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APPLICATION OF NATURAL VENTILATION IN MULTI-STOREY RESIDENTIAL BUILDING IN MALAYSIA

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ABSTRACT

The increase of population with the scarcity of land cause the construction of multi-storey building becomes popular. Thus, causing the increase of the usage of energy due to the low rate of ventilation through the multi-storey type of building. Therefore, this research was conducted to study about the need of natural ventilation in the multi-storey residential building. This study mainly focuses on the factors that affect the rate of ventilation and the architectural elements which help to enhance the performance of natural ventilation. The method used to conduct this research was by reviewing past literature about the methods and mechanics of natural ventilation application. Then, data collected from these papers were divided into factors and solution for easier review in this study. The significant of this study is to create more sustainable multi-storey building which may help in creating more comfortable environment for the residents.

Keywords: *multi-storey, residential, natural ventilation, sustainable*

INTRODUCTION

Problem Statement

According to Ismail and Wan Mohd Rani (2016), the increase of population in urban area has resulted to the increase of multi-storey residential building which currently is the highest energy user in Malaysia in terms of residential building per square meter due to its building density. This is because of the usage of cooling appliance installed due to the hot and humid climate in Malaysia. Zhong et al. also mention that in their writing that modern peoples spend more time indoors for working and living. Therefore, the need of indoor thermal comfort and air quality appliances leads to the increase of energy consumption

Purpose of Study

The purpose of the study is to maximise the application of natural ventilation in multi-storey residential buildings especially in hot and humid region which consumed more energy due to the appliances installed in the buildings for cooling purpose.

Aim and Objective

The aim for this research is to explore the application of natural ventilation in multi-storeys residential building which located in hot and humid climate region such as Malaysia. It is expected I would be able to learn about the factors that can affect the natural ventilation and the architectural solution which help in influencing the natural ventilation.

Scope of Study

The scope for this study is limited to only hot and humid region which located along the equator line. All the literature that been used must located in those regions only which can make this study more accurate due to the same characteristic of climate which usually affect the natural ventilation. In addition, building scope also limited to multi-storey type of building only either residential, commercial or any other. Thus, this study only covers about the natural ventilation in multi-storey residential buildings which located in hot and humid region only.

LITERATURE REVIEW

Introduction

Nowadays the population of the world keep increasing which make the demand for residential housing keep increasing too. In the meantime, the area for those residential building become scarce. This scarcity leads to the increase of construction for multi-storey building which can compact the residential housing in a small area. However, this type of building usually consumes more energy than other types of building due to its character which high in density. In Malaysia, it become worst due to its hot and humid climate. Therefore, the need of natural ventilation is like a must in the multi-storey residential building to conserve more energy consumption.

Natural ventilation can be defined as the utilization of flow produced by the convection current naturally or by forced due to natural wind flow which then generate circulation in the building while regulating the temperature. (Erin, 2004) Natural ventilation is one of the major aspects that included in the sustainable building which make it very important during designing process in order reduce the consumption of energy in a building. This aspect should be included in the multi-storey building which is a building that constructed with four and above number of apartments according to Law Insider.

Biofacade

Figure 1: Test room with biofacade((Blue Trumpet Vine)

Source: (Sunakorn and Yimprayoon, 2011)

Biofacade is a green façade which usually a climbing plant which planted vertically at the façade of building as shading devices. In a study by Sunakorn and Yimprayoon in 2011, it suggests that the biofacade can improved the thermal performances and ventilation of a building. However, it helps only in daytime and not in nighttime due to the character of the plant which cause the heat to dissipate in nighttime obstructed. An experiment was conducted in Thailand which has the same climate as Malaysia on a real building. Three climbing plants were explored, thus *Thunbergia grandiflora* also known as Blue Trumpet vine was chosen for the experiment due to its rate of growth which is fastest compared to the other two vines. Then, it was planted in front of a room window on the rooftop of faculty of Architecture building in a planter box with vertical net and supporting steel frames for the plant to climb. The room located beside another room with no biofacade which become the control variables for this experiment.

Two cases were used for this experiment which is adding ventilation variable in this experiment with opened and closed backdoor. Data was collected during daytime and nighttime.

The result of this experiment shows that on both opened and closed backdoor cases, air velocity in test room with biofacade is higher than without biofacade around 0.05-0.35m/s during daytime. At night, there were minor velocity in both rooms. They suggest that small void between leaves which contain higher pressure due to lower temperature of air around the leaves plays important role in inducing higher air velocity as the pressure at backdoor is lower. The study also shows that the leaves do not become an obstruction to the flow of air due to its movability. In addition, in daytime the process of photosynthesis and evapo-transpiration help in controlling the temperature of the building. (Sunakorn and Yimprayoon, 2011)

In the other hand, they suggest that not all type of climbing plants can give the same result as their research. The properties of leaves can cause varies result which effect the velocity and temperature of the air. The smaller and denser the leaves, the better thermal effect that we can achieve due to the large area of surface for evapo-transpiration process of plant. In tropical climate, air temperature that affected by plants are always lower than ambient air.

