Natural Ventilation Approach in Designing Urban Tropical House

Izudinshah Abd. Wahab, Lokman Hakim Ismail
Department of Construction Engineering and Architecture,
Universiti Tun Hussein Onn Malaysia
izudin@uthm.edu.my

Abstract

Building ventilation is necessary in providing acceptable indoor air quality (IAQ). It is a process of supplying fresh air and removing or diluting indoor pollution concentration. With an increasing awareness of energy saving lately, people are trying to rely more on natural ventilation to give better indoor air quality and thermal comfort. However, due to not much of air movement via wind driven in high density urban area, stack effect is seems to be more reliable than cross ventilation. Stack ventilating phenomenon is generated by the differences of inside and outside air pressure to create air flow through its upper most and lowest building openings. Thus, stack effect ventilation is highly depending on the size of the openings which will influence the air pressure inside the building. Controlling the neutral plane level in the house by the sizes of the openings is essential in driving the air in and out. Besides that, the height between the upper most and lowest openings may also contribute to the amount of air driven through the process. While in tropical area, maintaining the indoor temperature lower than the outdoor temperature is also important to keep the pressure difference for wind flow besides providing indoor thermal comfort to the occupants.

Keyword: Ventilation, Stack effect.
1.0 Introduction

Malaysia is located in the tropical climates region and has economic growth predicted to be continuously stable for the next three decades. The construction industry growth anticipated that the Malaysian architect and engineer would be able to promote new design concepts of housing that reflect the demand based on the current needs. According to Real Estate and Housing Developers’ Association of Malaysia (REDHA), the demand for housing is expected to remain strong for the next 12 to 18 months, after which the market will stabilize.

With variety of houses developed to match the demand, buyers are supplied with ample choices based on their priority. Unfortunately, thermal comfort of the houses seems are not given reasonable consideration among developers. Previously, the low cost of electricity and domestic air-conditioning systems associated with higher expectations of social lifestyle and levels, have contributed to the high popularity of artificial cooling equipment in buildings [1]. However, due to the unpredictable increasing price of electricity and petrol, people have become more environmentally responsive [2].

The indoor temperature of residential houses in Malaysia has been extensively studied over the last ten years by researchers. In the Malaysian humid tropics, urban houses are found overheat by about 3°C through out a day [3]. A research comparison on overall movement of indoor temperature towards outdoor temperature is shown in Figure 1.

![Figure 1: Outdoor versus indoor daily temperature during Malaysian heatwave](image)

Based on the research, hot and humid air is likely trapped indoor for the whole day which caused high indoor temperature. However, in comparison, the outdoor environment is perfectly comfortable for at least 14 hours per day.

In normal tropical situation, the closed attic space under the roof may become hotter than outdoor ambient temperature due to the air stagnant. This excessive heat is transmitted through the bedroom ceilings and becomes stored in the concrete walls and floor slabs. Unlike wooden traditional Malay house, Malaysia’s urban concrete houses therefore heat up like ovens during the day and barely cool down at night.
The scenario worsens when there is no active air movement in the house. Within compact layout of urban houses nowadays, even the 10% opening size upon the floor area requirement under the Uniform Building By Law 1984 may not help much. In Hong Kong, research shows that architects and designers have to vary the building height in order to maximize the ventilation. This may only success for upper floors while the compact lower floors air remains at its passive movement [5].

No doubt that there are many approaches through researches to deal with the matter. Insulating the building to prevent heat transfer is the most popular approach especially on roof, wall and window glass. The principle source of the problem is the absorption of solar radiation by the concrete roof tiles and the transmission of the heat into the non-ventilated attic space. Over the years, Malaysian attics have become less and less ventilated, to prevent the spread of fire and to keep out rain, birds and vermin. However, replacing the concrete tiles with a metal roof and insulating the roofs with glass wool or rock wool has proved highly effective in reducing the sealed attic space temperature to outdoor ambient [6].

As most of the houses nowadays are hotter inside compared to outside as shown in Figure 1, any house that can maintain its indoor temperature close to the outdoor may seen as good enough. Due to that, most designs try to open as much ventilation holes to balance the temperature by encouraging air movement. Besides, few designs even go more radical in the concept of open plan where more walls are omitted in the design. Anyway this approach may just balance the temperature indoor and outdoor without cooling it far.

2.0 Natural Ventilation

Building ventilation is one of the important aspects in providing an acceptable indoor air quality (IAQ). Good ventilation may help in supplying fresh air and removing heat and air pollution. 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 while maintaining reasonable usage of energy. 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 [7]. 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 the ventilation.

In urban surrounding, there is not much of wind driven air movement due to the physical development density. Thus, stack effect ventilation may become more reliable than the cross ventilation. Stack ventilating system relies on the difference of inside and outside air pressure to create the air flow.
3.0 Stack Effect Ventilation

Stack effect is a phenomenon of air movement from a high density area of air to a less density area of air. Technically, because of the temperature difference, the air inside the building is either more or less dense than the air outside. A natural air flow will be caused if there is an opening high in the building and another low in the building. 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 [8]. Stack effect works best when the air intakes are as low as possible and the height of building spaces is as great as possible [9].

