THE PERFORMANCE OF WIND WING-WALL ON AIR VELOCITY FOR HIGH-RISE RESIDENTIAL BUILDING IN MALAYSIA

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THE PERFORMANCE OF WIND WING-WALL ON AIR VELOCITY FOR HIGH-RISE RESIDENTIAL BUILDING IN MALAYSIA

by

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LIST OF ABBREVIATIONS

AT	Air Temperature
AV	Air Velocity
BREEAM	British Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CO_2	Carbon Dioxide
DSFs	Double-skin facades
GB	Green Building
GBI	Green Building Index
GDP	Gross Domestic Product
GHGs	Greenhouse gases
HVAC	Heating, ventilating and air-conditioning
IAQ	Indoor air quality
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change

LEED	Leadership in Energy and Environmental Design
MPA	Mineral Products Association
NAPIC	National Property Information Centre
PAM	Pertubuhan Akitek Malaysia
RH	Relative humidity
SESB	Sabah Electricity Sdn Bhd
SESCO	Sarawak Electricity Supply Corporation
Tg	Temperature readings
TNB	Tenaga Nasional Berhad
Tr	Mean radiant temperature
VAWT	Vertical Air Wind Turbine

LIST OF SYMBOLS

°C	degree Celsius
kph	kilo per hour
m/s	meter per second
mm	millimeter
sq.ft.	Square feet

PRESTASI DINDING SAYAP ANGIN TERHADAP KELAJUAN ANGIN UNTUK BANGUNAN KEDIAMAN BERTINGKAT TINGGI DI MALAYSIA

ABSTRAK

Isu pemanasan global telah mendesak ramai pihak untuk mencari jalan penyelesaian yang mesra alam bagi mengurangkan kesan perubahan iklim terutama dalam penjanaan semula tenaga. Masalahnya ialah apabila penduduk dunia bertambah, permintaan dan penggunaan elektrik semakin meningkat. Peningkatan penduduk di Asia Tenggara telah memaksa ramai pihak di negara seperti Malaysia, Singapura dan Thailand untuk membina bangunan bertingkat disebabkan oleh bilangan tanah yang terhad. Ramai pihak tidak menyedari kelebihan untuk tinggal di bangunan bertingkat tinggi bahawa semakin tinggi bangunan semakin tinggi halaju angin dan kelebihan ini tidak dipertimbangkan semasa proses reka bentuk bangunan. Terdahulu, bangunan yang sedia ada menggunakan cara konvensional untuk menyejukkan dalaman bangunan seperti penggunaan penyaman udara. Terdapat beberapa kajian di mana unsur dan teknik seni bina mampu meningkatkan kecekapan sistem pengudaraan di bangunan bertingkat tinggi yang berventilasi secara semula jadi. Salah satu kaedah terbaru dalam bidang pembinaan adalah dengan menggunakan dinding sayap angin di bangunan bertingkat tinggi. Dinding sayap angin adalah panel padat, atau dinding berdiri panjang di samping tingkap, balkoni atau bukaan lain yang boleh digunakan untuk menarik atau membimbing halaju udara ke dalam bangunan. Membina sayap angin adalah satu kaedah yang digalakkan untuk tujuan pengudaraan angin semulajadi ke dalam bangunan. Bagaimanapun, kajian terhad telah dilakukan terhadap penggunaan sayap angin dengan

reaksi mereka terhadap pengudaraan dalaman keseluruhan. Kedudukan negara Malaysia dikelilingi oleh lautan dan penduduk kebanyakannya tertumpu di kawasan pesisiran pantai. Oleh itu, pengudaraan semulajadi boleh ditekan untuk kegunaan praktikal tetapi maklumat untuk corak halaju udara empirikal seolah-olah terhad.

THE PERFORMANCE OF WIND WING-WALL ON AIR VELOCITY FOR HIGH-RISE RESIDENTIAL BUILDING IN MALAYSIA

ABSTRACT

Global warming has sparked many to seek environmental friendly ways to reduce the impact of climate change especially in generating energy. The problem is as world population grows, demand and consumption of electricity increases. Population increase in South East Asian countries has compelled Malaysia, Singapore and Thailand to go for high rise buildings due to the limited land mass. Many did not realize that as living in high-rise buildings the endowment given by nature that the higher the buildings the faster the air velocity and this endowment was not taken into consideration during design process to tap the availability of natural ventilation. Present buildings are design using the conventional way of cooling the interior and that is by air-conditioning thereby increasing energy aggravated by the population increase. Several studies show that different architectural elements and techniques are related in improving the efficiency of ventilation systems in natural ventilated high-rise building. One of the latest methods in the field of construction is the use of wind wing-wall in high-rise building. Wind wing-wall is a solid panel, or a long standing wall alongside windows, balcony or other openings that can be used to redirect or guide air velocity into the building. Applying wind wing-walls is a method that encourages the natural wind ventilation into the building. Anyhow, limited studies have been carried out on the application of wind wing-walls by their effectiveness on overall indoor ventilation. Since Malaysia is mostly surrounded by seas and populations are mostly concentrated in

the coastal area, the natural ventilation can be tapped for practical uses but information for empirical air velocity pattern seemed limited.

