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WIND TOWERS AND WIND DRIVEN VENTILATION

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ABSTRACT

Passive cooling techniques driven purely by natural wind forces present a highly attractive environmental solution in the perspective of low energy architecture. The physics governing passive cooling are well understood and have been extensively discussed in the literature. Indeed the necessary design details that must be incorporated to achieve the full potential of the technique, such as exposed thermal massive and good internal and solar gain control, are also well understood. Furthermore, the mechanisms by which occupant comfort is achieved can be quantified allowing various designs to be iterated towards the optimum solution.

However, issues concerning the design and sizing of apertures for ingress and egress of the ventilating air are less clear, and in particular, there are few "engineering" methods available to size wind towers and wind scoops. The present paper discusses the wind tower calculation method, developed by Battle McCarthy, in conjunction with Imperial College. The calculation method, derived from extensive wind tunnel testing, provides the designer with an accurate engineering tool for determining the size and number of wind towers and scoops for use in natural ventilation.

INTRODUCTION

Collaborative work between the aeronautical and building industry is once again leading the way in understanding how best to "engineer" a building. Whereas in the past structural engineers utilised the benefits of wind tunnels to asses and minimise wind loads upon the buildings, buildings are now being designed to utilise the positive aspects of wind. It is now the turn of the environmental engineer to work along side the aeronautical engineers, to understand air movement and pressure differences around the building, and capitalise on these to provide the most efficient natural ventilation system.

The solutions to providing wind driven ventilation are often "simple", traditional forms, which if developed at an early stage of the design process can produce low energy, low maintenance buildings. Buildings are being now being designed to both capture fresh air, using wind scoops, and extract the air via wind towers. These traditional devices can be adapted and improved to provide a simple and effective means of ventilation for even the most demanding buildings of the future.

This paper concentrates on buildings that utilise "wind driven" ventilation by means of a wind tower or wind scoop, as opposed to solar chimneys, which rely on stack, or buoyancy driven effects. The wind tower / scoop utilises the natural pressure created by the interaction of the building form with the local wind environment. There are a number of advantages of wind driven ventilation over the solar chimney. Most importantly, wind driven ventilation is a more powerful mechanism compared to stack effect at typical temperature differences encountered in building design. Wind driven ventilation is also particularly suited to temperate zones, where relatively strong prevailing winds may be relied upon during the summer.

To allow the architect or designer to take full advantage of wind forces, an understanding of the interaction between the building and the wind environment is required.

The task, when designing for wind driven ventilation using wind towers is clear: inlets must be placed in areas of relative positive pressure and the wind tower must be located in an area of relative negative pressure. This pressure difference, created between the inlet and the outlet locations, will then serve to drive the air through the building. Similarly, wind scoops, must be placed in areas of positive pressure and air extract locations, located in regions of relative negative pressure.

Battle McCarthy, in conjunction with Imperial College, have developed a calculation method for determining the size and number of wind towers and scoops for use in natural ventilation [1]. This methodology, which provides the designer with an accurate engineering tool, was developed from extensive wind tunnel testing, and is discussed in the following sections. The work was funded under the Department for Transport, Environments and Industries "Partners in Technology Program".

INVESTIGATIONS INTO THE PERFORMANCE OF WIND TOWERS and WIND SCOOPS

Physical models of buildings, with both wind towers and wind scoops, were tested in the Imperial College atmospheric boundary layer wind tunnel. In addition, computational fluid dynamic studies were performed for a number of building types. The objective of the experiments was to assess the relative importance of the different of parameters governing the driving pressure difference. Factors such as the size, position and orientation of the wind tower/scoop were tested in conjunction with the effects of the building and roof form and the building orientation. In addition, different devices were tested, namely, chimney wind towers, circular and square oast towers and scoops and combined wind towers and scoops.

Wind Tunnel Tests

The experiments were performed in the Imperial College atmospheric boundary layer wind tunnel at a scale of 1:50. An atmospheric boundary layer representative of suburban conditions was used in all experiments. This was determined using a power law relationship with an exponent of 0.26 and profile zero height of 4.5 m (at full scale), figure 1.