Like many other environmental principles, the stack effect can either be a problem or an opportunity. While it may encourage the natural ventilation system of a house, it may also bring the hot and humid air of tropical climate countries into the building. 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.

However, stack effect seems to be the least considered when dealing with the process of cooling a house but yet may contribute a significant result. As shown in Figure 2, stack effect is the movement of air into and out of buildings, chimneys and flues and is driven by a difference in indoor-to-outdoor air density resulting from temperature and moisture differences. Less dense hot air rises and is replaced by denser, cool air. The greater the thermal difference and the height of the structure, the greater the stack effect process take place.

![Figure 2: Stack Effect in a Two Storey House](image)

The potential for stack-effect ventilation can be estimated during the design process through use of the following equation.

\[
V = 60KA [gh (Ti – To)/Ti]^{1/2}
\]

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 (ft);
- \(Ti\) (inside) is the higher of two differential air temperatures (°R);
- \(To\) (outside) is the lower of two differential air temperatures (°R).
From a design perspective, there are three variables that will affect the rate of stack-effect ventilation:

1. Area of openings (inlet, outlet, and stack size – with the smallest of these three areas ruling)
2. Difference in elevation height between the inlet and the outlet.
3. Difference in dry-bulb air temperature between the stack inlet and outlet.

Of these three variables, the areas and the height are most amenable to architectural and engineering decision making. Although temperature difference can be modified through design decisions (location of inlet, solar augmentation, and the like) it is probably a less controllable variable as it fundamentally relies on micro weather conditions surrounding the building.

While traditional kampong house may exploit the potential of stack effect in cooling the house to the most, house in urban area is likely to face the hot surrounding due to compact development and urban heat.

4.0 Enhancing The Stack Effect Performance

4.1 Climatic Characteristic

As stack effect performance is very much related to the temperature difference between indoor and outdoor environment, understanding the climate characteristic is essential. The tropical climate of Malaysia can be classified as warm-humid equatorial, having high temperature and humidity throughout the year, obtains intense sunshine, high temperature, strong glare, high radiation levels and rainfall. The average temperature and humidity is relatively high and consistent throughout the year. The monthly averages are almost constant though.

The air temperature average is consistent between 26°C and 32°C with high relative humidity ranging from 80% to 90% and never falling below 60%. The annual mean temperature is about 27°C (80°F) with the average monthly temperature ranging from 1 - 3°C (2 - 5.5°F). Average maximum temperatures are about 30°C (86°F) and sometimes may reach 38°C (100°F) on clear days; The monthly average daily solar radiation in Malaysia is 4000 - 5000 Whr/m², with the monthly average daily sunshine duration ranging from 4 hr to 8 hr [10].

Rainfall is also high over the year and sometimes comes with strong wind, averaging 2500mm to 3000mm annually and is more intense with the monsoons [11]. Other sources quote Malaysia as having a yearly mean temperature of between 26°C and 27°C and relative humidity (RH) of 70% to 90% throughout the year. The mean maximum daytime temperatures between 29°C and 32°C while the mean minimum temperature is between 22°C and 24°C [12].

As the daytime temperature is considered quite high, a building in Malaysia has to be able to insulate the indoor surrounding in providing a good thermal comfort for the users. This can be achieved by using proper building materials combined with good design. Maintaining a significant lower temperature inside compared to the outdoor temperature may help in enhancing the air flow into the house via stack effect ventilation process. However, encouraging rapid air flow into the building during daytime in Malaysia may also bring the heat into the building. Thus, proper consideration on how to slightly cool the air before entering the building is important.
4.2 Passive Design Strategies in Traditional Malay Houses
The importance of discovering indigenous design and methods of construction cannot be over emphasized. As what been and being studied on indigenous architecture in some countries, many works in this area has also been done in Malaysia especially on its passive design strategies.

Most traditional Malay House shares the same strategies to attain optimal climatic control which include;
1. Allowing adequate ventilation for cooling and reduction of humidity.
2. Using of low thermal capacity building materials so that little heat is transmitted into the building.
3. Controlling direct solar radiation
4. Controlling glare from the open skies and surroundings
5. Protecting against heavy rain
6. Assuring adequate natural vegetation in the surroundings to provide a cooler microclimate

[13]

Figure 3: Climatic design of the traditional Malay house [14]

As what shown in Figure 3, most traditional Malay houses were designed with elevated floors, high double tiered roof, large window opening and open concept interior space layout. These characters allow ample natural ventilation to move around and across the building. Elevated floors enable cross ventilation to move underneath the floors that may cool the floor materials. At the same time, gaps between the wood flooring may also allow air movement to sip into the building or vise versa.
As what we understand from the stack effect phenomenon, the higher the upper opening from the lowest opening, the better the ventilation performance will be caused. Thus, high attic with double tiered roof as what designed in most traditional Malay houses seems very significant to stack effect ventilation. The potential may also be supported by the ample size of window openings of the building.