Single-sided Ventilation (SSV)

Two common type of ventilations that usually applied in a building are cross ventilation (CV) and single-sided ventilation (SSV). According to Marzban, Fiorito and Ding, cross ventilation is known as better strategies in ventilation compared to single-sided ventilation. It is because wind turbulence will affect the airflow strongly in SSV. Thus, it makes the process to provide a better environment in the building with SSV more complicated. SSV happens when all openings, regardless the numbers, were all in one side of building façade only. This happened especially in multi-storey

building which has compact residential within and small opening and it is not necessarily wind-driven ventilation. (Zhong et al., 2022)

Transom Ventilation Panel (TVP)

Therefore, there are some approaches that were studied previously. One of the approaches is a Transom Ventilation Panel (TVP). It can be applied in both CV and SSV which make it as a complement in the design to increase the rate of ventilation in the building. In the end of the research by alfaki et al., it was concluded that TVP roughly can increase the air velocity indoor by twice. The parametric study in the research also shows that a unit of residential that equipped with TVP can achieve 27% greater ventilation. (Aflaki et al., 2019)

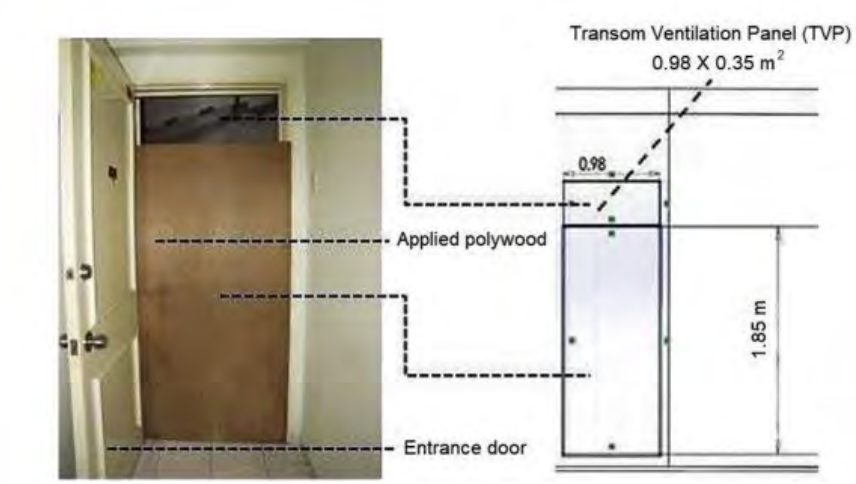

Figure 2: Transom ventilation panel

Source: (Aflaki et al., 2019)

The experiment was using a model which consist of living, dining, kitchen, bedroom, and study room which then added with TVP. At the end of the experiment, they suggest that the air enters the living through the sliding window and pass-through dining room and went out through TVP at the entrance door. This happened due to different of pressure within the model between the window and TVP. They presume that a vortex in the flow field occurs because of obstacles such as furniture, occupants and wall which cause the air velocity drops in some part. They also found that the air velocity near the TVP increases due to the size of air outlet which is smaller than sliding window.

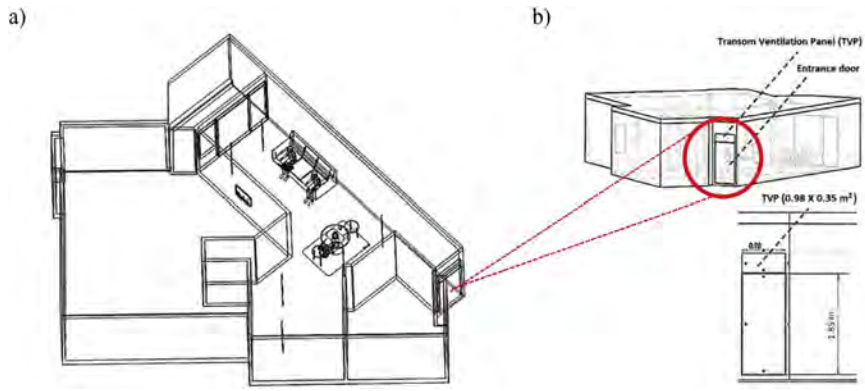

Figure 3: Model used for the experiment with installation of TVP

Source: (Aflaki et al., 2019)

Ventilation Shaft

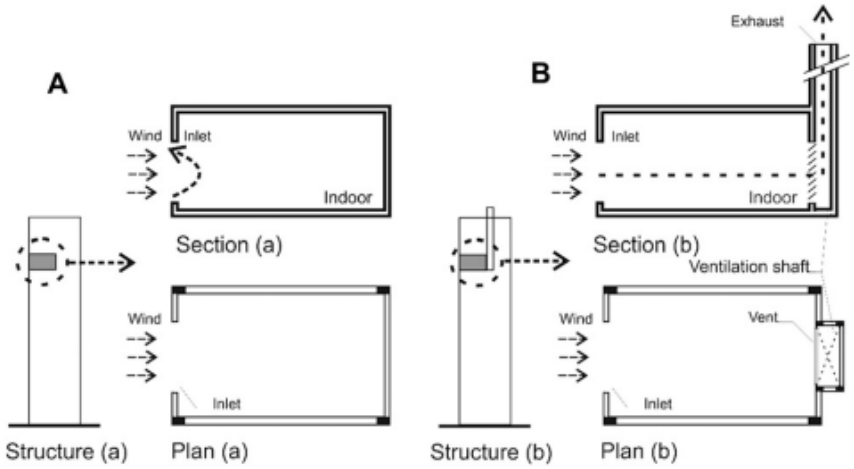

Figure 4: Principle of ventilation shaft: (A) Airmovement in a room without a ventilation shaft. (B) Air movement in a room with a ventilation shaft