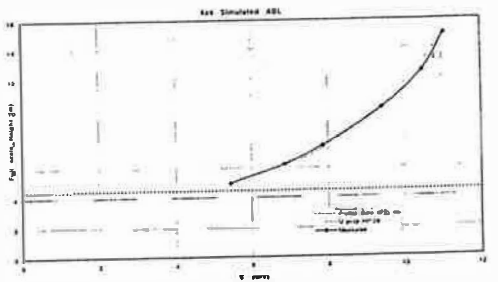

Fig. 1. Boundary layer profile used in the present experiments

Models

The basic test geometry is a flat roofed square building, 20m (full scale) in length and 10m (full scale) high, figure 2.

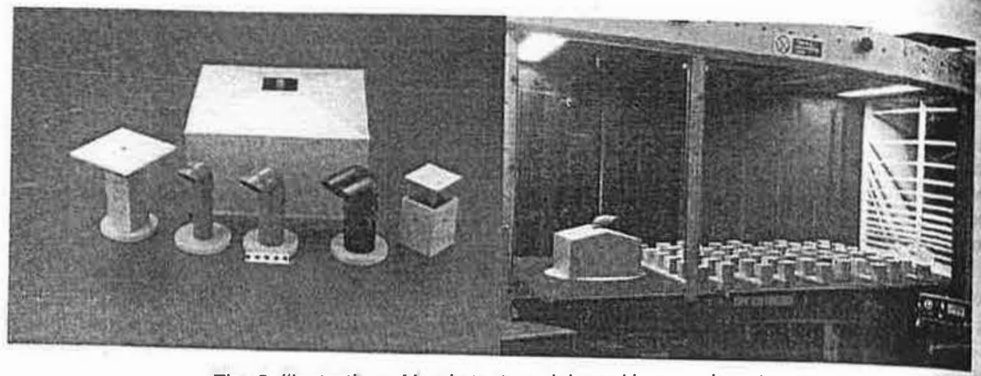

Fig. 2. Illustration of basic test model used in experiments

Experimental approach

For each combination of tower/scoop design parameters, the mass flow versus internal pressure characteristics were measured experimentally. To do so, the wind tunnel scale building geometry was connected to a device capable of providing a given mass flow rate (both supply to the building, for testing wind towers and exhaust from the building, to tests wind scoops), figure 3. Building internal pressure was also measured, relative to the static pressure of the freestream. In this fashion, the performance of each combination of design parameters could be tested independently of the other openings that will be present within the building.

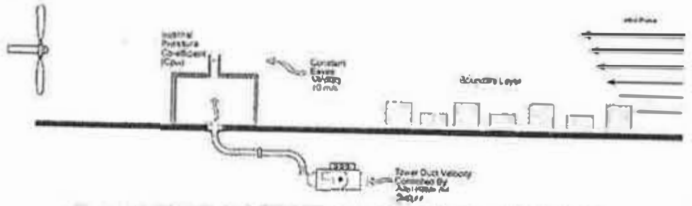

Fig. 3. Schematic of test set-up, flow is from right to left.

Typically, one finds that for a wind tower, the internal pressure reaches a minimum when the exhaust velocity is zero, i.e. no mass is being drawn through the device. As the mass flow through the device is increased, the pressure within the building must increase, in order to "drive" the given mass flow.

The mass flow through the device is progressively increased from zero, the point of maximum pressure difference, up to some upper limit. The internal pressure is measured and reduced to the internal pressure coefficient, given as:

$$C_{P_{in}} = \frac{P_i - P_\infty}{1/2 \rho U_\infty^2} \qquad (1)$$

where U_∞, p_∞, and ρ are the freestream velocity, pressure and density measured at eaves height in absence of the building, respectively. The mass flow is used to calculate the air speed in the device, V_{WT}, which is expressed as a function of the eaves height velocity.