CHAPTER 1 : INTRODUCTION

1.1 ISSUES AND PROBLEM STATEMENT

1.1.1 Global warming and climate change

Climate change is the greatest humanitarian disaster of our life. Resource from Intergovernmental Panel on Climate Change Fourth Assessment Report, Climate change 2007, Working Group III : Migation of Climate change, Chapter 1 shows that the energy supply recorded the highest percentage due to global warming causes which is 25.9% , followed by industry which is 19.4%. Meanwhile, waste and wastewater recorded the lowest percentages among all which is 2.8% (IPCC 2007). This shows that when we burn fossil fuels like coal, oil and natural gas for energy or cut down and burn forests to create pastures and plantation, carbon gain and overwhelm our atmosphere. Due to the impacts of this changing, it responsible for rising seas, prolonged droughts, rising temperatures, ecosystems will change and storms become stronger. It also intimidated our health, economy and community.

Global warming is one of the most controversial science issues of the 21st century, provocation the very organization of our global society. The problem is that global warming is not just a scientific concern, but encompasses economics, sociology, geopolitics, local politics, and individual's choice of lifestyle. Global warming also is caused by the massive increase of greenhouse gases such as carbon dioxide (CO_2) in the atmosphere, resulting from the burning of fossil fuels and deforestation.

According to Mark Maslin (2004), there is clear evidence that greenhouse gas concentration in the atmosphere have been rising since the industrial revolution in the 18th century. The current scientific is that changes in greenhouse gas concentration in the atmosphere cause global temperature change.

1.1.2 Climate in Malaysia

Malaysia climate depends on its location in the area of an equatorial zone. Malaysia has an equatorial climate which is constantly high humidity, high temperature, relatively light winds and heavy rainfall throughout the year.

There are four seasons of monsoon winds in Malaysia climate. Firstly, the longest in duration which is southwest monsoon and northeast monsoon. Usually southwest monsoon begins in May or early June and ends in September. The wind flow is generally southwesterly and light, which is below 15 knots. Meanwhile, northeast monsoon usually begins in early November and ends in March. At this time, the wind flow are steady which is 10 to 20 knots. During the other two inter-monsoon seasons, the wind flow are generally light and variable. Because of Malaysia is located near the coast, land and sea breezes, it influenced the wind flow pattern.

According to Malaysian Meteorological Department, Malaysia receives about 6 hours of sunshine per day. The sunniest regions which is west side of peninsular and east side of peninsular receives 7 hours of sunshine per day, while in Sarawak receives only 5 hours per day. Moreover, Malaysia has constantly high temperature throughout the year. Temperature range daily between 5^{o}c to 10^{o}c near the coast and 8^{o}c to 12^{o}c inland.

The relative humidity in Malaysia is high, which is 70% to 90%. Therefore, people rely totally on natural ventilation for comfort purposes by having many openings in their houses or buildings and other ventilation techniques such as chimney or stack ventilation.

Unfortunately, this scenario has been changed when land is now limited and expensive to owned especially in urban areas. As population grows, demand and consumption of electricity increased and people depending on electrical equipment for cooling and lighting purposes.

1.1.3 Oversupply of high-rise residential building in Malaysia

According to National Property Information Centre (NAPIC), there is a trend of developers preferring to build higher value condominiums, indicating that condominium sales seem more profitable for developers and that there may be an oversupply of high-rise units in the near future. The new trend of living in high-rise residential building has become more popular, especially in urbanized area. This modern living concept has developed in major states such as Pulau Pinang, Kuala Lumpur, Selangor and Johor.

This scenario has gradually changed over time due to land becoming scarce and expensive to own. Besides increasing prices of property, many suspect that currently there is an oversupply of properties, especially in Pulau Pinang. Based on the population growth in Pulau Pinang, Malaysia Property Incorporated found that there is oversupply of about 45,000 units of properties in 2015 and assuming that 22,000 units by 2020.

On Penang island, the most crowded populated district is Georgetown, Air Itam, Jelutong, Bayan Lepas and Tanjung Bungah still remains one of the most desired places for property. Moreover, on mainland such as Seberang Perai, Batu Kawan and Butterworth is expected to see more new housing units in coming years.

1.1.4 The increasing of energy consumption

Apart from the oversupply of high rise dwelling units, also the increasing energy consumption takes a similar trend. Statistic reveals that heating, ventilating and air-conditioning (HVAC) system in building produce more than 50% of the energy consumption Bastide.A *et al*. (2006). According to Saidur *et al*. (2009), air conditioning had the highest energy consumption of (57%), and followed by lighting (19%), elevators (18%), pumps and other equipment (6%). In Malaysia, due to the high economic and population growth, have led to the increase in energy consumption.