Source: (Prajongsan and Sharples, 2012)

Other approaches from previous studies were a ventilation shaft which is a wind-induced ventilation system which hypothetically can increase the velocities of indoor air while increase the thermal comfort in a single-sided residential building. The system proposed ended with the conclusion which parallel to the early hypothesis. This system helps in causing the external air to enter the building room better which cause by the different of wind pressure. Ventilation shaft works mainly

by the wind-pressure difference between inlet and the outlet which drive the air. (Prajongsan and Sharples, 2012)

An experiment was conducted by Prajongsan and Sharples (2012) to enhance the effect of natural ventilation by ventilation shaft using a hypothethical unit of 25-storey residential building. A bedroom with 48 square meter area and 3 meter height was used for the purpose of this study. A Computational Fluid Dynamics (CFD) was used to measure and calculate the fluid properties while predict the air temperatures, pressure and velocities that will occur around the building through a predefined air volume. Layout of the room involved shown in Figure 5. Some parameters were included to compute the data such as building location, opening sizes, internal heat gains and weather.

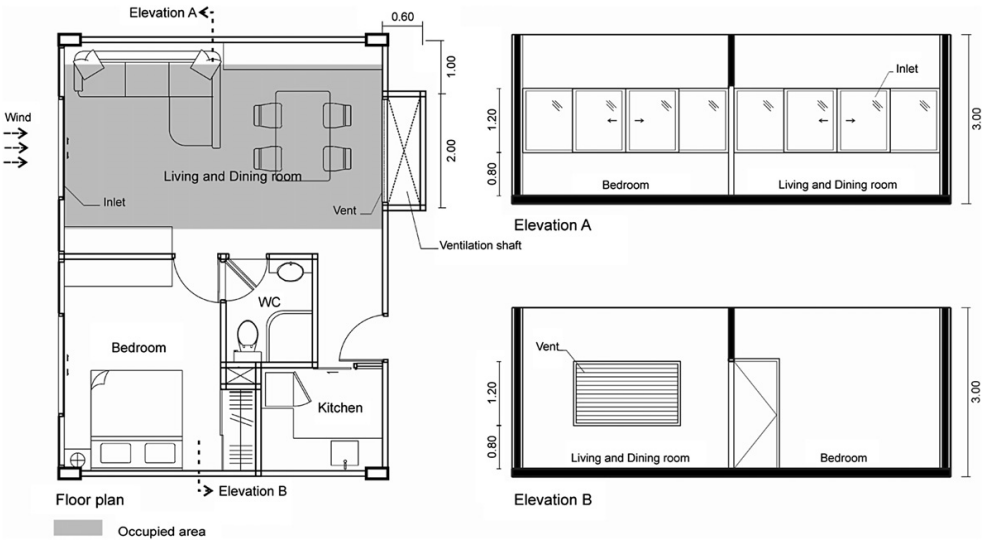

Figure 5: Floor plan and elevations of the test room

Source: (Prajongsan and Sharples 2012)

The result of the experiment shows that the average air velocities in test room much higher than that in reference room especially when the speed of wind above 1 m/s. they suggest that the velocities of air in test room were related to the conditions of wind outdoor. Higher outer wind speeds induce higher internal air velocities with small wind incidence angles. This suggest that wind induced ventilation strategy of ventilation shaft is highly efficient in maximise the usage of natural ventilation. (Prajongsan and Sharples, 2012)

Void and Atrium

Void is another passive strategy that usually applied in the multi-storey building which located in the middle of the buildings. Void can be described as air

well that located in the centre of a building in a normal condition which may help with natural lighting and ventilation of the building. (Muhsin et al., 2016) Previous studies which related to void mostly suggest that it can improve the rate of ventilation in a building by improving its natural ventilation process.

In 2016, Fakhirah Muhsin and her colleagues had conducted a study to investigate further about the effects of void in multi-storey buildings. They choose a Malaysian medium rise multi-storey housing which located in suburban area as the subject for the study with another simulation model like measured building with void which 50% larger in size. At the end of the study, they found that the ventilation rate values for the model with enlarged void is higher than the existing model which about 36.53% maximum when the size of void increases about 50%. Further discussion also stated that the velocity of air distributed across the void in model with larger void is higher than the existing model which support the first data about the increase of ventilation rate as ventilation rate affected by the air velocities. Therefore, they suggest that voids as an important parameter to be investigated to enhance the natural ventilations in multi-storey buildings. They also suggest that the increase in volume of the void can significantly increase the rate of ventilations in a multi-storey building at 0° wind angle due to increase in performance of natural ventilation.

Another passive strategy that similar as void is atrium which originally referred to main room or central court with heart in Latin word but in the modern era, it is a common space that connecting with adjacent spaces covered with glass wall and roof in a building. (Moosavi et al., 2013) the position of the atrium in a building plays an important role which may determine the potential effect of atrium in environmental aspect.

