USE OF A WIND WING-WALL AS A DEVICE FOR LOW- ENERGY PASSIVE COMFORT COOLING IN A HIGH-RISE TOWER IN THE WARM- HUMID TROPICS

P J Jones
Welsh School of Architecture
Cardiff University, Cardiff CF1 9LR
fax: 44 1222 874623
e-mail: jonesp@cardiff.ac.uk

K Yeang
T.R.Hamzah & Yeang Sdn Bhd
8 Jalan Satu, Taman Sri Ukay, 68000
Ampang,Selangor, Kuala Lumpur, Malaysia
fax: 603 456 1005
e-mail: kynnet@pc.jaring.my

ABSTRACT This paper discusses the use of the 'wind wing wall' as a device for the passive low-energy 'comfort cooling' of the occupants in the interior of a tall building. The case study building is a 21-storey, high-rise office tower, the UMNO building designed by Hamzah and Yeang located in Penang, Malaysia (latitude 5.24 °N) which has been designed to be air-conditioned, but can also be naturally ventilated if conditions are suitable. The paper describes cfd air flow modelling of the wind effects on the building and the effect on internal temperatures, air movement and ventilation.

1 Introduction

The UMNO building, designed by T.R.Hamzah & Yeang, is an office building situated in the centre of Georgetown, Penang. The building comprises of some 21 storeys, 14 of which are office spaces.

Offices in Malaysia are usually air-conditioned. The external climate is warm and humid with little seasonal or diurnal variation. In addition, in office spaces there is usually a high internal heat load from lighting, machines and people. The UMNO building has been designed to be air-conditioned, but it can also be naturally ventilated if conditions are suitable. The building maximises the use of daylight, so the occupants can enjoy natural lighting and the use of electrical lighting, with its associated energy use and heat gains, is reduced. It has solar shading to reduce the impact of solar heat gains. It has windows that can be opened to allow natural ventilation, driven mainly by the prevailing wind conditions. The wing walls are orientated to 'catch' the prevailing wind and the windows and balcony doors are adjustable to control the rate and distribution of ventilation. The building is situated on an open site with no interference from other high rise buildings. Fig.1 shows the building.

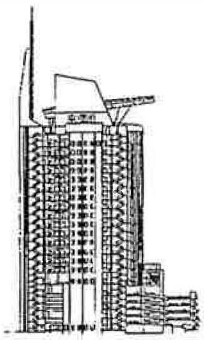

Fig.1 The UMNO building

This paper describes the analysis of the building in relation to its potential for natural ventilation. It first discusses the analysis of the wind impact in relation to the building form. Computational fluid dynamics (CFD) airflow modelling was used to predict the wind pressures on the building, in particular at the location of the openings. From this, surface pressures at openings were obtained, which could then be used for the prediction of ventilation rate, internal air movement and temperature distribution. These predictions were obtained for 'stack' (that is, for calm conditions with no wind) and for a range of window opening conditions with wind forces.

2 Comfort ventilation

Ventilation is needed for occupants breathing and to exhaust odours. It can also remove heat, although generally, this requires higher levels of ventilation. E.g. for a typical density of office occupation, 1-2ac/h of fresh air ventilation may be needed to supply the ventilation needs. However, the order of 5ac/h, or more, may be required to exhaust typical office heat gains, such that the internal air temperature is within about 1°C of external air temperature.

One of the ways in which natural ventilation can improve occupant comfort as a form of passive low-energy cooling of building, is through a direct physiological effect on the occupants. For example by opening the windows, the wind is let in and in doing so, provide a higher indoor air speed, which make the occupants inside feel cooler. This approach is generally called, comfort ventilation. Introducing the outdoor air with a given speed into a building may provide a cooling effect even when the cooling temperature is actually elevated. This is particularly true when the humidity is high and the higher wind speed entering the space increases the rate of sweat evaporation from the skin of the occupants, thus minimising the discomfort that they feel when their skin is wet. Such comfort ventilation may be desirable from the physiological viewpoint, even when the outdoor temperature is higher than the indoor temperature, because the upper temperature limit of comfort is shifted upwards with a higher air speed. Therefore even if the indoor temperature is actually elevated by ventilation with the warmer outdoor air, the effect of the comfort of the occupants (up to a given temperature limit) might be beneficial. The important factor is the airspeed over the body of the occupants. This air speed can be increased by the greater opening of the windows and also by the use of such devices as ceiling-fans in closed buildings.

