OPTIMUM VENTILATION AND AIR FLOW CONTROL IN BUILDINGS

17th AIVC Conference, Gothenburg, Sweden, 17-20 September, 1996

The Effects of Building Form on the Natural Ventilation of Commercial Buildings

D.K. Alexander, H.G.Jenkins, P.J.Jones

Welsh School of Architecture
University of Wales, Cardiff
Bute Building,
Cardiff CF1 3AP, U.K.

1 Synopsis

Wind pressures can significantly affect ventilation performance. However often they are overlooked in the design of a naturally ventilated building, with buoyancy forces presumed to offer the worst case scenario for design. The result is that airflow patterns and the ventilation performance of the building is often different from the design intent.

Successful natural ventilation design requires careful consideration of the building form, and so must involve the architect at the early stages of fabric development. Whilst devices and features may be used to enhance the performance of ventilation outlets, the wind flows at inlets are more likely to be affected by the form of the building, and less amenable to improvement by small devices. Performance may be improved by larger features that in effect become part of the building form itself. Therefore the designer requires a greater awareness of the effect of wind on natural ventilation. They may require access to targeted design information and design tools that are as yet generally unavailable.

2 Introduction

As part of a current EPSRC funded investigation, a number of current building designs were studied using wind tunnel and CFD techniques. Each design case study had an explicit intent to naturally ventilate all or part of the interior. The studies focused on the likely performance of the ventilation design with regards to wind driven ventilation. Example building models are shown in figures 1 and 2.

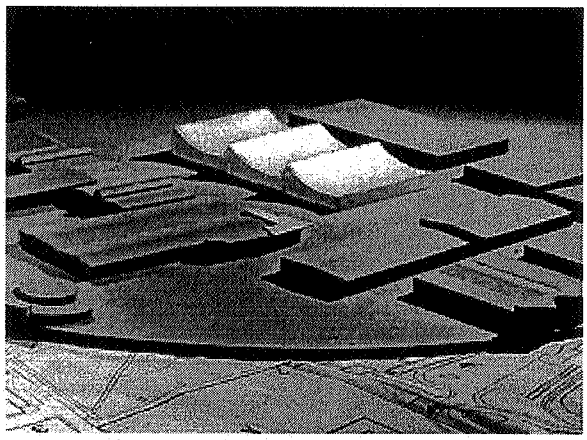

Figure 1 Wind Tunnel Model

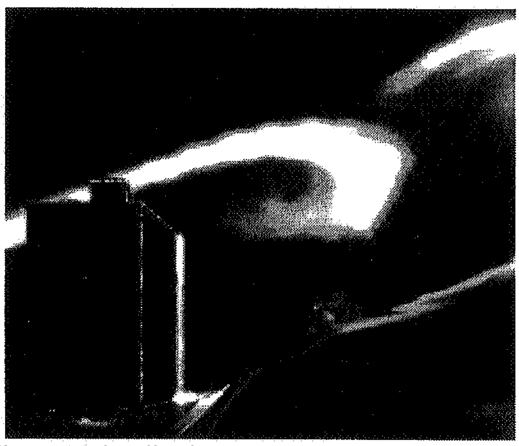

Figure 2 Visualisation of Air flow over a Building

3.1 Wind vs. Stack Effects

It is apparent that many natural ventilation design strategies have been developed with only buoyancy in mind, that is, the design has focused on the provision of low level inlets and high level outlets. This is understandable for two reasons. Firstly, the design intent is often developed using summer and winter design conditions, when temperature difference is robust and can easily be estimated. Secondly, thermal buoyancy and stack effects are well understood, documented, and accepted into design theory.

In contrast, there is often little design intent involving wind conditions. Wind pressures are not felt to be mysterious, but they are considered unpredictable and as a result erroneously ignored. The "no wind" scenario is often considered to be the worst-case for design development. If wind has been considered in the design then it is generally presumed to be beneficial, that is that wind induced ventilation will always be fortuitous, assisting the buoyancy flows. Further detailed design of wind flows, when the subject is taken more seriously, can be crippled by the overall complexity of dealing with the buildings and its surroundings and the lack of appropriate design information and suitable tools.