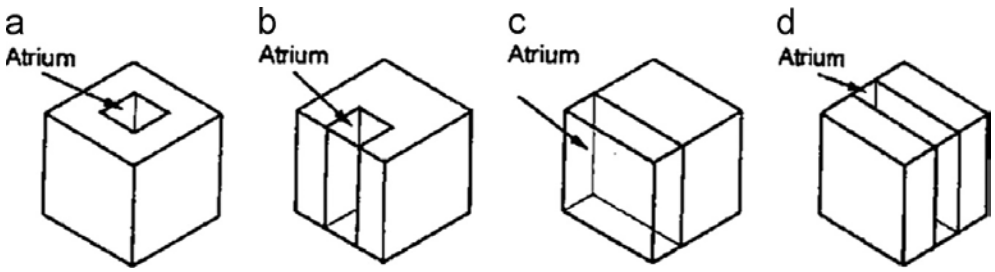

Figure 6: Generic forms of atrium

Source: (Moosavi et al., 2013)

Each atrium form has its own advantages in environmental. For example, strategy to gain more solar heat during winter in temperate climates, atrium is attached as glazed façade. Centralized and linear atrium are the best suitable

strategy in hot and humid climates such as Malaysia due to its characteristic that minimize the fluctuations of temperature through the year.

Through Moosavi et al., 2013, natural ventilation that caused by the void is buoyancy driven type ventilation due to buoyancy driven force induced from different pressures inside and outside of the building. They suggest that there are three factors that mainly affect the buoyancy driven ventilation which are, lower-level opening, higher level opening and heat sources. Previous studies also said that increase in temperature may enhance the rate of ventilation by increase the warm air layer depth creating differences in air pressure. However, since the buoyancy force not strong in nature, wind induced force needs to be compromised together in designing the atrium.

Solar Chimney

Solar chimney is another passive strategy that can enhance the efficiency of natural ventilation in multi-storey buildings which agreed by most previous studies. It maximises the buoyancy effect in the air while inducing adequate air flow rate. This is because it was designed to maximise the solar gain to create sufficient temperature difference between internal and external air of the building which inducing the air flow. The effect of radiation and convection in the solar chimney itself produced air movement which naturally helps in increasing the ventilation rates. Therefore, it still can be used during windless days due to its utilisation of solar energy. (Khanal and Lei, 2011).

It is said that different design parameters had been studied to find the optimum design solutions to enhance natural ventilation process. Among thus studies, Khanal and Lei (2011) had suggested chimney aspect ratio, ventilation height, thermal characteristic of absorber material, aperture areas and chimney tilt angle have shown the most effective in enhancing natural ventilation. The effect of tilt angle and geometry of the chimney may give direct effect to the temperature and air flow in the chimney. For the aspect of absorber materials, it gives large effect on the temperature and thermal performance of the solar chimney as the absorptivity of the materials can directly affect the energy efficiency.

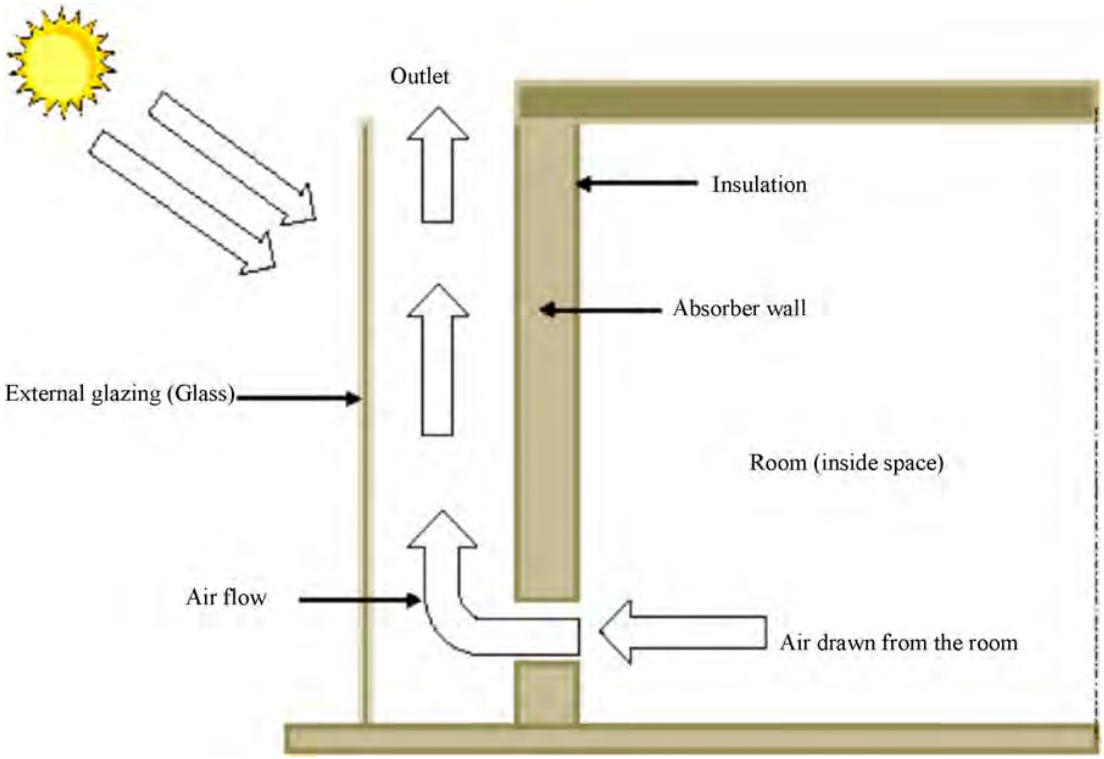

Figure 7: schematic of solar chimney with vertical absorber geometry

Source: (Khanal and Lei, 2011)

In year 1998, Hirunlabh et al. had conducted an experiment to investigate the effect of metallic solar wall chimney on natural ventilation. A small house model with 2.68m height and base area 3.35m x 3.45m was used as the subject of the experiment. Metallic solar wall chimney was installed on the south wall of the house such as figure 2.5b below. It is also painted with matt black colour at outer surfaces while covered with commercial glass 5mm thick. A set of thermocouples were used at some point in the chimney to measure the temperatures while the air velocity was measured by anemometer at the outlet and inlet of the chimney.

