

Natural Ventilation in Buildings

TONY ROFAIL B E BSc ME CPEng
Director, WINDTECH Consultants Pty Ltd

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0.0 BACKGROUND

Natural ventilation is the intentional flow of outdoor air through an enclosure under the influence of wind and thermal pressures through controllable openings. It can effectively control both temperature and contaminants, particularly in mild climates. Temperature control by natural ventilation is often the only means of providing cooling when mechanical air-conditioning is not available. The arrangement, location, and control of ventilation openings should combine the driving forces of wind and temperature to achieve desired ventilation rate and good distribution of fresh air through the building.

Natural ventilation is driven by pressure differences across the openings caused by ambient pressure and temperature differences between different openings within a unit. The current drive for sustainable design has led to the need to focus on Natural Ventilation as a factor towards the reduction of greenhouse emissions.

The BCA Vol.1, Part F4.6 prescribes the minimum openings in the wall(s) for natural ventilation to be the equivalent of 5% of the floor area. There is no mention of flow paths for cross-ventilation or effects of shielding, which can often be more critical than area of opening(s). Hence blindly following the BCA provision does not guarantee good design in terms of natural ventilation.

1.0 NATURAL VENTILATION AND THE DEVELOPMENT APPLICATION PROCESS

Recently, a number of local government authorities have stipulated that the natural ventilation characteristics of new residential developments be independently assessed. Local government authorities can require as much as 80% of the dwellings in a residential development to have good natural ventilation.

On July 1, 2004, the NSW Department of Infrastructure, Planning and Natural Resources (DIPNR) introduced BASIX, the Building Sustainability Index, with the aim of reducing the use of potable water and to reduce greenhouse gas emissions by setting energy and water reduction targets for house and units. BASIX encourages good natural ventilation design by weighing in the effect of the natural ventilation characteristics of a dwelling on the overall energy requirements. BASIX also relies in

most cases on the NatHERS simulation tool for predicting the energy requirements of a dwelling. As an alternative to the natural ventilation provisions in BASIX, a function is provided in the NatHERS software to partially account for the effect of good natural ventilation on the energy requirements of the dwelling. Note that “good natural ventilation” is very loosely defined in comparison to the natural ventilation provisions within BASIX itself. An alternative to NatHERS is the second generation simulation tool, AccuRate, which provides a better assessment of the effect of natural ventilation, particularly in the case of hot, humid climates by accounting for the cooling sensation of the airflow in the dwelling. The effect of the air-flow on the cooling sensation can be quite significant, as shown in Figure 1. However, DIPNR is yet to approve the use of the AccuRate simulation tool as an alternative to NatHERS.