As in Malaysia, the value for electrical power consumption (kWh) was 122,000,000,000 in 2014. International Energy Agency (IEA statistics @ OECD / IEA) states that over the past 10 years, this indicator reached a maximum value of 122,000,000,000 in 2014 and minimum value of 53,420,000,000 in 2000.

Malaysia Energy Statistics handbook 2015 by *Suruhanjaya Tenaga* also recorded that over the past 6 years, in domestic sector, number of consumers for Tenaga Nasional Berhad from 2009 untill 2014 reached a maximum value which is 6,710,032 in 2014 and 6,128,224 in 2009. This shows that Malaysia among the rapid growth development country while the number of population is increase rapidly. Therefore, the high demand

of electricity must be parallel to the sufficient supply for maintaining the Malaysia's economic development.

1.1.5 The impact of air velocity on high-rise building

There are many high-rise residential buildings constructed especially in Southeast Asia, thermal comfort level always become priority in designing the buildings. According to the questionnaire survey that conducted in Singapore by N.H Wong *et al*. (2009), residents in the middle part of the building tend to be more unsatisfied with thermal comfort, while residents on the upper floor gave a positive feedback. Anyhow, the residents who lives on the upper floor claims that the wind was too strong and annoying, but it can also become the positive factor in such hot climate in Singapore.

Whereas, a study by Ardalan Aflaki *et al*. (2014) conducted in Kuala Lumpur confirms that there is significant effect of building height on air velocity. The results show that the amount of indoor wind in the living room at unit in the upper floor is four times higher than the amount for same room at unit in the lower floor.

Despite the building height, several studies have been carried out to highlight the effect on air velocity ratio and air flow pattern within the opening sizes, location and orientation of windows Almeida *et al.* (2009). It is found that occupants prefer to open smaller windows when the temperature increases. However, sometimes it is needed to use special openings in a high-rise building, due to the high wind velocity according to Roetzel *et al.* (2010). Ventilation louvers as a substitute for ventilation opening nowadays as it is become recognized as a sustainable way to cut down heating and

cooling costs. This type of opening also is an effective system for controlling the climate and guiding the fresh air into the building.

Mohamed, Prasad, & Tahir, (2008) state that in Malaysian housing industry, the used of balcony is to encourage the access natural wind into the building. Larsen & Heiselberg (2008) had reveals that the amount of wind passing through opening will depend on the wind speed, temperature inside and outside of room, wind direction, disturbance characteristics in the wind and the pressure variations.

Natural ventilation strategy also depends on outdoor turbulence as well. According to study by Dahlan *et al.* (2008), orientation, shapes of the building, wind direction may influence the amount of air on the indoor space. The research is focused on the special character of high-rise buildings in Kuala Lumpur, Malaysia. The research was supervised in two high-rise dormitory buildings and it was found that the temperature in the building rises with the height. The temperature also was recorded higher on the west side, compared on the other sides

1.1.6 Passive design strategies

Passive strategy is an exchange process between heating performance and cooling performance. The characteristics of the building determine which strategies is the best on the energy performance. Meanwhile, passive ventilation strategy is attracting the natural air flow around the building into the interior of the space. Buildings can be designed to enhance the natural air flow and take advantages on reducing the energy consumption. There are many passive elements that contribute to natural ventilation such as operable windows and opening, building orientation, building shape, architectural features and space planning.

High-rise buildings in Malaysia have center-core structures such that the residential units are only externally facing on one side. This results in a one-sided opening and the installation of a wing-wall has been suggested to increase ventilation. The wing wall is a wall extend located at between two openings. The wind pressure difference between the windward and the leeward surfaces of the wing-walls causes the surround wind to flow into and out of the room. According to the Gan (2000), single sided ventilation without a wing-wall that has high air velocity near the openings can cause the air velocity decrease substantially with the depth of the room.

Nowadays, applying wind wing-walls is well known method in high-rise building. According to S.Chungloo and C.Tienchutima (2011), applying wing-walls can increase the natural ventilation of a single-sided opening. They also claimed that the appropriate installation of a wing-wall with a balcony is preferable to increase the wind induced ventilation.

1.2 RESEARCH OBJECTIVE

The investigation focuses on the effect of facade components, such as a wing wall between two openings and a balcony, on the air velocity distribution inside the room. Apart from the main objective, several specific objectives have also been formulated in this research as follows :

1. To investigate the consistency of air velocity at various height.
2. To determine the air velocity (minimum 2m/s) occurring at which height of the building that can be tapped as renewable energy.

1.3 RESEARCH QUESTION

Therefore, two research questions have been stipulated as a guideline in achieving the research objective :

1. Does the installation of the wind wing-walls affect the air velocity into the building?

2. Which wind wing-wall position is most effective?

1.4 HYPOTHESIS

Potentially, wind wing-wall becomes one of the passive design strategies in reducing energy consumption in tropical climate high-rise building. Hypothetically, the higher up the building, the air velocity will increase. So, to identify the element and the situations, an experiment was conducted to measure the amount of air velocity inside the space at the various height of the building.