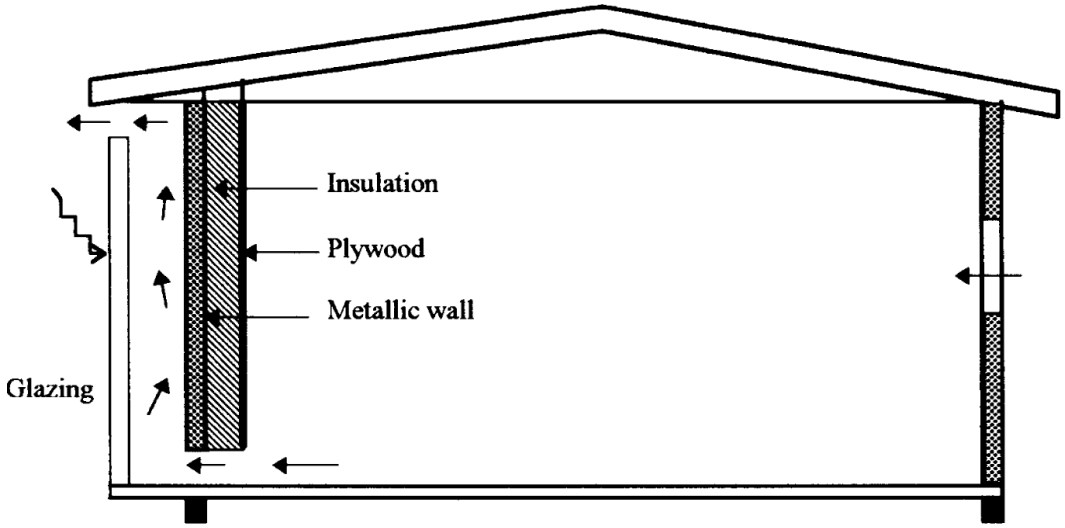

Figure 8: Schematic representation of house model with metallic solar wall chimney

Source: (Hirunlabh et al., 1998)

At the end of the experiment, the result shows positive effects on natural ventilation. The temperature reading in the chimney is high enough to create thermal different between the chimney and internal of the house thus creating natural air ventilation. It was also found that the temperature of the metallic wall is highest at the middle while lowest at the openings because of the contact with the incoming room air and ambient air. Therefore, Hirunlabh et al. suggested that the usage of metallic solar wall chimney can produce optimum natural ventilation by reducing heat gain significantly in the house. The air circulation in the house improves the thermal comfort significantly due to the efficient use of solar energy. (Hirunlabh et al., 1998)

METHODOLOGY

The method that will be used for this research is by reviewing previous studies about natural ventilation in high rise building which located in the region of hot and humid climate. The studies are searched through UiTM Library website which contain numeral previous studies and books about architectural and natural ventilation. Some studies are searched through google scholar which have more articles and studies but unfortunately some of them cannot be accessed due to some reasons. Keywords used to find all those are including “natural ventilation”, “natural ventilation in multi-storey”, “multi-storey building”, “single sided ventilation”, “natural

ventilation strategies". The aims of the search are to find the factors and solution to natural ventilation.

After reviewing all those studies, the data collected from those studies were divided into two groups which are factors that affecting the rate of ventilation and architectural solutions that can enhance the natural ventilation. The architectural solutions suggested by previous studies must be included with at least one case study which shows it is not just based on theories alone. For the factors found, they will be divided into few categories of factors which then discussed in further.

Besides, other literature about general natural ventilation studies also will be included to get more precise information how the natural ventilation works in general. This will create a clearer understanding in how to apply it in the multi-storey building. This type of literature may also provide the effect of natural ventilation which may help to justify the needs of natural ventilation in high rise building.

DATA ANALYSIS AND FINDING

Factors affecting natural ventilation

Ventilation itself means that the movement of air between inside and outside of a building while natural ventilation giving the meaning that the movement of air caused by natural means between inside and outside of a building. (Yusof, 2021) It help in removing hot air in the building and providing fresh air from outside through mechanisms such as wind pressure effect, stack effect, venturi effect and wind catcher. Thus, to help in enhancing the rate of ventilation by these effects, some architectural solutions were studied with its significant factors.

Climate factors

One of the major factors that affect the natural ventilation in a building is the climate itself which in this this study focused on the tropical climate which experience hot and humid weather along the years. In hot and humid regions which are located along the equator such as Malaysia, natural ventilation is one of the most important aspects to be considered in designing a building to achieve thermal comfort with minimum cost. Climate can be discussed in smaller aspect which can be categorised as climate factors.

One that can be considered as climate factors is the sun path which determined the solar angle of the sun. This factor may influence the solar radiation gained by a building which may affect the temperature value inside the building. Along

the equator, the sun position during day will mostly cause the angle of solar to lean near the normal line especially during noon which then make the countries located along the equator to receive large amount of sunlight throughout the year.