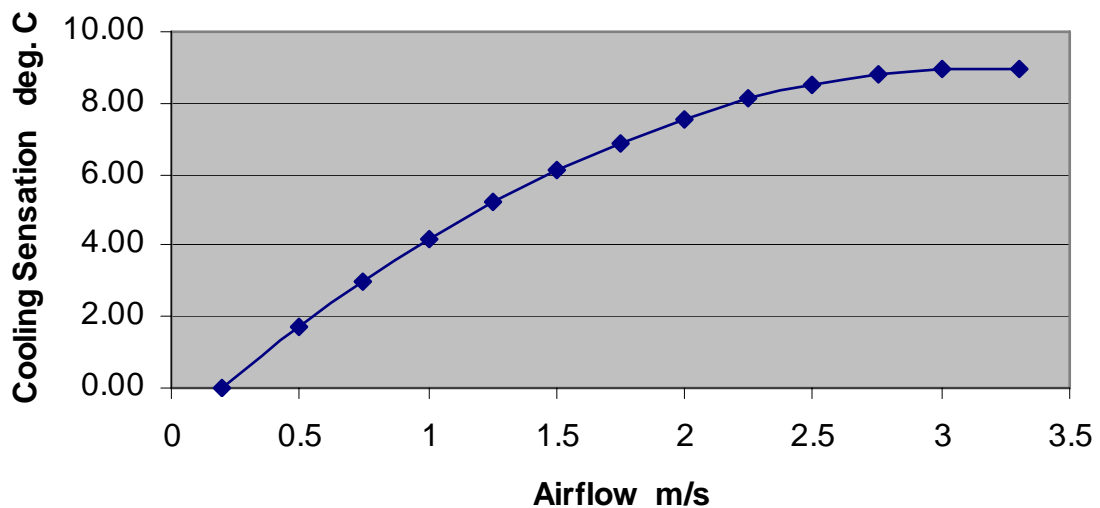


Figure 1. Plot of Cooling Sensation of Air Flow (after Aynsley and Su, 2005)

2.0 NATURAL VENTILATION ASSESSMENTS

Natural Ventilation Assessments are carried out as either qualitative desk-top assessments or quantitatively, through the use of modelling techniques. Desk-top assessments are most commonly employed as there are no planning controls that stipulate specific performance levels.

In the case of desk-top assessments, these tend to focus on the wind directions that prevail throughout the year. In the case of local climates such as those of Sydney, less emphasis is placed on the winds that prevail during the winter months, when windows are less likely to be open. The other key parameters are number of different aspects that are exposed to either positive or negative external wind pressures and the number of principle wind directions (with consideration of directional frequency) under which sufficient cross-ventilation can be achieved.

In some cases, modelling techniques are employed. These are discussed in the next section.

3.0 MODELLING TECHNIQUES

CFD: The application of Computation Fluid Dynamics for this type of study is very limited due to the difficulty in accurately modelling external flows around buildings. This is currently a very expensive process and tends to lead to highly inaccurate results. This is due to the following:

- Inability to resolve the dynamic behaviour of the flow and its consequence with regards to accurately modelling separation and reattachment.
- Limitation in the ability to model surface-fluid interaction.
- This method of modelling is currently not viable particularly for cases where there are complex surrounds and landforms.

Wind Tunnel Testing: This approach, which involves the use of a physical model that is set up in a wind tunnel, which models the boundary layer flow to the same scale remains the only reliable method of predicting the surface pressures on a building, which are required to derive the internal flows. The accuracy of the wind tunnel modelling of the surface pressures has been confirmed against full-scale measurements (Rofail, 1995).

A scale model of the development is prepared and fitted with pressure sensors. Pressure sensors are linked to each location of openings for each of the units being studied. Photographs of a sample model are given in Figure 2.

The testing was performed in a Boundary Layer Wind Tunnel. Testing parameters need to comply with the requirements of the AWES-QAM-1-2001.

Differential pressures across different openings within the same dwelling are measured. This enables the measurement of the differential wind pressure between the various openings and after accounting for pressure losses due to the “orifice” effect, the corresponding flow rates can be derived.

The mean differential pressure coefficient can be defined by the following equation:

$$\Delta C_{p_{\text{mean}}} = \frac{\text{(mean pressure at inlet – mean pressure at outlet)}}{\text{Mean Reference Pressure}}$$

The mean reference pressure is related to the reference mean wind speed by the following equation;

$$\text{Mean Reference Pressure, } P_R = \frac{1}{2} \rho V^2 = 0.6 \times V^2$$

Where the air density, ρ , is assumed to be equal to 1.20 kg/m³ and the value of the velocity, V , is the directional mean reference wind speed.

The airflow (m³/s) through the smallest opening with a unit is computed as:

$$q = A_s \cdot k_i \cdot k_o \sqrt{\frac{P_R \cdot \Delta C_{p_{mean}}}{\frac{1}{2} \rho}}$$

Where A_s is the area (m²) of the smallest opening and k_i and k_o are pressure loss coefficients for the inlet and outlet respectively. The pressure loss coefficients are taken as 0.6, which is typical.

4.0 CRITERIA

There is no definitive criterion in the BCA regarding the minimum flow required. Hence this exercise sets out to benchmark the performance of the corner-units and the double-ended units within this development as a minimum standard.

