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Natural Ventilation for Energy Efficient Office Buildings: A Comparative Analysis on Three Buildings in Kuala Lumpur

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Abstract: Natural ventilation is one of the criteria of passive design strategies to reduce the usage of active ventilation especially an air-conditioning system which will involve a hugeamount of operation cost. The aim of this study was to identify and analyse the criteria of natural ventilation in the selected office buildings. The analysis had been made based on the architectural and passive design component provided in MS 1525:2007 for the office building. This case study is important in helping to understand the relationship between natural ventilation, energy efficiency and cost effectiveness.

Keywords: Natural Ventilation, Energy Efficient Design, Office Building

1. Introduction

Refer to the Malaysian Standard code of practice on Energy Efficiency and Use of Renewable Energy for Non-residential Building (MS1525:2007), it was stated in the guideline for natural ventilation as said; "Natural ventilation is the use of fresh air of sufficient volume and air change to ventilate enclosed spaces without active temperature controls or mechanical means. Fresh air is required in buildings to alleviate odours and improved indoor environmental quality. Provisions for naturally ventilated lobby areas, corridors, lift cores, staircases should be encouraged. This could aid compliance with the requirements from the fire authorities for smoke venting of the spaces in the event of the fire. In some of these cases, spill air from adjacent spaces is sufficient for air change to ventilate the space and provide thermal comfort with reducing energy. Natural ventilation strategies rely on the movement of air through space to equalise pressure.

One of its purposes is to encourage the design, construction, operation, and maintenance of new and existing buildings in a manner that reduces the use of energy without constraining creativity in design, building function and the comfort and the occupants, and appropriately dealing with cost consideration (MS1525, 2007).

2. Literature Review

Ventilation has defined as the exchange of air [1]. To create a comfortable environment inside the office building, there is a need to provide good ventilation. Without the exchange of air, both the temperature and the humidity of room will increase above the out-door value, due to the heat and moisture output of human bodies and of the various human

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activities. Thus, for Malaysia climate, there is a need for a frequent change of air (ventilation) and a sensible air movement across the body surface [1].

Ventilation will also be necessary to the space between the roof and ceiling, and adequate openings must be provided for this purpose. Ventilation of the roof space can cause a ceiling temperature to drop 2 degree Celsius, without any other constructional change. Care must be taken to avoid air which has passed through a roof space reaching the living zone (e.g. discharged onto a veranda) as this will be much hotter than the normal out-door air [1].

The lightweight timber construction holds little heat and cools adequately at night. The elevated position provides a better security and better air movement than single storey shelters. The thatched roof is an excellent thermal insulator, although it may not be quite waterproof when new. The broad eaves shade the walls and openings, provide protection from driving rain and sky glare and permit the openings to be kept open most of the time [1].

According to [2], cross ventilation should be used (even in air-conditioned spaces, to cope with system breakdowns), letting fresh air in and exhausting hot room air. Good air movement promotes heat emission from the human body surface and gives a feeling of comfort. Sky-courts, balconies, and atriums as open spaces and transitional spaces at the upper parts of the tall building encourage wind flow into internal spaces. Side vents operating as wind scoops located at the edges of the facade capture wind and make the best use of the high wind speeds found at upper levels. Wind can be channelled into ceiling plenums to ventilate inner spaces [2].

Natural ventilation (NV) is widely recognised as a low energy approach to conditioning the interiors of buildings. Natural ventilation is one of the criteria of passive design strategies in order to reduce the usage of active ventilation especially air-conditioning system (operation cost). The term ‘natural ventilation' usually conjures up an image of a small scale building, with a shallow plan depth, operable perimeter windows and variable and unpredictable internal temperatures, air quality and airspeeds [3]. The manual operation of windows can be inconvenient, but on the other hand, it has been shown that the provision of personal environmental control can, in part, enhance satisfaction with the building's internal conditions through adaptive opportunity [4] and the ‘connectivity’ with the outside world can be welcome. The simple NV strategy is therefore only well suited to temperate climates, sites with a benign micro-environment, buildings with modest internal heat gain and when occupant activities will tolerate variations of internal temperature.