Yet, limited researches have been carried out on the application of the wind wing-walls and their effects on indoor air temperature and air velocity. Therefore, from data collection, an investigation is carried and to see whether the performance of the wind wing-wall high can reduce the energy consumption thus can generate electricity production.

1.5 RESEARCH SCOPE

This research focuses on the study of the performance of wind wing-walls which it becomes one of the design elements in reducing energy consumption in high-rise building. According to the Tiun Ling Ta *et al.* (2003), Pulau Pinang is one of the most urbanised and economically-important states in Malaysia. Penang Island, which includes George Town, is Malaysia's second largest city by population. Based on the current population given by the Department of Statistics for Penang, there will be increasing population in year 2020, which is 1.75 million. Besides the increasing population, there is an oversupply of properties, especially in high-rise category. This factor is the reason why Pulau Pinang is chosen to conduct the experiment.

There is an abundant number of high-rise building in Pulau Pinang, which enables the researcher to conduct the experiment. Due to the needs of the research, only two building is selected as the target scope. One residential building in Sungai Ara on the island is selected to conduct the pilot study. Meanwhile, Butterworth is selected to conduct the field study of experiment. Both of this area has been rapidly developed to accommodate the rising needs in housing.

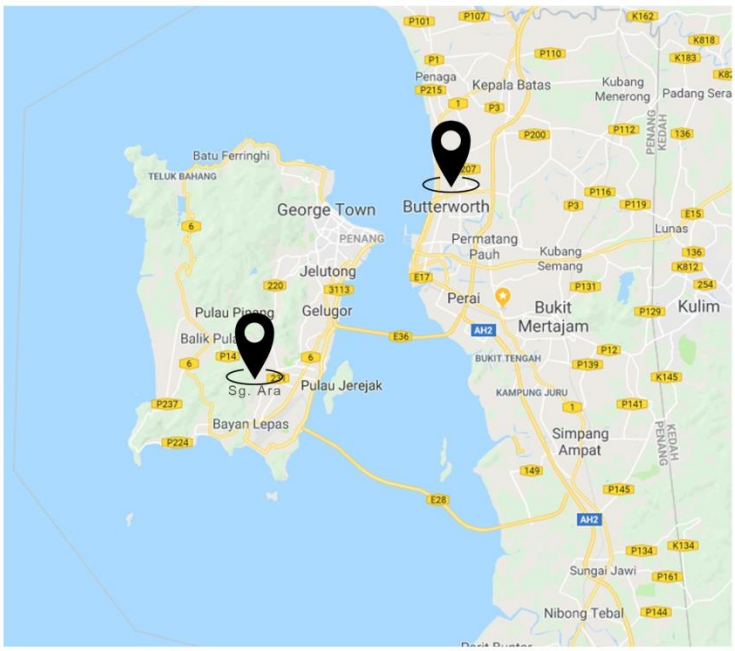


Figure 1.1 : The ‘pin’ shows the two locations where the experiment were conducted.

(Source : https://en.wikipedia.org/wiki/Penang)

CHAPTER 2 : LITERATURE REVIEW

2.1 INTRODUCTION

2.1.1 Global warming issues

The phenomenon of global warming is one of the most controversial issues in this century and has led the provocation to every structure of our global society. The obstacle is that global warming has affected our economics, sociology, geopolitics, local politics and individual's choice of behavior. Moreover, the increase of greenhouse gases, such as carbon dioxide in the atmosphere, resulting from the burning of fossil fuels and deforestation has become a global nightmare.

According to Mark Maslin (2004), there is a link between global warming and climate change. The current scientific is that changes in greenhouse gas concentration in the atmosphere do cause global temperature change. In the next 100 years, scientists predict that global warming could harm the planet by between 1.4 and 5.8°c and can cause a gigantic issue for humanity.

2.1.2 Sustainability in Malaysia

As the impacts of this changing, many housing schemes have been expanded in Malaysia since housing is an important for human habitat settlements (Huby,1998). According to Abu Hassan Abu Bakar *et al.* (2010), there is sustainable rating systems for buildings and groups of building that have been developed and rating tools like Comprehensive Assessment System for Building Environmental Efficiency (CASBEE), Leadership in Energy and Environmental Design (LEED), British Research

Establishment Environmental Assessment Method (BREEAM), Green Building (GB) Tool and Green Star influential in the development of other rating systems. In 2009, GreenbuildingIndex Sdn Bhd was incorporated by Pertubuhan Akitek Malaysia (PAM) and the Association of Consulting Engineers Malaysia (ACEM). This organisation was established to administrate GBI accreditation and training of GBI Facilitators and Certifiers. Furthermore, GBI has created two distinguished rating system tools that differentiated the non-residential and residential type of building. This specification was established based on Malaysian Tropical Climate and geographical characteristics, which is hot and humid for the whole year, environment, cultural and social developments.