Air-Flow Rates: Our interpretation of AS 1668-2:2002 is that a flow rate of 0.03 to 0.04m³/s through a residential unit is generally suitable for natural ventilation. This is based on the guidelines presented in Clause 4.8 (General use enclosures, e.g, offices, residences, shops, stores, corridors, bars,..)

Room Air Velocity: S.Selkowitz (2004) suggest that the assessment of the adequacy of natural ventilation should be based on air-speed within the unit rather than simply the amount of air-changes per hour. This is because the human body reacts more to the air-flow rather than just the quality of the air. It is considered by Selkowitz that a minimum average daily air speed in a room is of the order of 1m/s would provide an acceptable level of natural ventilation.

Residential Flat Design Code (NSW): Part 3 of this Code deals with Building Design. It states that corner-units, double-ended units and 2 storey units (where the upper floor is the top floor of the development, and is setback from the lower floor) can achieve good natural ventilation. The latter configuration is often misunderstood, as it is imperative that the second storey have the setback, and that it is at the top floor of the development, otherwise the difference in pressures between the 2 floors will be negligible, as was demonstrated in this case.

Wind tunnel tests undertaken by Windtech indicate that the flow rates in the double ended units and corner units for this development generally exceed the criteria calculated from AS1668:2-2002. However, 2 storey units, which do not fit the parameters of the Residential Flat Design Code, exhibit poor levels of natural ventilation, which reinforces the conditions for 2 level unit set out in the Residential Flat Design Code.

5.0 GUIDELINES FOR NATURAL VENTILATION DESIGN

Our experience is that thermally driven components in natural ventilation are negligible when compared with the pressure driven components (Rofail and Fernando, 1990).

Several general guidelines should be observed in designing for natural ventilation. Some of these may conflict with other climate responsive strategies (such as orientation and shading devices to minimise solar gain) or other design considerations. It is important to understand the general nature of natural ventilation and these guidelines provide some insight to the concept of natural ventilation.

1. In hot, humid climates, maximise air velocities in the occupied zones for bodily cooling. In hot, arid climates, maximize airflow throughout the building for structural cooling, particularly at night when the temperature is low.
2. Take advantage of topography, landscaping, and surrounding buildings to redirect airflow and give maximum exposure to breezes. Use vegetation to funnel breezes and avoid wind dams, which reduce the driving pressure differential around the building. Site objects should not obstruct inlet openings.
3. Shape the building to expose maximum surface area to breezes.
4. Use architectural elements such as wingwalls, parapets, and overhangs to promote airflow into the building interior.
5. The long facade of the building and the majority of the door and window openings should be oriented with respect to the prevailing summer breezes. If

there is no prevailing direction, openings should be sufficient to provide ventilation regardless of wind direction.

6. Windows should be located in opposing pressure zones. Two openings on opposite sides of a space increase the ventilation flow. Openings on adjacent sides force air to change direction, providing ventilation to a greater area. The benefits of the window arrangement depend on the outlet location relative to the direction of the inlet airstream.
7. If a room has only one external wall, better airflow is achieved with two widely spaced windows.
8. If the openings are at the same level and near the ceiling, much of the flow may bypass the occupied level and be ineffective in diluting contaminants there.
9. The stack effect requires vertical distance between openings to take advantage of the stack effect; the greater the vertical distance, the greater the ventilation.
10. Openings in the vicinity of the Neutral Pressure Level (NPL) are least effective for thermally induced ventilation. If the building has only one large opening, the NPL tends to move to that level, which reduces the pressure across the opening.
11. An inlet window smaller than the outlet creates higher inlet velocities. The rule of thumb is to have the outlet area 50% larger than the inlet area, assuming that they do not have a tendency to reverse roles with changes in wind direction.
12. Openings with areas much larger than calculated are sometimes desirable when anticipating increased occupancy or very hot weather.
13. Horizontal windows are generally better than square or vertical windows. They produce more airflow over a wider range of wind directions and are most beneficial in locations where prevailing wind patterns shift.
14. Window openings should be accessible to and operable by occupants.
15. Casement type windows are much less effective in comparison to sliding windows.