Where such conditions do not prevail, or where deep plan buildings and sealed facades are required, designers generally presume that a mechanical ventilation strategy is necessary— and this usually means air conditioning. This presumption is, in fact, enshrined in some standards. For example, ASHRAE Standard 62.1 [4] states that NV systems are permitted ‘in lieu of or in conjunction with mechanical ventilation systems’ but goes on to list a number of pre-requisites which should be met. As the work of [5] has shown, air-conditioned buildings invariably consume more energy to offer the same level of service to occupants than NV alternatives. The fans, pumps and control equipment being responsible for much of the additional electrical energy consumption (rather than the chillers) [6].

Hybrid buildings can reduce energy consumption whilst offering the potential to combat tough climatic and site conditions and the prospect of meeting stringent internal environmental conditions [5].

‘Advanced natural ventilation’ (ANV) [5] offers a way forward and in recent years there has been a resurgence of interest in stack-ventilated buildings. Stack ventilation happens when; buildings in which tall chimneys, light-wells or atria are used to draw fresh air through the building. Because the flow is buoyancy-driven, if properly designed, the volume flows of air will increase or decrease in line with the increase or decrease in the inside to outside air temperature difference. Thus, if internal heat gains increase, causing a rise in space temperatures, air flows will naturally increase (e.g. without any intervention from fans and with no need to adjust control louvre or damper settings). Stack ventilated buildings are, therefore, tolerant of changes in occupancy and robust to imprecision in the operation of airflow controls (e.g. dampers and windows) [6]. Stack ventilated buildings allowed air to be delivered at the low level and exhausted at the high level, i.e. a displacement ventilation strategy, which can yield improved air quality and more effective ventilation cooling than mixing ventilation [7].

Airflow rates are invariably controlled by dampers at the inlets and outlets by using a building management system (BMS). This makes the strategy eminently suitable for buildings with large, possibly open plan, spaces when no single occupant is exercising control over the internal environment, e.g. libraries, theatres and conference halls. However, the strategy does not entirely preclude operable windows, should this be deemed desirable, although some caution is required to avoid unwelcome draughts and the preferential supply of air from the windows rather than from the air delivery shaft when in mechanical cooling mode. Most importantly, it is possible for a NV building to have a sealed façade, thus opening up this low energy strategy as a real design possibility on noisy and polluted sites, in areas where security is of particular concern, to buildings which house valuable or easily stolen objects or where the façade must offer maximum design flexibility, for example, to adopt the vernacular of the surrounding buildings in areas of historic importance [6].

If the buildings are well designed with allowing NV, they do not require mechanical devices and air-conditioning system to enhance the airflow/circulation inside the building. Then, the operational cost of the building can be reduced and it is more cost effective.

3. Research Methodology

In order to find out the architectural and passive design strategies those have been applied to the office buildings (in the reduction of the overall energy consumption), a case study had been carried out to discover the natural ventilation criteria for the selected energy-efficient buildings in Malaysia. A comparative analysis was done based on the secondary data collected from the buildings' owners and also the observation of the three (3) aspects such as:

i) Cross ventilation
ii) Stack ventilation
iii) Air ventilation

The measures of this research are; i) Securities Commission Malaysia (SC Building), ii) Mesiniaga Tower and iii) LEO Building.

4. Data Analysis

4.1 Building 1 ~ Securities Commission Malaysia (SCM)

The building draws on the bumbung limas roof design (or over-hanged roof) (see Fig. 1), shading the walls and allowing natural ventilation. A unique double glazing recycles cooler waste air into a central atrium. Architect Serina Hijjas (designer of this building) foresees the development of a building skin that would 'maintain itself', and respond to climatic changes such as wind, sun, rain and temperature, while creating a building which would be self-sufficient in energy demands. She combined a traditional design for passive design strategy with a modern design.