In most cases wind conditions are important to the performance of the ventilation design. In mid-season conditions, for instance, temperature differences (and therefore stack pressures) may be low. Wind speeds are rarely calm in most locations, and wind pressures generated in summer and winter conditions may rival buoyancy pressures. The example in figure 3 is a graph of wind speed recorded at Cardiff through a warm week in August, presented as an average day. This example shows a clear diurnal pattern in wind speed. During midday, the times of high temperature and highest solar loads (and hence the greatest need for ventilation cooling), the wind speeds are significant and would produce significant ventilation forces.

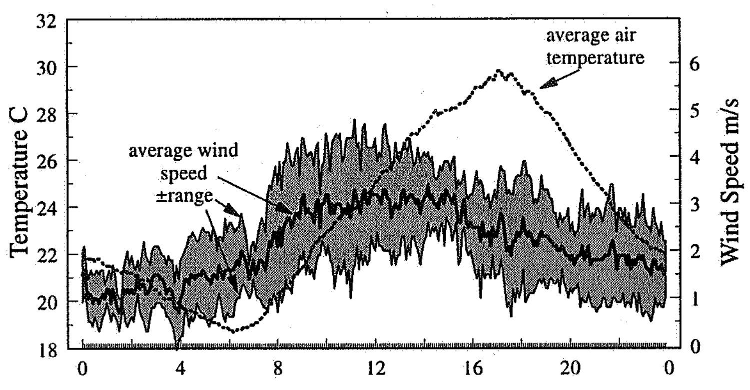

Figure 3, Wind conditions during a warm period in Cardiff

Wind induced forces may not always be beneficial; depending on the nature of the building form and on the location of inlets and outlets, wind pressure differences may oppose the buoyancy pressure gradient. For a range of wind speeds, this may result in a reversal of flows from the design intent. This can lead to comfort, odour or pollution problems. Further, particular wind directions and speeds may lead to the "capping" of outlets, that is, the wind and buoyancy forces may balance, resulting in the general decrease in ventilation. Ultimately this would leave only ventilation driven by turbulence and short term variations in wind velocity, or adventitious ventilation through other openings. This then would constitute the "worst case scenario" for ventilation, as opposed to the "no wind" case.

Buoyancy pressures can be calculated from

$$Ps = H \cdot 3462 \cdot \left[\frac{1}{Ti} - \frac{1}{To}\right] \qquad 1$$

where

Ps is Buoyancy pressure (Pa);

H is height difference between openings (m);

Ti, To are inside and outside temperature respectively (K).

The buoyancy pressure can be estimated as approximately 1 Pa for a moderate temperature difference of 10K and a 3m stack height.

Wind pressures are normally determined from pressure coefficient (Cp) values, where

$$Pw = Cp * 0.5\rho V^2 \qquad 2$$

where

Pw is Wind pressure on surface (Pa);

Cp is surface pressure coefficient,

ρ is air density (kg/m3);

V is air speed (m/s).

Therefore for moderate winds (3 m/s) wind pressures can commonly be in the range -3 to +3 Pa, depending on the orientation of the opening.

Thus wind pressures can easily equalise or dominate buoyancy pressures at quite reasonable wind speeds. The term "Cp gradient" can be used to describe the difference in Cp between proposed inlet and outlet areas, and can also be used in the above equation to estimate the wind driven pressure across two openings. A negative Cp gradient implies the wind pressures oppose the buoyancy pressures. For the example moderate conditions as used above (10K temperature difference, 3m stack height, 3 m/s wind), a Cp gradient of only -0.2 would cancel the buoyancy pressures, leaving minimal ventilation. Such adverse Cp gradients have been found in practical designs.

3.2 Inlets and Outlets

The successful natural ventilation design requires the identification of suitable areas for inlets and outlets, robust against different wind speeds and directions. It may be straightforward to develop a strategy for one wind direction, allowing the inlets on the upwind face and the outlets on the downwind face or roof, but rarely will such a simple site be found; the wind comes from different directions, though the course of a year, season or even a day. The wind flows will be influenced by the building as well as by its' surroundings.