Abu Hassan Abu Bakar *et al.* (2010) states that sustainability methods should include sustainability criteria that relate to the environment, society, economics, site/land use, communication and transportation are the important factors for developing the rating tools.

Herbert (2009) writes that tackling over the root cause contributed by building characteristics might prevail over the matter of global warming as building has a significant impact to reduce the greenhouse gases (GHGs). The formula of sustainability index in housing evolution will produce high indoor thermal comfort among the occupant. Moreover, the energy requirements of buildings are affected by a variety of factors such as internal loads, appliances and lighting, thermal insulation, type of glazing and blinds, building technology and operation modes.

Additionally, M.bojic *et al.* (2000) describes that in high-rise building, there could be a pile of more than 100 air-conditioners simultaneously rejecting condenser heat into a recessed space, which acts as a chimney. He also states that an air conditioner will consume more electricity for producing the same amount of cooling, its cooling capacity may be de-rated, and its operation may be interrupted. Therefore, this incident can be taken into consideration and due allowance is made in designing residential building to minimize its adverse effect, it would help to ensure sufficient cooling capacity and minimize electricity use of air conditioners.

In Malaysia, the progression towards 'green architecture' or climatically responsive design, which leads toward 'modern regionalism' seems to be slow compared to Europe's development. There is very little attempt to promote passive ventilation in solving all indoor comfort problems. Adopting the mechanical ventilation is the only solution especially in high-rise building.

The author of 'Prospect Of Wind Driven Natural Ventilation In Tall Building', (Dr Abdul Majid Ismail) points out 4 elements in appropriate design, such as the building should preferably be designed with end cores located at the hottest part of the building that can create buffer zones separating the hot walls and working areas. Besides, added architectural elements such as planting, atrium and wind scoop could activate wind-driven ventilation. An external wall that can filter the buildings by direct solar radiation and an open floor could be provided to boost free air movement.

The orientation of the buildings, openings, internal layouts and thermal comfort of occupants can influence the indoor thermal condition for high-rise residential due to the local climate.

Research on Innovative Designs For Natural Ventilation in High-Rise Building (2014) has looks into the design development of residential high-rise structures to reduce the dependency on mechanical ventilation through the local climate. Moreover, an effective way to reduce energy consumption and create better indoor thermal condition is consider on passive design strategy. However, the building characteristics such as form and height of the building can effects on overall indoor ventilation and air velocity.

2.1.3 Overview the energy consumption in Malaysia

Environmental pollution is increasing nowadays and the condition became worsened due to energy waste from buildings, human enterprise or industries. It is also can leads to more carbon dioxide production as well as greenhouse gas emission.

In Malaysia, due to the high economic growth and population have leads to the increasing energy consumption. In the past three decades, the total electricity consumption increased by 9.2% from 1980 to 2009. Figure 2.1 shows the electricity consumption among the ASEAN countries. Malaysia has recorded to gradually increased in consumption of electricity. The stable growth in manufacturing, as well as the increased in export, active domestic demand, higher tourism activity and opening of new retail outlets have contributed to the growth in electricity consumption (National Energy Balance, 2007).

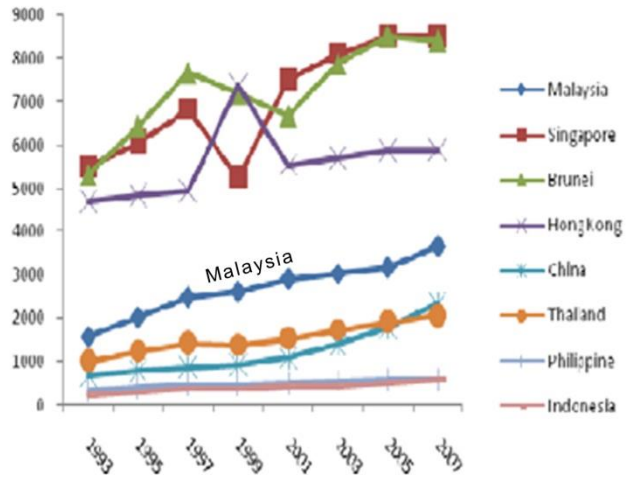


Figure 2.1 : The electricity consumption in kilowatt hour per capita in Asean countries. (Source: Hussain. et al., 2011)

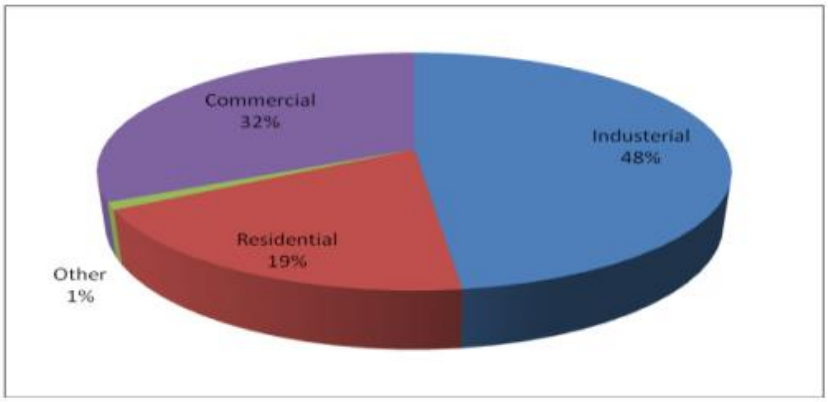


Figure 2.2 : The statistics of energy uses in Malaysia (EC, 2007) (Source: Hussain *et al.* 2011)