The traditional Malaysian Kampong house design promotes high levels of natural ventilation and air movement, by using large openings in the external façade in order to encourage wind-driven cross ventilation. This, together with solar shading provides an environmentally selective design that can produce internal comfort conditions for much of the time. However, modern buildings in noisy polluted city locations tend to be designed such that they totally reject the climate and rely on air-conditioning and artificial lighting. But air-conditioning carries with it high energy and operating costs, and there is a growing concern over the quality of indoor environments in air-conditioned buildings, and the health of the occupants in relation to complaints of 'sick building syndrome' and poor indoor air quality. In Europe, there is an increasing interest in buildings that combine the benefits of natural and mechanical ventilation in some hybrid form, with mechanical ventilation only operating in spaces or at times when it is needed. The design of the UMNO building provides the potential for using this hybrid approach to environmental design in the Malaysian climate.

3 UMNO form, orientation and location of openings

The UMNO building has been shown in Fig.1. The form of the building with its wing-walls and balconies has been designed to direct the wind pressure to the main ventilation openings. Each floor of office space is open plan with most work places having access to an openable window/door and natural light. The main openings are in the form of windows and balcony doors, and are located on the south-west and north-east elevations. These allow for cross-ventilation driven by the prevailing wind conditions. Other windows are located along the north-west facade for user controlled ventilation. Fig.2 shows a typical office floor plan with the main openings identified.

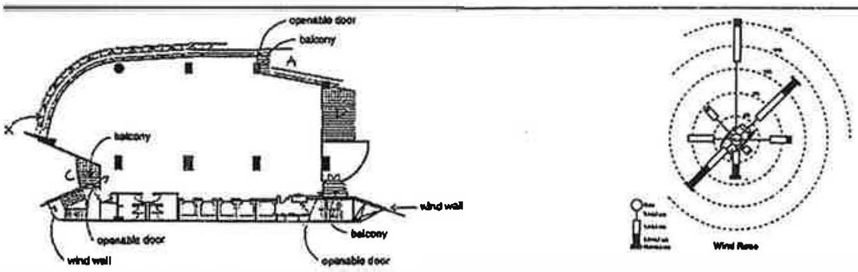

Fig.2 Typical office floor plan with the openings identified and wind rose for site.

4 The wind wing wall

Contrary to popular belief that normal incidence of wind gives better ventilation, it is in fact the oblique wind with angles of 30° to 60° from the normal that can provide better ventilation in rooms. When the wind is oblique to the building, a pressure gradient is created along the windward walls. This pressure can be increased by adding a single 'wing-wall' a vertical projection one side of the window). This is simply a short wall placed perpendicular to an opening in the building, to collect and direct a greater range of prevailing winds (where these come from a range of incidences) into the building. Thiswill enhance the internal conditions of comfort (e.g. air-changes, temperature, humidity). The design of this device depends on local wind conditions, the plan depth and built form, and needs to be tested by wind-tunnel tests or by CFD (Computational Fluid Dynamics) simulations to ascertain effectiveness, size of openings, control components, wing-wall size and shape, orientation and location.