Vertical or near-vertical facades are particularly problematic. Identified as inlets or outlets for one direction they can easily reverse flows for even small shifts in wind direction. In addition, high level openings on a windward facade naturally have higher wind pressures than the equivalent low level openings. This is an adverse gradient as described above. An example of such a system is provided in figure 4a.

Openings on vertical faces, when they are to act as outlets, are amenable to improvement by the addition of shields or deflectors, modifying the local flow so that direct impact is avoided. This can substantially alter the pressure regime, as shown figure 4b, wherein a simple plate baffle has been placed in front of the upper opening. This sort of feature can be used to "tune" the airflow patterns generated by the building form.

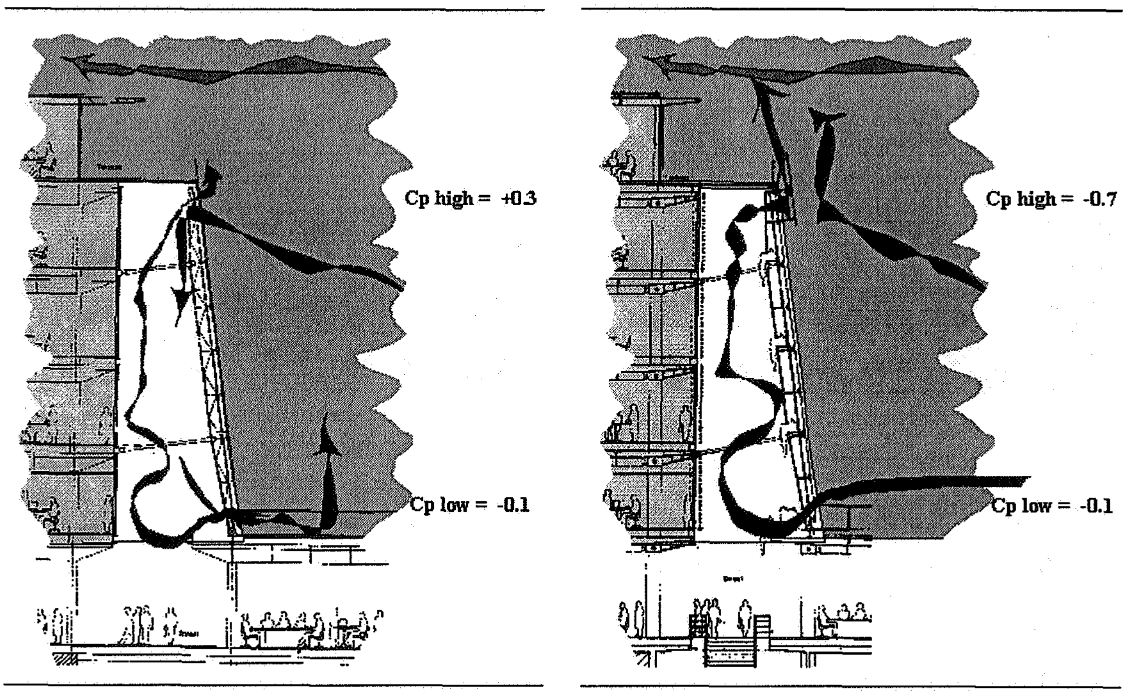

Figure 4, Ventilation of a simple atrium, before and after a wind baffle is placed over the outlet positions

In the above case the scheme was fortunate in having a relatively consistent prevailing wind direction. However the shielding concept can be used to reduces directionality for a feature, such as an extract tower; an example is the "H-pot" stack termination device which can successfully increase suction pressure for a wide range of wind conditions, as illustrated in figure 5 .