This led to another factors which is the temperature. As the regions gain sunlight throughout the year, it causes the temperature to rise higher during hot weather and while in monsoon weather, temperatures become low due to the humidity caused by the high amount of rain achieved every year. Temperature is one of the most important factors that help in achieving stack effects which naturally help in inducing natural ventilation. Heat gained by solar radiation increase the temperature of air in the building which cause the air particles to become less dense. This causes the hot air to rise upwards and exit the building through outlet opening while cold air from surrounding to enter the building. This process known as the stack effect which to create a ventilation throughout the building.

Surrounding conditions

Surrounding condition of the site also plays a major role in influencing the natural ventilation of a building. This aspect including the terrain or landscape shape which may block or obstruct the flow of wind from surrounding. (Ismail and Wan Mohd Rani, 2014) For example, in an urban area, surrounding building may cause the wind flow obstructed to the other buildings or may force the wind to flow to other direction. Therefore, the wind incidence angle which may enter the building may change and cause the ventilation to be disrupted. On the other hand, spacious area may cause the building to achieve more wind due to no obstruction that disturb the flow of wind in the area.

Another factors that can be taken out from surrounding conditions is the wind velocity which influences a lot in natural ventilation due to the mechanism of wind driven ventilation. As we know in Bernoulli's principle, the pressure will increase when the speed of fluid decrease and pressure decrease when speed of fluid increase. Therefore, during windy day which its velocity is high, it causes the pressure surrounds the building to become lower than pressure in the building which then forced the air inside the building to exit through the opening which is the effect of wind driven ventilation. However, this factors also can be influenced by the surrounding landscape where there are obstructions, the velocity of wind may decrease due to collision with the obstruction.

Air pressure factors also can be considered in this category because it is natural occurrence which always exist. Air pressure can be influenced by amount of energy gained by the air particles. The higher the amount of energy gained by the air particles, the higher the air pressure due to the increased of kinetic energy in the particles which cause the particles to move faster and collide with each other more

frequently. Thus, to induce a ventilation by using air pressure, there needs to be different air pressure inside and outside the building. Higher pressure will always move to lower pressure region. Therefore, there should always be a pressure different between inside and outside of a building to create a natural ventilation but in hot and humid climate usually the pressure different between outside and inside of typical building is not significantly enough to achieve maximum rate of ventilation. Due to that reason, scholars from around the world had been searching for the solution required to enhance the rate of ventilation in hot and humid climate.

Building form and building envelope

Lastly that will be discussed in this paper is about building form and building envelope which also having its own roles in enhancing the natural ventilation of a building. This includes the internal planning and design which make the passages for the wind to flow through the building. Internal spaces planning may influence the ventilation through the building by its arrangement and form. Ismail and Wan Mohd Rani, 2014 had stated that larger size of windows and openings with small number of rooms may facilitate greater natural ventilation by decreasing the resistance created in the building so that the wind can flow in higher velocity while providing cooler environment.

The position and orientation of the building is one of the factors that included in this category which highly influenced the rate of ventilation. It is due to the exposure towards the sun and wind direction that the rate of ventilation can be increases or decreases. While the opening facing the typical direction of wind, the rate of ventilation can be enhanced significantly due to the angle of incident of wind which enter the inlet opening that near the normal line. Thus, it increases the velocity of wind that enter the building while maintaining the thermal comfort in the building. The same principles also applied when the opening facing the sun but in the opposite way. When the opening facing the sun, it increases the heat gained by air in the building while causing the temperature in the to rise thus, decreasing the thermal comfort in the building. These examples prove that the significant impact of the orientation and positioning of the building towards the ventilation in a building.

Façade of the building or the building envelope itself also may become an important factor that may help in controlling the natural ventilation in a building. Previous scholar had said in their studies that the façade of high-rise building in Malaysia are more vulnerable to the impact of solar radiation and external temperature compared to low-rise building. This is due to the greater exposure of climatic elements such as sun, wind and rain towards this high-rise type of building. Therefore, it becomes one of the problems that haunted architects to solve this issue by focussing on mitigating solar energy on the façade of the building. Thus, making

the high-rise building mostly not having good thermal comfort due to weak ventilation mechanisms in the building.

Architectural solution to natural ventilation

Biofacade

Based on the studies, it was found that there are already some solutions that may help enhancing the natural ventilation experiences in a multi-storey building nowadays. It is due to the increase of populations which alert all the researchers to find the solutions for the ventilation strategies in multi-storey buildings as it keeps on being built by time. Thus, this will affect the cost of energy consumption especially in hot and humid climate regions which consumes more energy due to the character of multi-storey residential building which compact in density while having not much opening.

One of the solutions was mentioned by Sunakorn and Yimprayoon (2011) which is the usage of biofacade which can reduces daytime temperature significantly while the leaves itself was proved not obstructing the flow of wind. In the other hand, the leaves help in increasing the air velocity by creating different pressure around the leaves and surrounding. This façade also can be seen as biophilic strategies as it uses the characteristic of plants which in theories absorbing the carbon dioxide in the air to produce more oxygen to help in reducing air temperature. As we know carbon dioxide accumulated in the air will produces layers of carbon dioxide which then cause the rising of temperature by trapping the heat from sunlight; called heat island. Therefore, planting plants on the façade of buildings will eventually help to reduce the temperature in the building while maintain the thermal comfort of a building. This especially beneficial to multi-storey residential building which cannot have many opening for cross-ventilation process which derives the idea of driving more cold air into the building.