Figure 2.2 shows the distribution of the total energy consumption in Malaysia department. As we can see, industrial sector shows the highest percentage among all, which is 48%, and the second-largest user is commercial sector, 32% and followed by residential, which is 19%.

2.2 PRINCIPLES ON NATURAL VENTILATION

2.2.1 Natural ventilation

Natural ventilation is a process which supplying fresh air and removing it through an indoor opening without using any mechanical equipment in order to reduce and exhaust pollutants. Fresh air from natural ventilation can be achieved by operable windows, double facades, ventilation stack, balconies, gardens and atrium in tall buildings.

According to A.Wood (2007), occupants can control and boost fresh air provision as needed. Depending on climate, façade of the buildings and least ventilation loads can be reduced. As a matter of fact, natural ventilation for tall buildings are the same with other buildings types, relying on pressure differences that across the openings.

The pressure differences are generated by :

I. Effect of wind
II. Temperature difference that can react to air density
III. a combination of both

2.2.2 Natural ventilation strategies for tall building

Natural ventilation strategies for a tall building can also be categorized based on the connections between the spaces in the building. According to D.W.Ethridge *et al.* (2008), in isolated spaces, the openings to the other parts of the building must be small in relation to openings in the external envelope.

I. Space A : *single-sided ventilation (large single opening)*

II. Space B : *single-sided ventilation (two small openings at different height)*

III. Space C : *cross-flow ventilation (large opening)*

IV. Space D : *cross-flow ventilation (small opening)*

V. Space E : *flows pattern due to buoyancy alone*

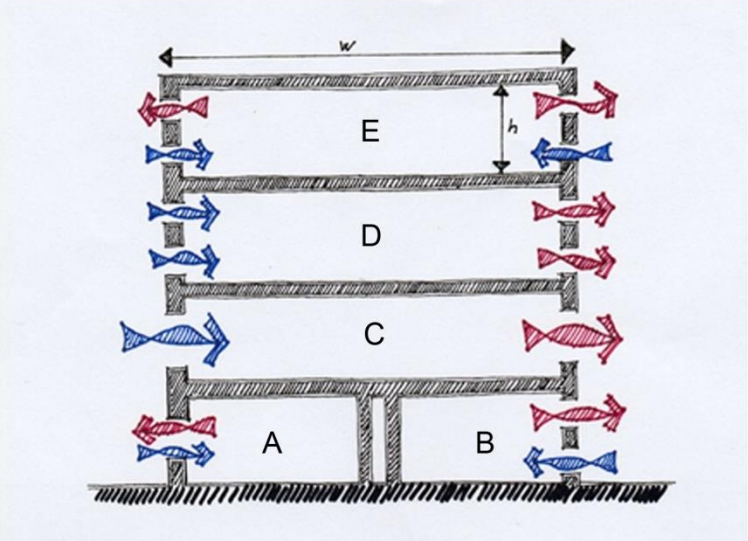


Plate 2.1: The ventilation patterns for isolated spaces in a building (Source : D.W.Ethridge *et al*. 2008).

(The illustration is drawn back based on original)

In the other strategies, the spaces in the buildings are connected by a large internal opening, such as atrium or stack.

The atrium is used to generate inward flow of fresh air into all occupied floors. The wind and buoyancy will act together and create the effectiveness of the strategy if the indoor air temperature is higher than outdoors. (D.W.Ethridge *et al*. (2008)