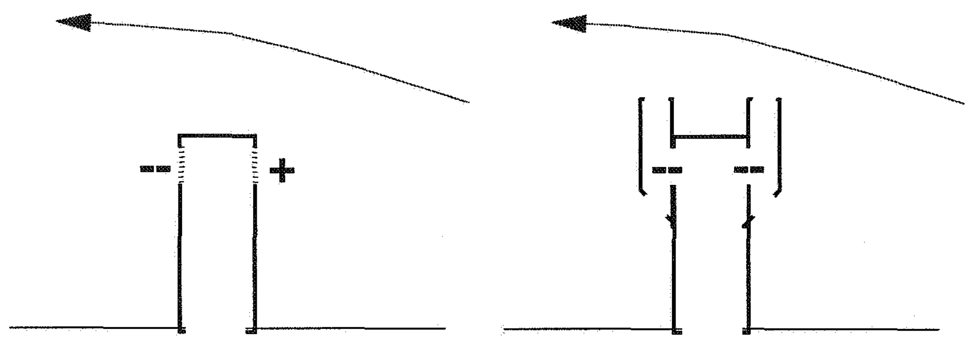

Figure 5 "H-pot" termination increases suction pressure, pressure at outlet denoted by - (suction) or + (positive pressure)

Shielding devices are generally appropriate only for outlet areas. Inlet areas appear to be less susceptible to improvement (that is in relatively increasing local air pressure) by the addition of simple devices. The air flow near inlets is largely determined by the bulk of building and its' surroundings. Often inlets are positioned at low levels (perhaps as dictated by buoyancy considerations) and may be in the wake of nearby structures for some wind directions. In general the small pressures involved in natural ventilation constrain inlets and outlets to be as close as possible to the spaces they will serve, so as to avoid high duct pressure losses. As illustrated in figure 6, the wake can disrupt the design flows, defeating even a well chosen extract device.

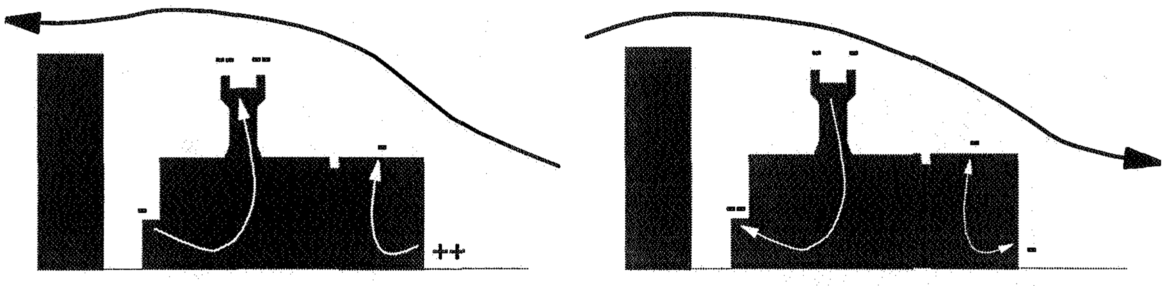

Figure 6, The effect of building wake on ventilation flows

The disrupting wake need not be caused by nearby buildings, but may be caused by the building itself. A common natural ventilation design feature is the repetition of a device as a building module. However a device, developed in isolation and perhaps ideal for greenfield site, may have its' potential degraded when used as a module, with each device causing disruption and wind shadowing for each downstream neighbour, as illustrated in figure 7.

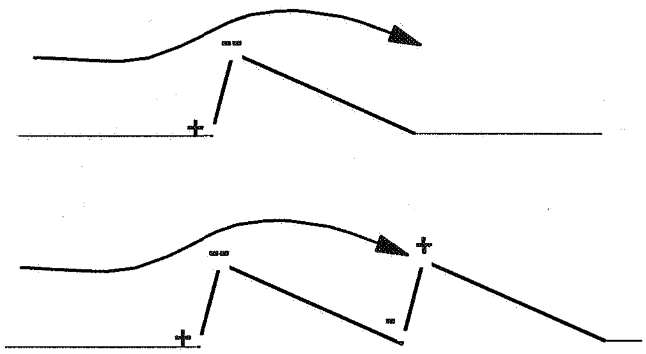

Figure 7 Effect of upstream device on downstream neighbour.

