestory	Family hall	Outside
Wind speed (m/s)	0.21	0.34	0.84	1.38	0.7

Table (xiv):
Predicted air movement for Condition 3 during night time.

Monitor Point	Void	Living	Rear clerestory	Family hall	Outside
Wind speed (m/s)	0.2	0.13	1.39	0.2	0.71

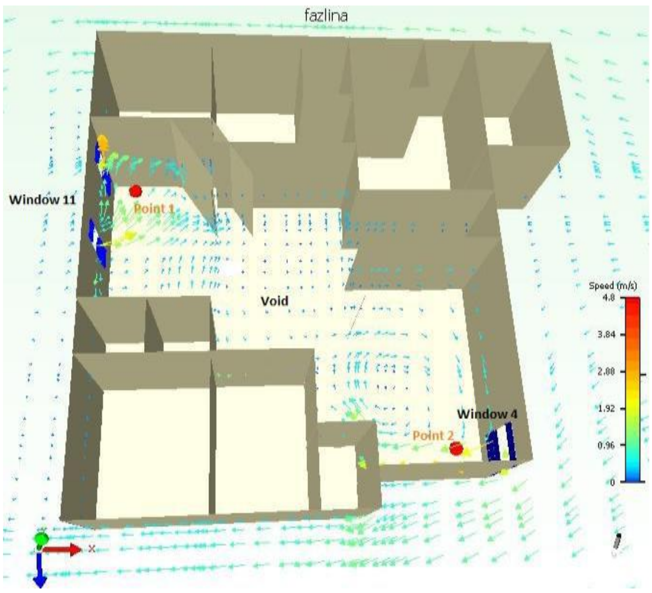

Fig. 16. Predicted wind vector in the house at Ground Floor in Condition 2, night time.

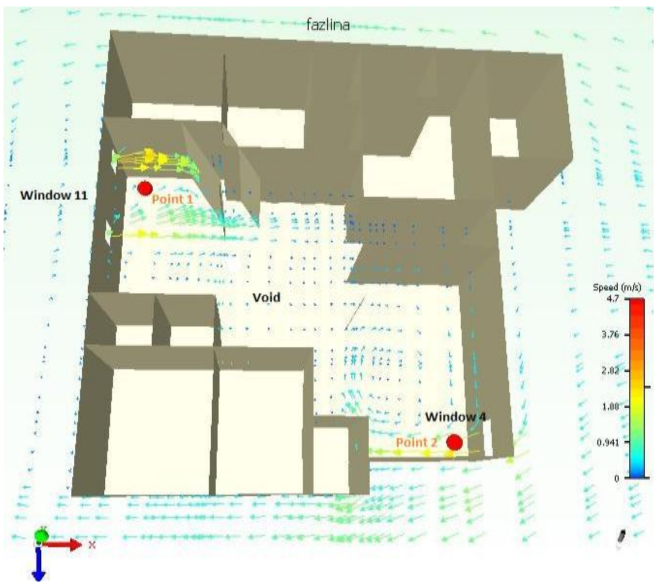

Fig. 18. Predicted wind vector in the house at Ground Floor in Condition 3, night time.

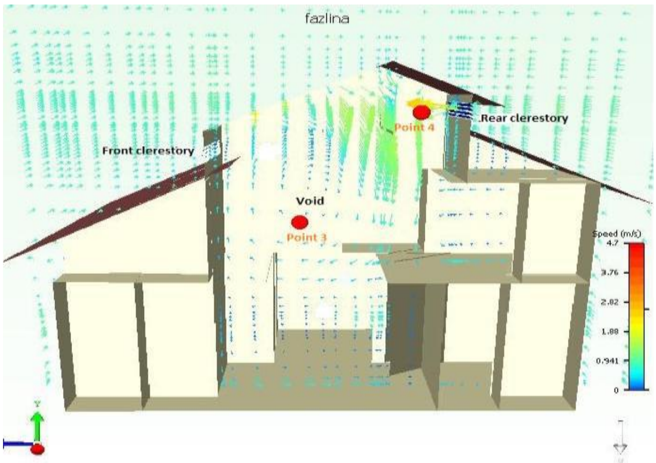

Fig. 19. Predicted air movement through the atrium acting as the stack throat in Condition 3, night time.