Fig.3(1)shows the conditions without the wing-wall. Wind 'A' from a perpendicular angle of incidence hits the wall and the orifice. The flow that enters the orifice is 'a' which is generally smaller in dimension than the opening dimension 'x'. Fig.3(2) shows the situation when wind has an inclined incidence to the wall. The wind 'B' hits the external wall, generating flow 'b' into the interior. Assuming that wind speeds 'A' and 'B' are the same, then flow 'b' is smaller than 'a', since wind 'B' has an oblique angle of incidence. Fig.3(3) shows the situation with the addition of a wing-wall. The wall is located on that side of the orifice that should enable it to collect the greater range of prevailing winds. Which side of the orifice for the wing-wall to be located depends upon an assessment by the designer of the wind-data of that locality. In this instance, this is assumed to be primarily within 45° incidence from direction 'A' and 'B'. The flow through the orifice is 'c' which is equal to or greater than flow 'a' or 'b' due to the wing-wall. Fig.3(4) shows a design with a wing-wall at both sides of the orifice. This is better in situations where wind comes from an 90° spread of varying incidences (of varying times, directions, speeds, etc.) to the surface of the external wall of the building. The orifice should have openable panels (e.g. full-height sashes) that operate as 'valves' to be adjusted depending on external wind conditions for that moment and should be placed closer to the leeward wing-wall for situations of greater inclined wind incidences. The perpendicular wing-wall configuration is more effective at stagnating the approaching air-flow which results in flow more perpendicular to the opening and with less contraction. In addition, the wing-wall devices should also have compatible adjustable horizontal 'spoilers' at each floor level to minimise vertical flow over the face of the building and to further control the incoming winds in the event of conditions of very high wind speeds. Fig.3(5) shows a single wing-wall option which is more efficient for winds coming from inclined incidences than Fig.3(4).

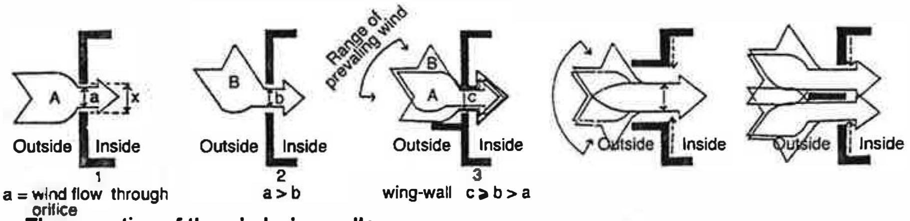

Fig.3 The operation of the wind wing wall

5 Wind analysis

The wind speed will increase in height according to a power law. In order to assess the potential for natural ventilation, the wind pressure over the buildings' external surfaces needs to be estimated at the opening locations. This would normally be carried out using a physical scale model in a wind tunnel. However, this was not an option in this design and therefore a mathematical wind tunnel analysis was carried out using the CFD airflow model DFS-AIR.

A model of the building was constructed mathematically in the computer and used to obtain an estimate of the surface pressures at each opening. The wind rose for the site, shown in Fig.2, indicates that a typical wind condition for the site would be a speed of 2.5m/s (at a height of 10m from ground level) and a south-west prevailing wind direction. The power law relationship was then used in the airflow model to calculate the boundary layer wind speed at increasing heights.

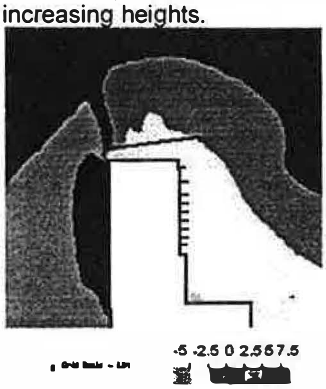

Fig.4 Wind flow around the building (vertical section) in the form of air pressure contours

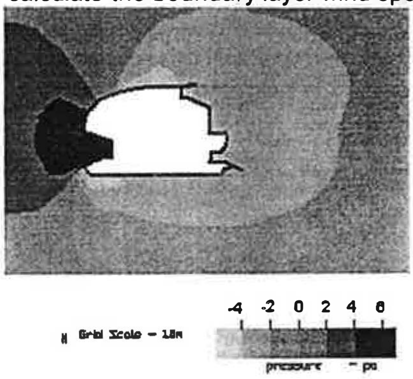

Fig.5 Wind flow around the building (Floor 12) in the form of air pressure contours

The results of the simulation are shown in Figs.4 and 5. Fig.4 describes the wind flow around the building in the form of air pressure contours. The maximum wind impact on the windward elevation is at about 75% the height of building, which is a general rule for buildings on an open site. Fig.5 shows the pressure distribution around the building for a typical office. It shows a positive pressure of about 6Pa at openings on the windward balcony and a negative pressure of about 3Pa on the downwind balconies and side openings. These surface pressures were then used in the internal airflow simulation to predict the wind induced ventilation rates for typical wind conditions.