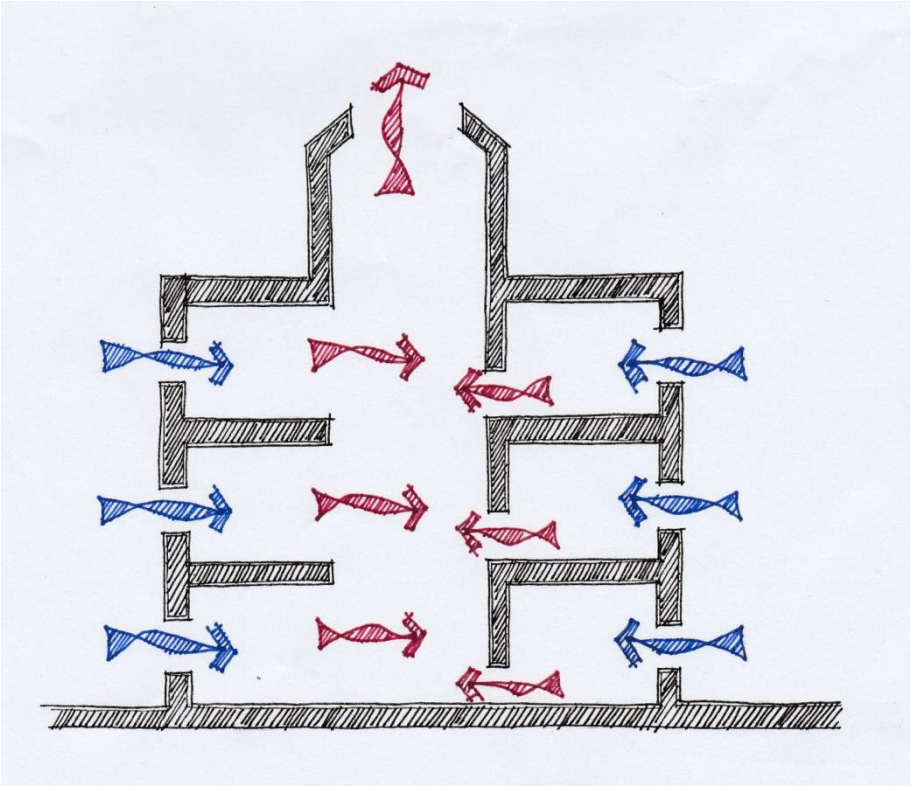


Plate 2.2: The ventilation patterns for connected spaces via an atrium.

(Source : D.W.Ethridge *et al.*(2008).

(The illustration is drawn back based on original)

According to D.W.Ethridge *et al.* (2008) the main problems for tall buildings is when high-pressure differences, which generated by buoyancy due to the height of the building. To overcome this situation, designing the building segment will exceptional. Example installing internal resistance in the form of segmentation through the height of the atrium or stack will take the fresh air into the building from a low level and exhausted form a higher level.

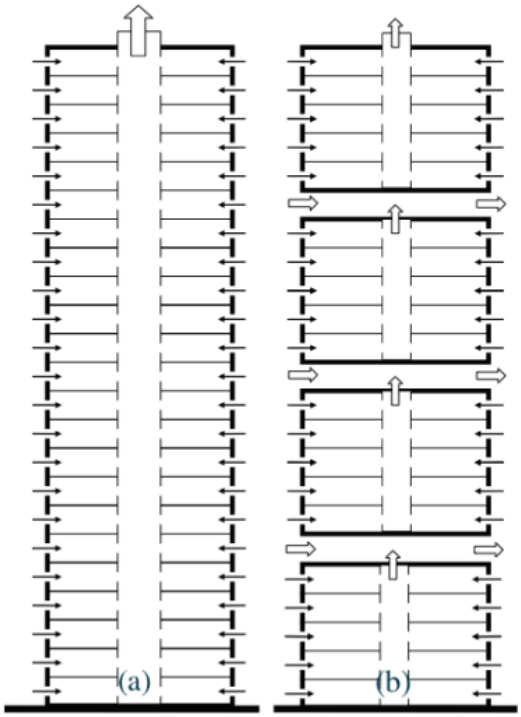


Figure 2.3 : The segmentation of a tall building for an efficient and reliable natural ventilation.

(a): atrium without a segmentation

(b) : atrium with a segmentation

(Source : D.W.Ethridge *et al.*(2008).

2.2.3 Ventilation type

Excellent ventilation strategies depend on how air is taken into a building and how it is extracted. The different approach, which are similar to a low-rise building is as follows :

1. *Single-sided ventilation*

It occurs when fresh air from the outside is taken into and exhausted from the space through the same opening. The depth of the space must be a maximum 2.5 times its actual height in order to make this strategy work.

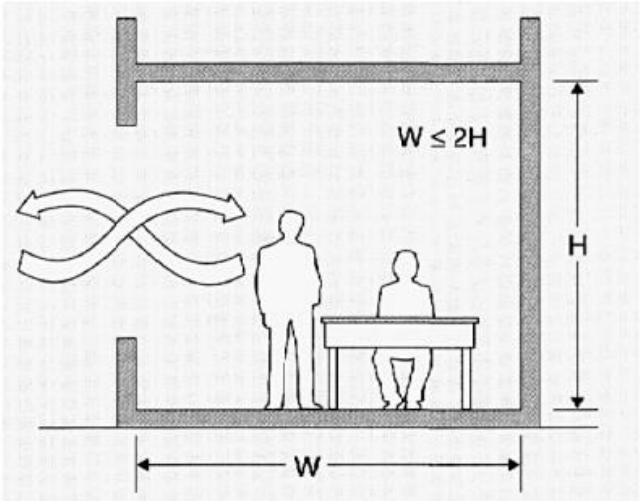


Figure 2.4 : The single-sided ventilation

Source: Aysin *et al.* (2014)

2. Cross-ventilation

It occurs when there is a pressure differential between the two sides of a building's envelope connecting openings. In this case, the depth of the ventilated space must not exceed 5 times of its height.