Single-sided ventilation (SSV)

Thus, we go to the single-sided ventilation (SSV) strategies which is the limitation of strategies that can be applied in the multi-storey residential building due to its compactness and side by side tenants' residents. This character also causes the tenants to consume more energy by heating, ventilation, and air conditioning (HVAC) systems. HVAC systems were recorded to consume the most energy in multi-storey residential buildings about 50-60% which then increase the emission of carbon dioxide into the surrounding. (Zhong et al., 2022)

Therefore, SSV is recommended to achieve thermal comfort in the building while reducing the usage of energy. It usually categorised according to its number of openings. SSV can be affected by difference in temperature, wind pressure or both at the same time. The temperature difference between indoor and outdoor usually varies with time and climate while the wind pressure naturally unsteady and difficult to predict which make it more complex to study and applied in building. However, wind driven SSV will be affected by the angle of incident of the wind entering the opening. There will be less turbulent when the wind incident angle is normal to the opening and make the wind flow generally stable. If the wind flows parallel to the opening, the airfields become unsteady and turbulent at the opening. Thus, the SSV rate becomes unsteady. (Zhong et al., 2022)

There are two mechanisms that will be discuss in related to SSV which are transom ventilation panel (TVP) and ventilation shaft. Both mechanisms are proved to be efficient in enhancing natural ventilation in multi-storey residential buildings. These two mechanisms were studied in different case studies which both concluded they were respectively efficient creating best natural ventilation experiences.

TVP was studied by Aflaki et al. (2019) which deliberately based on wind speeds and directions throughout the year in a central area of hod and humid region. The results had proven that instalment of TVP in multi-storey residential building can gain more wind flow through the residential unit. It can double the velocity of the air flows from outside into the building. However, the arrangement of furniture inside the unit also plays important roles in creating the best flow of wind without any obstruction. TVP was installed above the entrance door so that the wind can flow through out all the area in the unit from the windows and other opening creating cross ventilation. Therefore, TVP may cause a positive change to the air change rate to produce better indoor air quality (IAQ).

In the other hand, ventilation shaft was studied by Prajongsan and Sharples (2012). It is in theory that it will be able to increase indoor air velocities to achieve thermal comfort level in multi-storey residential buildings. However, it is proven with the case study by Prajongsan and Sharples. The result of high internal air velocities can be defined as comparable as the indoor air velocity in a cross ventilated housing unit. This is due to the mechanism of ventilation shaft that creates different wind pressure between inlet and outlet of wind which derives faster wind flows from the windows. They suggested that wind-induced ventilation is better than stack-induced ventilation in term of increasing air velocity especially in SSV. It is also said that the ventilation shaft does not only increase indoor air velocity but also providing a better airflow experience throughout the unit.

Therefore, it is proven that both mechanisms that suggested can help in enhancing the natural ventilation in the single-sided ventilated residential units which had become abundant recently due to the growth of population and the scarcity of land for residential. The effect can be better if the two mechanisms can be both

installed in the same unit, however, further studies need to be done to ensure the compatibility and effectiveness of both mechanism when installed in the same unit. In theory, it may enhance the natural ventilation more but with the positioning of those two mechanisms, it may cause some disturbances to the air flows inside the unit especially when there are lots of units that compacted in a single multi-storey building.

Void and Atrium

Void and atrium which have almost the same characteristic but slightly different which make it a different component. However, the function of void and atrium are the same mostly. It is to help in providing natural lighting and ventilation in a huge building. These strategies were known worldwide and applied in most of large building around the world especially in residential and commercial buildings. These strategies do not involve any instalments in the building rather it involves the designing process of the building itself. This will depend on the form, size, and orientation of the building.

In a study by Muhsin et al. (2016) they compare between different void configuration to unrevealed the relationship of ventilation performance and void characteristics. The result of the study shows that the natural ventilation can be enhanced from 3.44% to 40.07% with the increase of void's size by 50%. Maximum enhancement of natural ventilation can be achieved at wind angle of 0° while at 45° wind angle, the effect of the void in increasing the rate of ventilation is significantly lower. Previous study also had state that a void with 50% ratio is more efficient compared to 0% ratio of void in a building in terms of air change rate. Therefore, it is proven that the potential of voids to increase the rate of ventilation in multi-storey residential buildings with the best configuration of voids and wind angles.

Atrium in the other hand, are more flexible in position compared to void in multi-storey building. Some position of atrium that usually applied in building are such as centralized which are common in hot regions, semi-enclosed, attached, and linear which have their own advantages according to the region the building is in. Atrium can be said to help in inducing buoyancy driven ventilation which influenced by the height of inlet and outlet opening and heat sources. When air particles gain heat from sun, the energy in the particles increases, thus decreasing the density of air particles which make it flows upwards and exit the building through the outlet. Then, new cold air will enter the building through the inlet opening that on the lower height of the building. This describes the mechanism of buoyancy driven ventilation that can be enhanced by atrium which increases the heat gain of air in the atrium spaces. However, buoyancy force cannot be said to be the best method as it force is low, so wind induced force should be accompany the buoyancy force simultaneously to create a better natural ventilation experience.