RESULTS

Effect of device height

The first test was to assess the effect of increasing the height of each of the devices (chimney wind tower, oast tower and wind scoop). Each device is placed in a central position on the flat roofed model. The effectiveness of the device is then tested at 3.5m, 5.5m and 7.5 m full-scale height above the eaves. It is found that for each increase in height, the performance of each of the devices is improved. This is due to the fact that the wind speed is greater at the increased height.

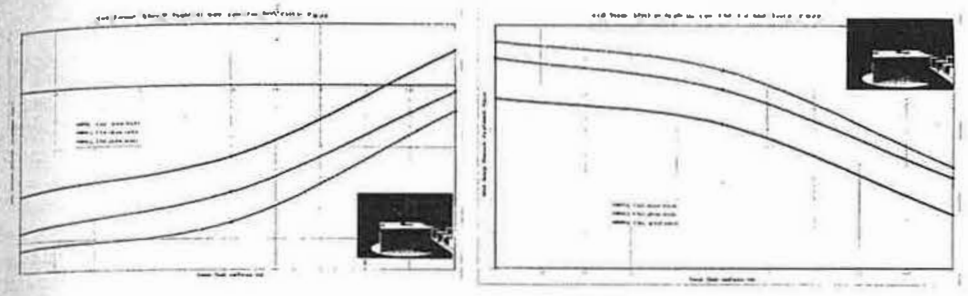

Fig. 4. Effect of device height; oast chimney and windscoopp.

A comparison between the wind towers (the chimney and the oast tower) shows that the chimney performs better than the oast tower. The internal pressure difference is greater at zero mass flow and also for a given pressure difference, there is a greater mass flow.

The Diameter of the Device

The wind towers and wind scoop were then tested to assess the effect of increasing the diameter of the particular device. Each device is placed at a height 5.5 m above the eaves, in a central position on a flat roofed building. The diameter of the devices tested were 2m, 2.5m and 3.2m. The performances of the both the chimney wind tower and oast tower are improved as the diameter is increased.

Generally the results show similar trends that indicate that the internal pressure of the chimneys is independent of the size of the wind tower. This means that suction (negative pressure) over the chimney and oast tower is not dependent on the size of the wind tower. An increase in diameter size will be directly proportional to the flow rate, due to the increased volume of air that passes through the wind tower. The size of the wind tower will not effect its efficiency, but only the volume of air that passes through it.

The performance of the wind scoop does improve as the tower duct velocity is increased. Again, it is concluded that the size of the scoop does not effect the performance in terms of pressure, however a larger device will be able to provide a larger volume of air.

The position of the device on the roof

Each device was fixed at a height of 3.5m above the eaves and was tested in a number of differing locations on the flat roof model. The test locations were the windward edge of the building, the centre of the building and the leeward edge of the building. Results were also taken at two building angles; with the building square on to the freestream direction (0°), and the building at a 45° angle to the freestream direction. The device was not rotated and was kept orientated away from the freestream direction for the extraction devices and facing the freestream direction for the wind scoops.

The results show that the wind towers are most effective at the windward edge of the building (producing the largest negative pressures), and least effective at the leeward side of the building. The oast tower at a leeward position upon the roof (building angle 0°) is so ineffective that it actually produces a positive pressure co-efficient (due to re-circulation). The position of the wind scoop is not critical, as pressure coefficients are found to be similar for each position. The angle of the building influences the performance of the devices. The performance of the oast chimney and the scoop are improved in all cases when the building is angled at 45°. It is assumed that the less bluff shape produces a higher velocity field around the building, and consequently a lower pressure and therefore improves the performance of both the oast wind tower. The pipe chimney performance is reduced when the building is at an angle of 45°.

The effect of the form of roof and the building form

Each device was tested at 4.6m above the eaves of a building with a ridged roof and a pyramidal roof. An extended rectangular building with a ridged roof (the base model extended by a factor of 3 on the facade facing the airflow) was also tested. Measurements were performed for two building orientations with respect to the freestream (0° and 90°). Results were compared to the earlier test with a flat roof building.