16. Inlet openings should not be obstructed by indoor partitions. Partitions can be placed to split and redirect airflow, but should not restrict flow between the building's inlets and outlets.
17. Vertical airshafts or open staircases can be used to increase and take advantage of stack effects. However, enclosed stair-cases intended for evacuation during a fire should not be used for ventilation.

6.0 CASE STUDY 1: Testing of an Auxiliary Natural Ventilation System for a residential development in the Sydney Metropolitan Area

A comprehensive wind tunnel study has been carried out by Windtech Consultants Pty Ltd to establish the differential wind pressures between the various openings in the corner, double-ended and double storey units within a development such that the corresponding amount of air flow between these openings can be determined. The results are compared against the airflows predicted for mid-wall units that are linked to an auxiliary form of ventilation using ventilation ducts that rise to the roof of the development. The results of confirmed the adequacy of the proposed system.



Figure 2: Photographs of the model in the wind tunnel

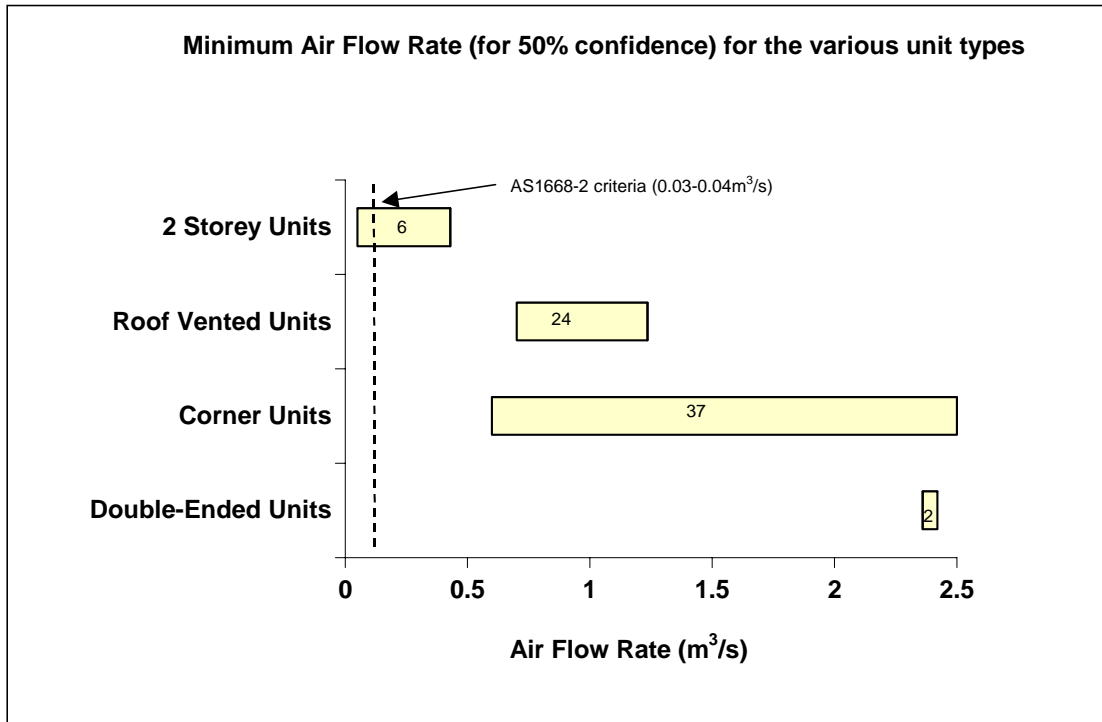


Figure 3: Minimum Air Flow Rate, based on 50% confidence, for the various unit types