4 The Building Designer as Wind Engineer

It has become apparent that the form of the building (and its' immediate surroundings) can have a greater effect on the likely performance of the ventilation system than what may be termed devices (that is stacks, wind catchers, fins, wings, and cowlings). Outlet devices may be to some extent "tuned" to improve their performance under varying wind conditions. However due to the difficulty in affecting the pressure near inlet areas, ventilation problems posed by the building form may not be correctable by "bolt-on" devices selected from a natural ventilation "catalogue".

The form of the building largely determines the wind flow characteristics around the building and consequently the patterns of surface pressures. Small features cannot disturb these gross trends until they themselves become of significant size and so effectively become part of the building form itself.

Devices intending to grossly modify the pressures and flows near the building need to be large compared to the building before a substantial effect may be seen. These large devices effectively become part of the building form and become architectural features. Figure 8 shows a student design project lead by such principles, and illustrates the scale of the devices under consideration.

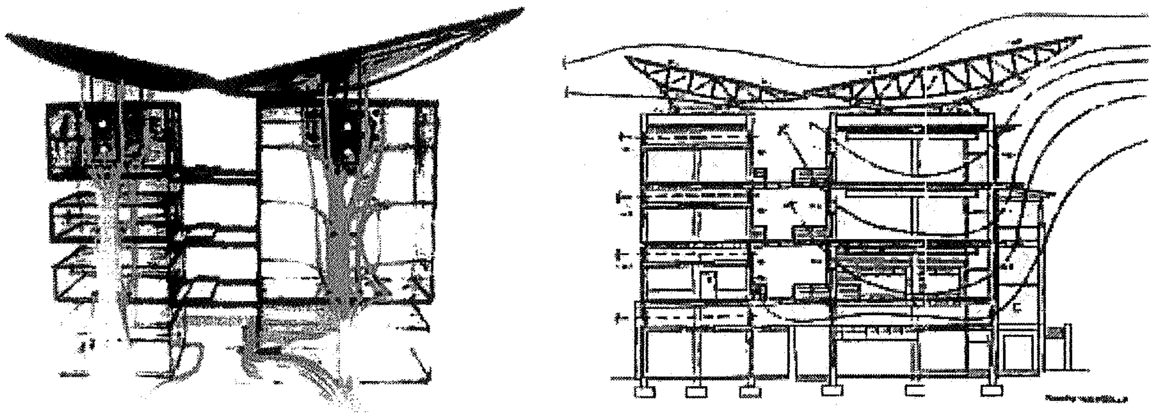

Figure 8, Student design project for wind enhanced ventilation of an office block

The control of the building form lies in the hands of the architect, and as such the architect becomes the prime designer of the ventilation system. Where the form of the building may be tempered by other criteria, such as cost or noise control, or a desire to capture solar energy, the problem lies outside the competence of most architects.

There is currently little information available aimed at the architect; idealised flow patterns contained in handbooks and primers offer little useful information and often serve to reinforce a concept of a rigid stack flow or wind direction. The lack of design information often means ventilation design is passed on to engineers or consultants, by which time the form may have been set.

Numerical information and calculation tools developed for natural ventilation exist, but are still in a format suited for use by engineers. As such they are often "unfriendly" to the architect, even to the ever emerging generations of increasingly computer literate and numerate designers. Appropriate design and information tools are needed to allow early design choices to be made.

5 Summary

Wind tunnel scale modelling can provide an important input into the early design process, however as yet they are inaccessible to many designers.

Wind pressures can significantly affect the ventilation performance of a building, altering flow paths in relation to the design intent and potentially detracting from the overall ventilation performance when in conflict with a buoyancy driven design.

Successful natural ventilation design requires the consideration of the building form, and so must involve the architect at the early stages of fabric development. While devices and features may be used to enhance the performance of outlets, the wind flows at inlets are more likely to be affected by the form of the building, and less amenable to improvement by small devices. Performance may be improved by larger features that in effect become part of the building form.

Therefore the designer requires a greater awareness of natural ventilation principles, and requires access to design information and design tools targeted to their professions, that are as yet generally unavailable.

Acknowledgements

The authors would like to thank the EPSRC for financial support during this project, and the design teams for the access to the design data for many works in progress.