6 Internal airflow analysis

The aim of the internal airflow simulations was to predict internal ventilation rate, air speeds and temperature distribution in order to assess the potential for natural ventilation and to provide advice on window opening strategies. The CFD airflow model DFS-AIR was again used, but this time to predict the internal air movement in relation to a range of operating conditions for natural ventilation. The model is able to account for the pressure boundary conditions at the openings, based on the wind pressure simulation data described above, as well as simulating internal heat gains and heat transfer at internal surfaces, for example heat gains through the windows. Internal heat gains, due to people, lights and small power, were assumed to be 35W/m^2. The simulations were carried out:

- for a typical external air temperature of 30°C
- for a calm day with no wind and ventilation driven by the stack forces generated due to internal external temperature differences;
- for three wind conditions (1.0, 2.5 and 5m/s; south-westerly) and a range of window opening configurations.

Table 1 indicates:

- For stack effect only (i.e. calm conditions) the ventilation rate with all windows open is about 1ac/h.

- At low wind speeds (1-1.5m/s) the ventilation rate is about 4ac/h.
- At medium wind speeds (2.5m/s) the ventilation rate increases significantly and upwind windows need to be closed down to 50% (or less), or completely closed and side windows open, to give ventilation rates between 6 and 12ac/h.
- At high wind speeds (5m/s) the upwind windows need to be closed to 20% or less. Closing downwind windows is of secondary importance (closing them to 50% only reduces the ventilation rate from 11.9 to 10.8 ac/h).

Table 1 Ventilation rates for different wind speeds and opening configurations

	UPWIND	SIDE	DOWNWIND	AC/H
STACK	C(100%)	X(100%)	A,B,D,(100%)	1.0
LOW WIND	C(50%)	0	A,B(100%)	2.1
	C(100%)	0	A,B(100%)	4.1
MEDIUM WIND	C(100%)	0	A,B(100%)	24.0
	C(50%)	0	A,B(100%)	12.6
	C(100%)	0	A,B,D(100%)	33.8
	0	X(100%)	A,B,D(100%)	6.3
	C(100%)	0	D(100%)	28.0
HIGH WIND	C(20%)		A,B(100%)	11.9
	C(20%)		A,B(50%)	10.8

The results for the stack only condition with all windows open, Case 1, are shown in Fig.5. Fig.6 presents the internal temperature distribution and the air speed vectors at 1.2 m height. Fig.7 presents the internal temperature distribution and air speed vectors respectively for Case 2, with windows A,B and C open and for a wind speed of 2.5m/s .

Fig.6 Internal temperature distribution and air speed vectors at 1.2 level

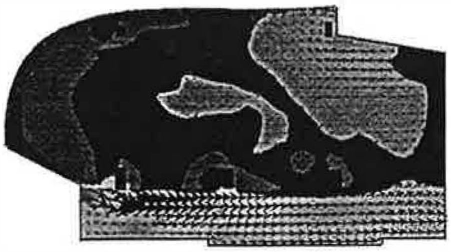

Fig.6 Internal temperature distribution and air speed vectors, open window, air speed 2.5 m/s

Fig.8 presents the relationship of internal air temperature and air speed to ventilation rate. The relative high air speeds at the high ventilation rates are due to localised high air speeds near the openings. The graph indicates the impact of the natural ventilation rate on internal comfort in relation to reduced air temperature and increased air speed.