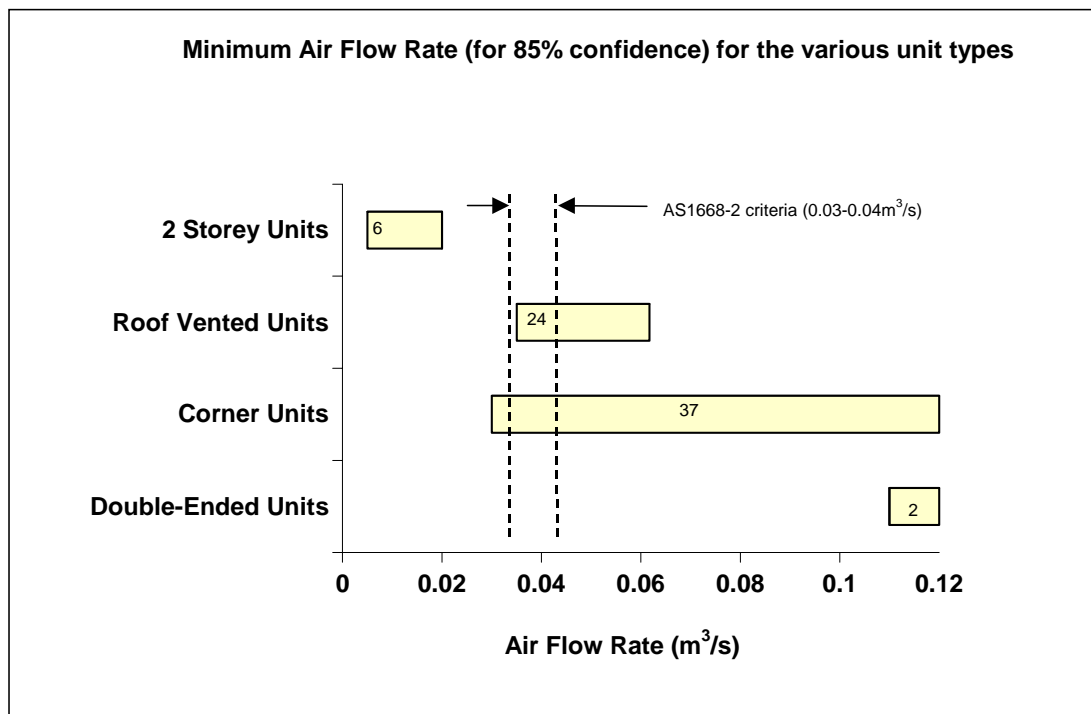


Figure 4: Minimum Air Flow Rate, based on 85% confidence, for the various unit types