Fig. 1 - Bumbung Limas of Securities Commission Building. [8]

Air intake louvres are provided with all around the eaves of the overhanging roof structure, while air exhaust outlets are provided to the selected high points of the sloping roof structure and an open Cooling Tower fan discharge as well as the pre-cool Air Handling Units. Below are the processes on how the building was naturally ventilated.

i. The thermal flue façade which extends from level 1 to level 4 is essentially a modification of a double glazed façade with a 1.2-meter air gap serving as a multi-purpose maintenance walkway – ventilation air gap – buffer zone.
ii. Used cooled air from the office space is exhausted at ceiling levels into this air gap between the inner and outer glazing. The quantum of this 'recycled' cooled air is equivalent to the fresh air intake provided for office occupants.
iii. The air gap acts as a cool buffet zone keeping solar heat out of the building, and maintains a flue temperature between 28°C to 38°C which also serves to eliminate condensation on the glass surface, in addition, the thermal flue provides inherent acoustic function.
iv. The lower portion of the atrium, for example, the occupancy zone (Lower Ground 1 to Ground Floor) is air-conditioned by means of Low-Level air displacement principle.

v. From the Level 1 to level 5, the hot air is allowed to stratify upwards to discharge via exhaust openings at Level 7. The temperature built up should be excessive temperature sensors installed at Level 6 atrium roof will trigger off the operation of 2 exhaust fans to accelerate and augment the 'natural' ventilation process.
vi. Additionally, for the atrium area, a low-level displacement air-conditioning system was adopted whereby cold air is discharged at the ground level and re-circulated on the floor above.
As a result, only the occupied zone is air-conditioned while hot air is allowed to stratify in the upper non-occupied zone. Thermostat-controlled fans are placed on top of the atrium to "bleed off" the hot air.

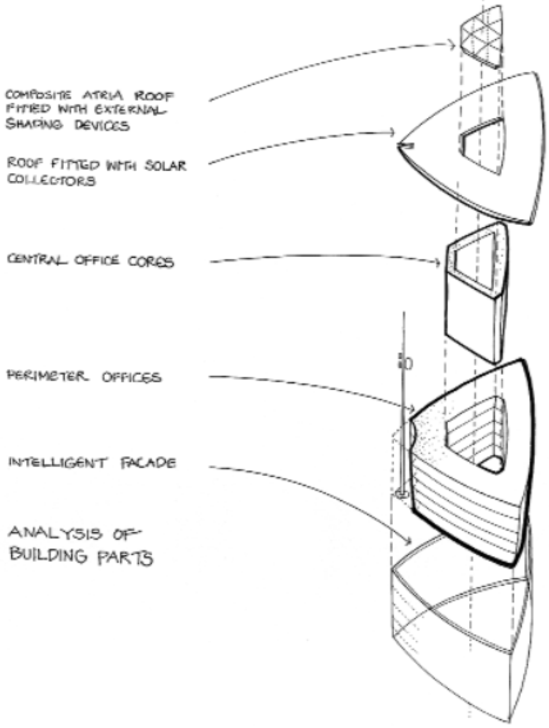

Fig. 2 - Securities Commission building section. [9]

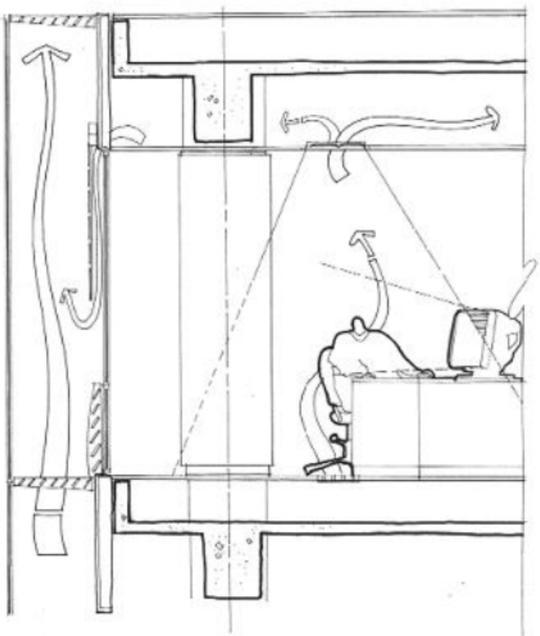

Fig. 3 - A study using computational fluid dynamics to model the facade's ventilation patterns.