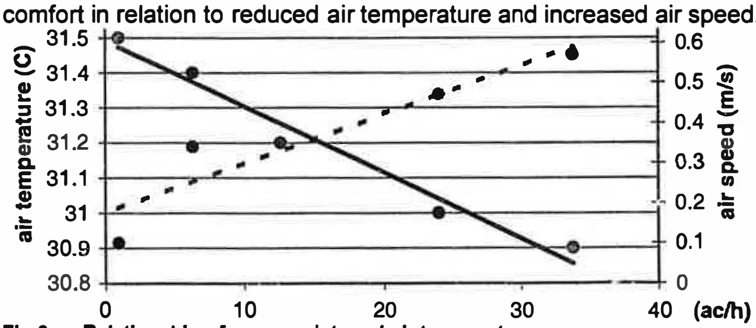

Fig.8 Relationship of average internal air temperature and air speed to ventilation rate for a wind speed of 2.5m/s

6 Discussion and conclusions

The wind condition was simulated to provide external pressure values at the opening door and window locations. The buildings' shape appears to respond well to the prevailing wind directions, with the combination of wing-walls and balconies providing relative high/low pressure areas at ventilation openings on the upwind and downwind elevations. For wind directions other than the prevailing winds, the pressure gradient across the building may be less, however the openings along X should provide sufficient control. For the stack only situation the ventilation rate is not very high, at about 1ac/h. The internal external air temperature difference is greatest (1.5°C higher) for the stack only case. This relatively small temperature difference, together with the relatively low ceiling height with respect to the stack effect, does not provide a strong stack force. The internal air speed is low and would not provide a significant comfort cooling effect.

For the window opening situations, where there are large openings up-wind and down-wind, the ventilation rates are very high (up to about 30ac/h). Obviously this is too high for comfort as the corresponding internal air speeds are between 0.4 and 0.5m/s in the vicinity of the openings, which could give rise to mechanical problems, such as papers moving. Closing down the openings on the up-wind side appears to be the best solution for controlling ventilation without excessive internal air speeds. The pattern of internal air movement for wind-driven ventilation appears to be localised in relation to the inlet openings. There are strong paths of air-flow originating from the inflow openings, which appear to mainly coincide with internal circulation routes, but there may be much lower air movement in the main occupied zone. There may be the need to consider some form of device that would diffuse the incoming air 'jet', such that the ventilation air is more evenly distributed and to avoid any 'short-circuiting between supply and exhaust openings. This might be in the form of a 'spoiler' or 'deflector' located near to the openings. The ventilation strategy should be to ensure that windows and doors can be opened wide, for low wind and calm conditions, but that they can have adjustable openings to allow them to be operated under average and high wind conditions. During medium to high wind situations it appears to be advisable to close down the windward openings to a minimum. It appears that the openings on the down-wind facades have only a secondary effect on ventilation rates although they may have a larger influence on patterns of internal air movement. The effectiveness of the wing-wall in the skyscraper eventually depends on the wind conditions around the building and on the design details of the building itself. The wind conditions around the building depends on the planning of the town and, in particular of the neighbourhood where the building is located. The main details of the building that affect indoor ventilation conditions are (after Givoni, B., 1994, pp. 42-43):

- The building configuration (and profilation e.g. projection, recesses, etc.).
- Openings at facade with respect to wind direction.
- Total area of openings in the pressure and suction regions of the building's envelope.
- Window types and details of opening.
- Vertical location of openings.
- Interior obstructions of airflow from the inlet to the outlet openings (i.e. when the air is flowing through more than a single room). This includes information such as the size and location of the openings connecting the adjacent rooms - the doors, etc.).
- Presence or absence of screens in the openings.

Criteria for evaluation indoor ventilation conditions include:
- Air speed at inlet opening,
- Maximum speed at any point in the space.
- Average air speed in the space.
- Average at occupancy level (i.e. at 1m above floor level).

The experiment shows that the wing wall is an effective device for the provision of comfort ventilation in high-rise tower buildings.