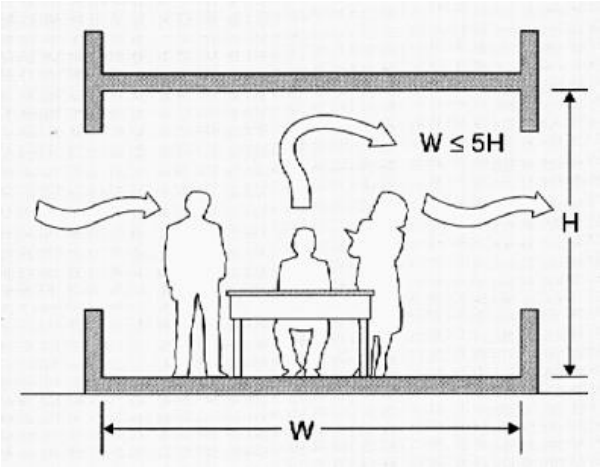


Figure 2.5 : The cross-ventilation

Source: Aysin *et al.* (2014)

3. Stack ventilation

According to McWilliams (2002), this strategy occurs when the fresh air is taken into the buildings from a low level and exhausted from a high level through a (chimney-like) stack due to the temperature and pressure differences between the interior and exterior.

This effect can be occurs in buildings with chimney, atrium or a double facades. In this case, mechanical equipment must be installed to aid the ventilation, as well as to cool the spaces in hot and humid zones. This is a mixed-mode of hybrid ventilation strategy which almost applied in the tall building in Europe. Research shows that the ventilation shaft is a sufficient wind-induced ventilation system for creating cross ventilation and relatively high indoor air velocity that can increase thermal comfort in residential unit. (Pimolsiri Prajongsan *et al.* (2011)

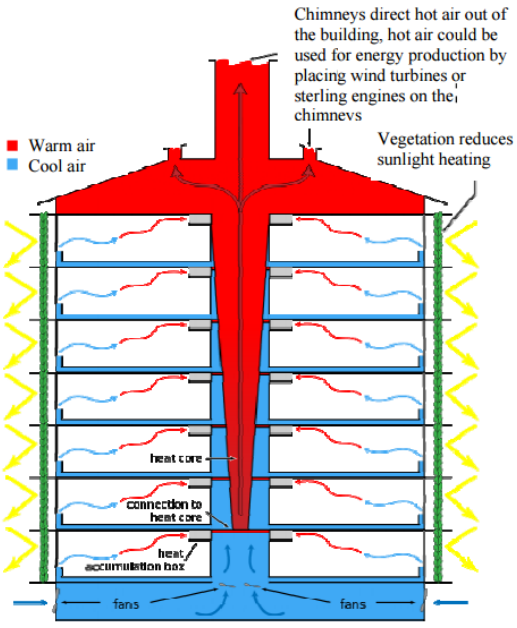


Figure 2.6 : The stack effect for natural ventilation in tall buildings

Source: McWiliams (2002).

2.2.4 Passive cooling strategy

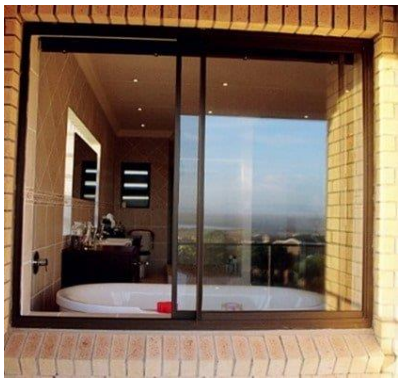
There are many cooling strategies that can prevent the building from overheating and remove the internal heat gain, example by using cooling outdoor air ventilation. However, this cooling strategy needs elements to attract the outdoor air ventilation into the internal spaces.

Elements that contribute to passive cooling:

1. *Windows*

   The windows that are used and installed in high-rise buildings are not standard glass windows, like used for regular homes. This is because the tall buildings are subject to great pressure, caused by the wind. The windows or glass panels that used in high-rise buildings need to be very strong and heavy duty. There are many types of windows are available based on their positions, materials and functioning.

   - Fixed windows
   - Sliding windows
   - Pivoted windows
   - Louvered windows
   - Casement windows
   - Corner windows
   - Ventilators
   - Skylight

Name	Picture	Function
Fixed windows		Fixed to the wall without any closing or opening operation. In general, they are provided to transmit the light into the room.
Sliding windows		Window shutters are movable in the frame. The movement may be horizontal or vertical based on our requirement.
Pivoted windows		Pivot is a shaft which helps to oscillate the shutter. The swinging may either horizontal or vertical based on the position of pivots.
Louvered windows		Ventilation louvers is a window blind with horizontal slats that are angled to received light and air, but to keep out rain, direct sunlight and noise.