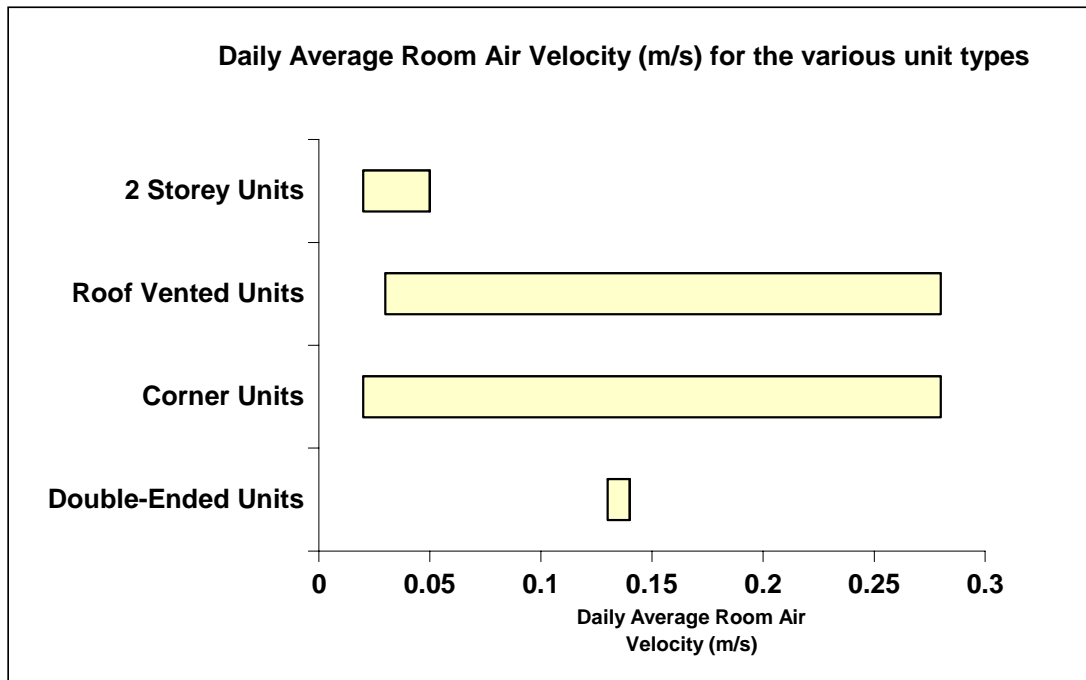


Figure 5: Daily Average Room Air Velocity

7.0 CASE STUDY 2: Enclosed Roof Garden on a Tall Building

A 250m tall office tower is proposed that features a communal recreational area at the top which will be enclosed within the curtain-walled building envelope. To reduce heat build-up within this “glass box” without excessive use of mechanical air conditioning, Windtech Consultants were asked to model the natural ventilation in the roof space of the building. This was performed using a wind tunnel model, shown in Figure 6.

The building is located within a hot arid climate and therefore the operable parts would be opened except during the summer months, during which time full reliance will be made on the mechanical system to service that large volume. For the remainder of the year, a target (set by the mechanical consultant) of a minimum of 4 air-changes per hour for 90 percent of the time (excluding summer) is to be achieved.

Based on the directional frequencies and wind speeds for the relevant months, as well as the distributions of the mean pressure coefficients for the different wind directions, an optimal configuration was arrived at, illustrated in Figure 7, and requires a total of 18 square metres of inlet areas and 27 square metres of outlet areas (on the roof).

The next most effective solution required 10percent more open area.