The pyramidal roof improved the performance of the wind towers. The performance was further increased when the building was angled at 45°. The ridge roof also improved the performance, but only when the building was angled at 45°. The extended building form with a pitched roof also improved the performance of the wind tower. The performance of the wind scoop was unaffected by either a ridge or the pyramidal roof, nor was it effected by the extended building form.

The angle of the device to the wind

In this series of experiments, the internal pressure was measured as a function of the angle formed between the device and the freestream direction.

The performance of the wind scoops is dramatically reduced as the scoops are deviated away from the wind direction. At 50° yaw away from the wind the scoop is completely inactive and begins to act as an exhaust. The oast exhaust is conventionally directed 180° away from the wind. The results show that the oast actually performs better as it deviates from the wind, and is most efficient at approximately 90° yaw. At this position the negative pressure around the oast exhaust pipe is at its greatest. If the yaw is any greater than 90° the oast begins to face into the wind and the oast rapidly begins to loss efficiency as it begins to act as a scoop.

Devices with both circular and square openings were also tested, and in the case of the wind scoop the square device was more efficient. The square oast tower is also more effective, and the performance is further increased when the device is at 90 °. This is due to the straight leading edge, on the upstream edge of the device, forming a strong separation region.

A Combined Inlet and Extract

A combined inlet and extract was tested at 3.5 m above a flat roof, and at 4.6m above a pyramidal roof. Results were with the building, and the device, positioned at two building angles (0° and 45°).

The combined inlet and extract device produced similar pressure differences between the inlet and the extract for both building angles. The building (and device) angled at 0° to the wind produces greater pressure at the inlet and lower pressure at the extract. When the building is angled at 45° the converse is true. The inlet is less effective, and the extract is more efficient.

This is explained by the previous test. The effectiveness of the scoop is more sensitive to the angle of the wind, and is therefore less effective as the device moves away from "head on" wind. The oast chimney is most effective at 45° from the head on wind.

Computational Fluid Dynamic studies

A series of Computational Fluid Dynamic analysis were simulated to compare the accuracy of CFD against the wind tunnel testing. These results were then plotted to asses the accuracy of the Computational Fluid Dynamic analysis against the wind tunnel testing. It was found that both methods were in close agreement. This increased confirmed the accuracy of the physical modelling.

THE CALCULATION METHOD

The results provided a thorough understanding of the interaction of wind environment, the building form and the device geometry. A calculation method was then developed to enable the user to size the height, diameter and position of wind towers/wind scoops, to provide the required ventilation. The calculation method involves a series of logical steps. Firstly, an appropriate design wind speed, which takes into account various adjustment factors for particular site conditions, is selected. This can be performed using information contained in the guide or by knowledge of the local site conditions.

The required mass flow rate must be determined, either from heat load considerations or by air change rate considerations. At this point the "uncorrected" device cross sectional area is determined and finally, a series of adjustments are made to correct for the device type; location; height; orientation; wind shading effects; local topological effects; number, area and position of openable regions; building air flow resistance; and finally device resistance. In this fashion, the internal diameter of the device is thus accurately determined to achieve the desired air volume flow rate, for the established design wind speed.

CONCLUSIONS

Passive cooling techniques driven purely by natural wind forces present a highly attractive environmental solution in the perspective of low energy architecture. The physics governing passive cooling are well understood and have been extensively discussed in the literature. Issues concerning the design and sizing of apertures of ingress and egress of the ventilating air are less clear, and in particular, there are few 'engineering" methods to size wind towers and wind scoops.

This paper has presented the wind tower calculation method [1], developed by Battle McCarthy, in conjunction with Imperial College. The calculation method is derived from extensive wind tunnel testing and provides the designer with an accurate engineering tool for determining the size and number of wind towers and scoops for use in natural ventilation.

REFERENCES

1. Wind Towers, calculation method. Available from Battle McCarthy Consulting Engineers, 10 Poland Street, W1V 3DF, London.