There are three main factors that affecting the atrium ventilation which are temperature, solar radiation, and wind. Temperature indoor and outdoor spaces will influence the pressure of air inside and outside the atrium which forces higher air pressure outside the atrium to enter the atrium spaces. Solar radiation can be problems to the effect of ventilation due to its radiation of heat especially during afternoon sun which then affecting the thermal condition inside and outside the atrium. Wind forces help to drive the air into the atrium to cause the pressure at the inlet opening increases and decreases the pressure at the outlet opening. However, the function of wind is limited due to obstructions of surrounding building and exposure. To summarize, the role of atrium is to provide fresh air flows and exhausting stagnant warmed air.

Solar Chimney

Small temperature difference between outside and inside air during typical hot days may cause stack effect to occur in conventional chimney which are insufficient especially in high density buildings. Therefore, the studies about solar chimney which utilise the solar gain to enhance the ventilation had been increased significantly to maximise the natural ventilation in multi-storey buildings. These studies were conducted to give more comfortable environment for tenant which live in multi-storey residential buildings which usually consume large amount of energy compared to other type of residential building due to its compactness. In solar chimney system, it utilises the effect of radiation and convection which result the movement of air which naturally enhance the ventilation which also called thermos-syphoning air channel. (Khanal and Lei, 2011)

There are few factors that may affect the efficiency of solar chimney which are the effect of geometry, tilt angle and absorptivity of materials. Previous studies had reported that the effect of absorptivity can enhance the ventilation up to 57% by rising the solar absorptance value of the absorber wall up to 1.0 from 0.25. This occurs because of the linear relationship between the surface temperature of the absorber wall and the solar absorptance which then concluded by other scholar that highest absorptance materials of absorber wall can results the best effect of natural ventilation in solar chimney.

Some previous studies had been mentioned by Khanal and Lei (2011) which shows the result of efficiency of solar chimney which were studied on full size model. A group of scholars had studied the performance of solar chimney by analysing a full-size model solar chimney with 2.25m^2 collector area and 15cm duct. The relationship between solar radiation and induced airflow were taken at the end of the experiment and it was found that about 140-330mm^3/h ventilation rate can be gained through the installation of solar chimney with solar radiation ranging from 200 – 1000W/m^2. They also studied about solar chimney assisted wind tower which is the combination of solar chimney mechanism and stack effect ventilation. At the end, the result shows

that it can induce an air flow rate about 1.4kg/s at solar intensity of 700W/m^2. Both experiments naturally have a controlled variable which is the geometry of the solar chimney. Its geometry inclined collector was set fixed at 30° which act as the controlled variable.

Previous studies mention by Khanal and Lei (2011) in their study also had applied the different geometry of solar chimney by two different scholars which resulted in two different results when using the same concept and procedure for the case study. One used a cylindrical chimney covered with a transparent sheet which resulted in the increase of 36.85% ventilation rate compared to the one with no chimney. Another case study was using a rectangular chimney laminated with 1mm thick steel sheet cladding on both sides and 4 mm thick of glazing at the front. At the end of the study, they found that it can enhance the rate of ventilation up to 56% by increasing the air gap. Thus, conclude that the geometry of the chimney also plays a very important role in increasing the rate of ventilation in high density buildings.

Tilt angle of the solar chimney also contributes to the rate of ventilation by influencing the thermal performance in the chimney. This is because the angle of incidence of the radiation of solar can influence the transmission of heat through the glass then affect the thermal performance of solar chimney. Some studies had been conducted previously by other scholars stated by Khanal and Lei (2011) which all suggested that the optimum inclination angle for solar chimney to achieve maximum ventilation rate value is in the range of 45° to 70° angle. They also suggested that the width of opening of the chimney also plays important roles in influencing the natural ventilation induced by the solar chimney.

Another study by Hirunlabh et al. (1999) which investigate the effect of the absorptivity of materials on the rate of ventilation in solar chimney. In the study, they found that the temperature in the model does not rise higher than the ambient air when no ventilation is produced. They suggest that it is due to the solar chimney can enhance the thermal comfort in the building when the temperature outside much lower than body surface temperature. They also stated that the advantage of the solar chimney is that it can give insulation to reduce the heat gain by solar radiation which then cooling the load of the building.

However, all the factors that plays a role in designing the solar chimney still in further research because the factors mentioned still too wide to be explored thus, make the researcher to be interested in extending the studies about the solar chimney. In addition, there are few types of solar chimney which usually and mainly used for application and studies are such as open-ended vertical channel chimney, inclined chimney and vertical chimney attached to building.

CONCLUSION AND RECOMMENDATIONS

Conclusion

in conclusion, multi-storey residential buildings are type of building which most need the concern of ventilation because of the compactness of the building thus making the tenants to consume large amount of energy to control the thermal comfort in the building. Therefore, natural ventilation become one of the most effective solutions which need to be considered during the process of designing. However, because of the characteristic of the multi-storey building itself which compact and does not having cross ventilation the application of natural ventilation in the building become quite problematic for the architects. Thus, many studies had been done about the solution towards the application of natural ventilation in multi-storey buildings either by installing other mechanisms or with the design itself.

Recommendations

However, further studies still must be done to pursuit a better environment for multi-storey residential buildings as increase in years, the development of technologies also increases. Thus, may create more simple solutions and more complex studies can be done to achieve maximum efficiency of natural ventilation in multi-storey residential buildings. The data that was collected were just few of the solutions that were studied, thus, make these studies is incomplete naturally because the solutions of the natural ventilation effectiveness are vast that cannot be compiled in single research. So, it is natural to keep on providing a research or review about the natural ventilation solutions for the comfort of the tenants especially in multi-storey building which needs more concern compared to other type of buildings.

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