4.2 Building 2 ~ Mesiniaga Tower (MT)

The main office spaces for this high-rise building are naturally ventilated and air-conditioned. The building is equipped with a Building Automated System which controls energy features including air conditioning and is utilized to reduce energy consumption in equipment. Below are the methods of how the occupants can experience relief from the tropical heat and humidity through natural ventilation.

i. Over 60 per cent of the workers has access to an opening window. They can experience natural ventilation via opening windows.
ii. The articulation of the exterior surfaces and the circular shape (from stairways and lift lobbies to the toilet areas) of the tower enable air to reach the central core.
iii. Balconies that are located in a spiralling configuration around the exterior are accessed via sliding doors that admit ventilation as well as daylight into the workstations.
iv. Ventilation and fresh air are induced into the tower via sky-courts and open ceilings. The sky-courts are terraced areas providing a space in the building which can be viewed as a transitional area between inside and outside.
v. By partially opening the top of the building, via a louvred sunroof, more wind movement and fresh air are induced into the spaces below. The sunroof also acts as a wind scoop to direct natural ventilation to the inner parts of the building as well as an exit for rising hot air.
The internal spaces of this building are not totally enclosed. The spaces can receive the cross ventilation, as well as daylight, providing cooling and a comfortable environment that relates to the tropical location.

4.3 Building 3 ~ LEO Building (LEO)

At the top of the atrium is a solar wall, or "thermal flue". The two-storey wall was painted black internally and fixed with vertical glass glazing acts as a ventilation system driven by natural forces. Solar radiation heats up the black wall, which in turn heats up the air in an 800mm gap between the wall and the glass. The hot air rises as in a chimney and escapes through vents. The resulting vacuum "sucks" outside air into the ground level of the atrium through sliding doors. When this air passes through the sliding doors, a spray mist system emits water particles, thereby cooling the air by a couple of degrees [10].

Fig. 4 - Two-storey black wall with vertical glass glazing [11].

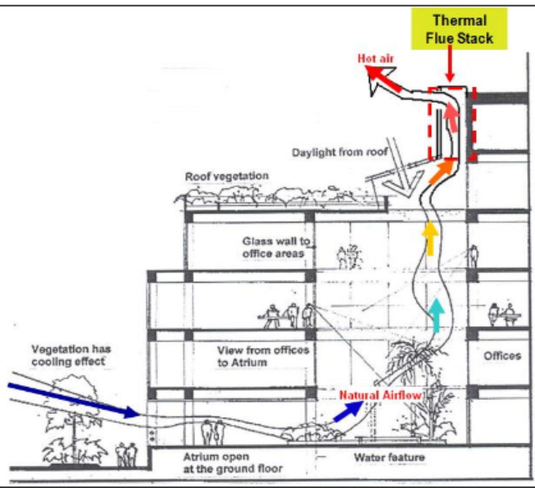

Fig. 5 - Airflow for LEO building. [11]

5. Findings

Table 1 - Comparisons between three selected office buildings based on design details to optimise cross ventilation proposed by MS1525:2007

	SCM	MT	LEO
Orientate the building to maximise surface exposure to prevailing winds	N/A	✓	N/A
Provide inlets on the windward side (pressure zone) and outlets on the leeward side (suction zone)	N/A	×	N/A
Use architectural features like wing walls and parapets to create positive and negative pressure areas to induce cross ventilation	N/A	✓	N/A
Provide openings on opposite walls for optimum cross ventilation effectiveness. If this is not possible, openings can be placed on adjacent walls	N/A	×	N/A
Make openings easily accessible and operable by the occupants	N/A	✓	N/A
Avoid obstructions between inlets and outlets	N/A	×	N/A
Have equal inlet and outlet areas to maximise airflow	N/A	×	N/A
Make outlet openings slightly larger than inlet openings to produce higher air velocities	N/A	×	N/A
Locate outlet openings on the windward side at the occupied level	N/A	×	N/A
Use good site planning, landscaping and planting strategies to tool incoming air	N/A	✓	N/A