In Condition 3, as the clerestory windows size are larger than the lower windows, the Neutral Plane Level is set to be higher. Therefore it supposed to generate the wind flow from outside through the smaller size low windows. However, again the pattern of stack effect does not detected in the simulation due to wind flow effect. Through the simulation, wind flow at both lower opening at W4 and W11 remain low at 0.13m/sec. and 0.2m/sec. Since the lower opening is smaller than the upper opening, the wind speed at clerestory should also be low. However, the wind flow at the clerestory windows was recorded 1.39m/sec. which may be due to the air turbulence when wind flow from outside met with the flowing up buoyancy pushed air from the atrium void.

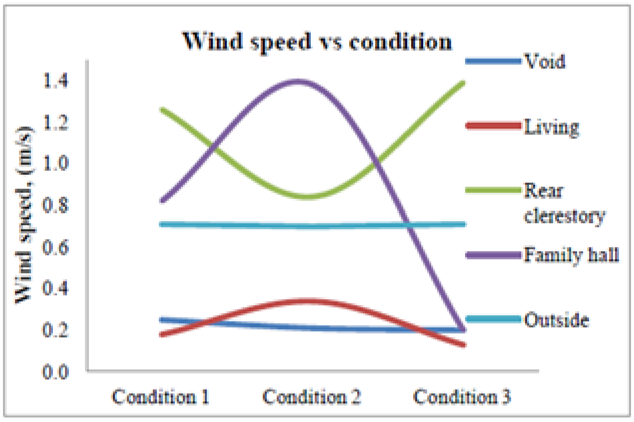

Fig.20. Comparison of wind speed for every condition during night time.

In comparison, the trend of night ventilation shows different pattern of movement. Although the atrium void air movement remain low in all three conditions, but air movement at the clerestory windows and Family Hall window (W11) contradict with the pattern flow supposed to happen via their position of Neutral Plane Level. This may be happened as not all the wind flowed into the house were distributed by buoyancy alone, but also subjected to wind effect.

IV. CONCLUSSION

Based on the research done, it was found that the size and positioning of inlet and outlet area greatly influence the location of neutral plane and the wind flow pattern. In daytime study of this research, upper openings of the clerestory windows reacted as the inlet for the wind flow while the lower openings acted as the outlet. At the same time, the roof of the house was also design to be able to catch the wind flow at the clerestory windows. Thus, the combination of the two forces of natural ventilation may enhanced the wind flow at that level. In balancing the pressure, the lower openings acted as the medium to flush the air out. Larger lower openings in Condition 2 was found to cause a better air movement at habitable area such as the Family Hall and Living Hall. This shows that lower Neutral Plane Level in hot daytime of tropical area may allow a better indoor air movement.

Meanwhile, in night time study of this research, the roof shape again acted as the wind catcher. This however, contradict with the stack effect flow which required the clerestory windows to be the outlet. Result shows slight chaotic wind vector at the opening reflecting dominancy of the wind flow going inside through the openings.

In both situation, enhancing air movement at the inlets and outlets shows a good flow around 0.2 to 0.3m/sec. of air movement in the void atrium. This is good enough to provide good healthy air. Having a controllable openings at lower level may help a lot in controlling the desired movement of air throughout daytime and night time. It is suggested the lower openings to be opened large to keep the Neutral Plane Level low during daytime. Meanwhile, it is suggested that the lower opening to be kept in minimum size to increase the height of the Neutral Plane Level. Larger upper clerestory openings in this condition may allow the air to flow in greater force at habitable level.

However, this calculation of neutral plane position only applicable for the structure that subjected to two openings at different height in a long throat such as chimney, atrium and ducts. The location of neutral plane might changed with the present of another openings between the inlet and outlet, thus changing the air flow pattern in the house.

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