Besides that, implementing open concept plan may also enhance the air movement inside the house. Conceptually, for a single unit of house, only bedrooms are required to be enclosed with walls, whereas dining and living halls may be designed as open spaces with roof coverage. Be them that way, the halls may still perform their functions.

![Figure 4: Open concept building interior layout to enhance air movement](image)

**Figure 4: Open concept building interior layout to enhance air movement**

### 4.3 Stack height and positioning.

Due to its physical nature, the stack effect ventilation requires a certain height between the inlet and outlet [15]. During stack ventilation processes, the pressure at the base of 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, doors or any other openings and leakages.

Stack effect works best when the air intakes are positioned as low as possible and the height of building spaces is as great as possible [9]. During night time, when the outdoor air temperature is lower compared to the indoor, pressure difference may push the cool air into the building through the low opening. The air will then push the hotter air inside the building above towards the uppermost opening.
During day time, the outdoor air temperature will start to increase higher compared to the indoor air temperature. Therefore, cooler air temperature inside the building will move lower towards the lowest opening. At the same time, outdoor air will enter the building from the upper most opening. This may also cause the heat to penetrate into the building along with the air. In order to minimize the indoor air temperature heating process like this, a proper design of the upper most opening is very important. It is advised that the openings are also sheltered and recessed slightly inside the building line to keep their surrounding cool.

However, 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 from outside of the house. This may be good for cross ventilation, only if there is wind driven to force the air in but it may give a poor performance of stack ventilation [16].

As a result, planning the opening size and location is very important in enhancing the stack effect performance as it affect the air pressure difference between indoor and outdoor the building. It is the pressure that moves the air in or out from the openings. A similar size of top most and lowest opening will move a similar quantity and speed of air in or out from the building. This will create a balance air pressure at half of the height between those two openings as shown in Figure 5.

![Figure 5: Balance Neutral Plane](image)

The balanced pressure at the height will equal to each other where it is referred to as neutral plane. Neutral plane is only maintained to be at half of the height between the upper most and lowest opening, if the cooling process is not required from the stack process. This may happen at night of tropical country surrounding where the cool air outside is encouraged to sip in to cool the interior. However, during daytime, neutral plane may best to be lower. Lower neutral plane means the upper most opening size is smaller compared to the lower opening size. As the quantity of air going out from the building through the large lower opening has to be the same with the quantity of air coming into the building through the smaller upper opening, a significant air jet and turbulent may resulted. This phenomenon has potential in giving sensible heat cooling to the building occupants.
4.4 Passive Indoor Temperature Cooling Method

Besides relying on the natural ventilation, the building envelope itself has to be able to maintain the coolness generated by the air movement. As the temperature kept low inside the building during hot weather outside, the air will keep pressing through the building openings, thus creating a non stop natural ventilation for the building.

A key feature of a passive house is that they incorporate very high standards of insulation. This reduces the amount of heat penetration through the wall to keep the indoor temperature cool in hot and humid area and vise versa in cold area.

**Building Envelope Insulation**

Insulating the building is essential to keeping the building cool in hot weather. As most of heat penetration is through the roof and wall, proper insulation systems are required to be installed to the roof and wall.

**Color of Building Envelope**

Considering the color for the building is also important in the approach to cool the house effectively. Dark-colored home exteriors absorb 70% to 90% of the radiant energy from the sun that strikes the home's surfaces. Some of this absorbed energy is transferred into the house by way of conduction, resulting in heat gain. In contrast, light-colored surfaces effectively reflect most of the heat away from your home.

**Shading**

Shading is actually the simplest approach in the process of cooling the house. Up to 40% of the costs of cooling can be saved by shading techniques such as landscaping, working the drapes and blinds. Trellises may be placed on the hottest side of the house, and blocked out at least 6” from the wall to protect the wall and provide a buffer of cool air [17].

The popular **vertical planting** on buildings nowadays is actually part of the trellises evolution. The design has become one of the most recommended solutions to cool the wall and the space behind. Several concepts are widely used, for example green roof, façades greened with climbing plants or living wall systems (modular pre-vegetated panels). Traditional Malay houses have proven on the ability to sustain cool indoor temperature by relying on the cool surrounding due to vegetation. By the same mean, appropriate vertical planting may also contribute the same function.

5.0 Conclusion

There are still a lot of factors that may contribute in enhancing the natural ventilation. While at the same time, ventilation itself may not be enough to provide a good thermal condition for the interior space as it may also involve the relative humidity of the air and the temperature itself. On the other hand, cooling process for human though is not only relied on the air temperature as it also involve the sensible heat cooling which very much related to the activities held in the room. Different setting and location of the building may also required different approach in providing a good thermal condition of the building, thus opening an ample room of researches and studies in this field.
References