Table 2 - Comparisons between three selected office buildings based on design details to optimise stack ventilation proposed by MS1525:2007.

	SCM	MT	LEO
Provide at least two ventilation openings, one closer to the floor (inlet) and the other, higher in the space (outlet)	✓	N/A	✓
Maximise the vertical distance between these two sets of openings. Increasing the differential height will produce better airflow	✓	N/A	✓
Provide equal inlet and outlet areas to maximise airflow	×	N/A	×
Provide adequate openings in stairwells or other continuous vertical elements so that they can work as stack wells. Such spaces may be used to ventilate adjacent spaces because their stack height allows them to displace large volumes of air	✓	N/A	✓
Use louvres on inlets to channel air intake	×	N/A	✓
Use architectural features like solar chimneys to effectively exhaust the hot indoor air	×	N/A	✓

These three buildings have been designed by allowing natural ventilation. Wind can blow air through the openings of the building. For example, Securities Commission building was designed with the over-hanged roof. This type of roof allows natural air ventilation comes inside the building atrium and cools the interior area. Mesiniaga Tower was designed with the opening at the stairways, lift lobbies and the toilet areas to allow natural ventilation. While the LEO Building uses the natural forces of wind to deliver fresh air into buildings or frequently referred to as the 'stack effect'.

Natural ventilation applied to Securities Commission building and LEO building is thru stack ventilation (buoyancy-driven). The air forces happen when the heat built-up in the atrium naturally causes air buoyancy. Cooler air entering from the bottom of the atrium will displace the hot air. Convective air 'flushing' at night leaves cooler air in the morning to absorb heat generated in the atrium space slowing the rate of heat radiation to the hall. For LEO building, black-wall helps to maximize the airflow, so the cooling process will be faster.

Mesiniaga Tower is a high rise energy-efficient office building. For this building, wind can naturally ventilate when it flows through the circulation corridors and balconies. The passive design strategy for Mesiniaga Tower is quite different compared to the Securities Commission Building and LEO Building because it is a high rise building. According to [12], the urban location has a potential to retain the wind pressure on the building surfaces. While at the lower levels, the wind pressure is reduced to 60-70%. This finding is evident if the comparison is made between tall buildings in urban and open areas (rural).

6. Summary and Conclusion

Table 3 - The difference method of natural ventilation for the building samples.

	SCM	MT	LEO
Natural Ventilation	Over-hanged roof design - air intake louvres are provided with all around the eaves of the overhanging roof structure Thermal flue façade - a modification of a double glazed façade serves as a multi-purpose maintenance walkway, ventilation air gap and buffer zone.	**HIGHRISE BUILDING** Wind can naturally ventilate when it flows through the circulation corridors and balconies. The articulation of the exterior surfaces and the circular shape of the tower enable air to reach the central core. Opening window – allow natural ventilation Sky-courts and open ceilings - allow ventilation and fresh air A louvred sunroof – allows more wind movement and fresh air are induced into the spaces below and also acts as an exit for hot air	The solar wall on top of the atrium (thermal flue) – a ventilation system driven by natural forces

Even the building designs of these three (3) buildings are the difference, the principles of allowing naturally ventilated are met with MS1525:2007. All three selected energy-efficient office buildings have been designed by allowing natural ventilation. Natural ventilation applied to Securities Commission building and LEO building is thru stack ventilation (buoyancy-driven). While the LEO Building uses the natural forces of wind to deliver fresh air into buildings or frequently referred to as the 'stack effect'.

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