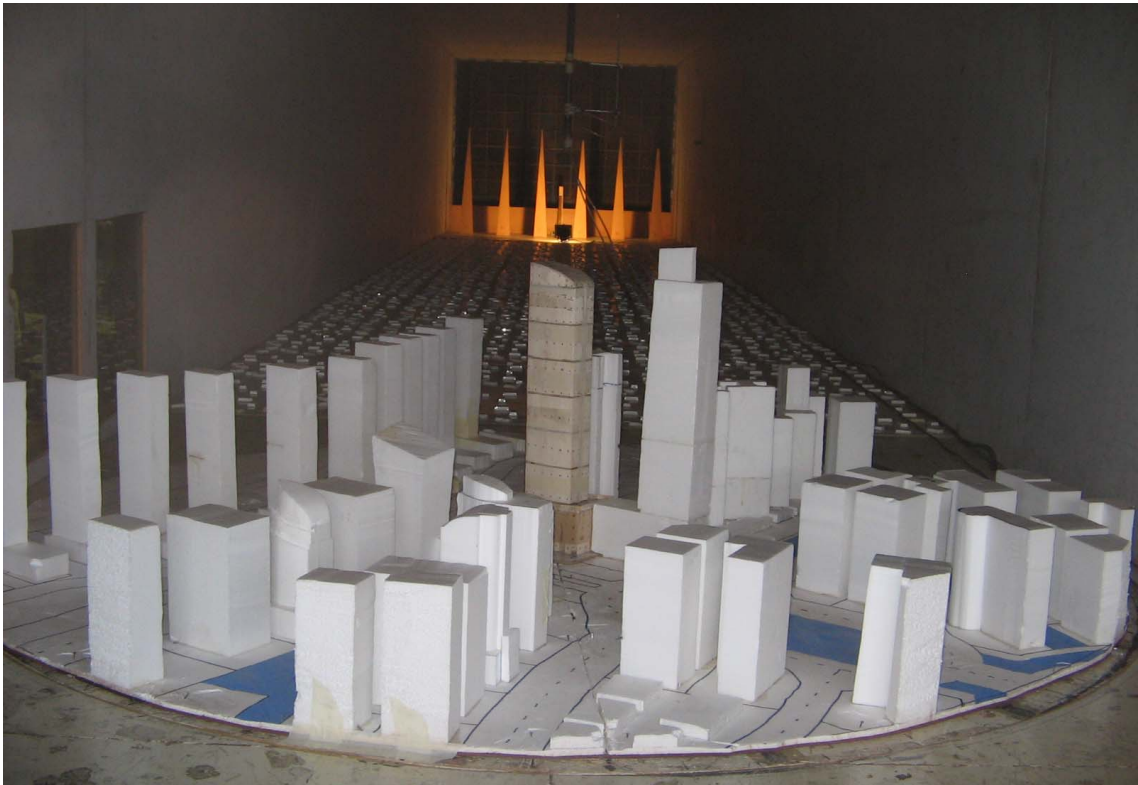


Figure 6: Model set-up in the wind tunnel

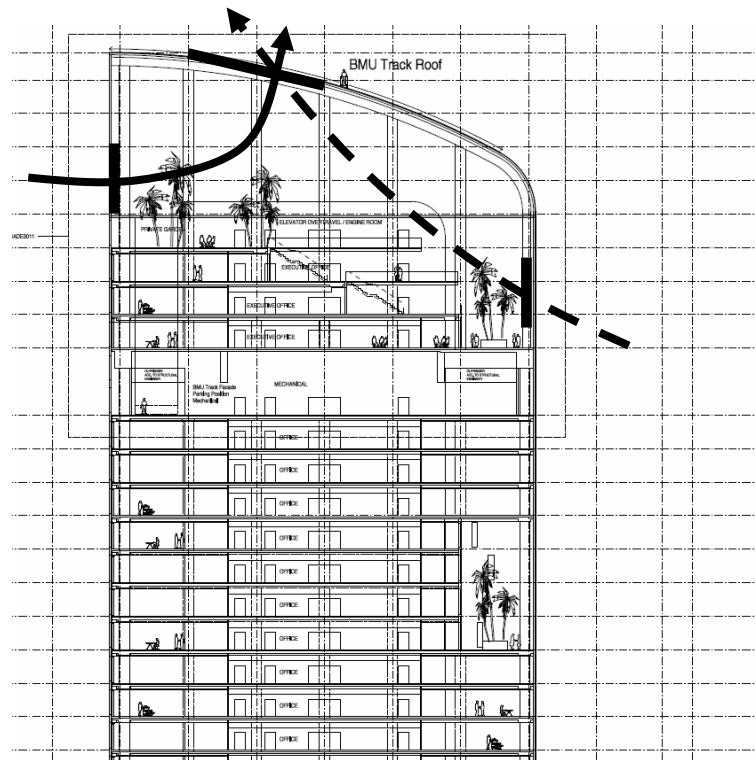


Figure 7: Recommended roof ventilation system

REFERENCES

Australasian Wind Engineering Society, 2001, AWES-QAM-1-2001, "Wind Engineering Studies of Buildings"

Aynsley, R. and Su, B, 2005, "Insulation of Roofs in Warm Climates", 2005 CIB W92/W107 International Symposium, February 7th – 10th; 2005 – Las Vegas, NV USA

Building Code of Australia, Volume 1, Part F4.6

Residential Flat Design Code (NSW), Part 3: Building Design

Rofail, 1995, "Full-scale/ Model-scale comparisons of Wind Pressures on the TTU Building", Proceedings of the 9th International Conference on Wind Engineering, India, January 1995.

Rofail, A.W. and Aurelius, L.J., 2004, "Performance of an Auxiliary Natural Ventilation System", 11th Australasian Wind Engineering Society Workshop, Darwin.

Rofail, A.W and Fernando, S, 2000, "Case Study: Assessment and Optimisation of Natural Ventilation for The University of NSW Main Service Tunnel"

Selkowitz, S., 2004 (Head of Building Technologies, Lawrence Berkeley National Laboratories, California, USA) – private communication.

Standards Association of Australia, AS1688-2:2002, "The use of Ventilation and Air-conditioning in Buildings."

<http://sustainability.nsw.gov.au/information/about.jsp>