

# AIRFLOW AROUND CONIC TENSILE MEMBRANE STRUCTURES

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## ABSTRACT:

This paper reports qualitative wind tunnel experiments, which were conducted using a number of physical models representing a simple conical membrane structure. Horizontal, inclined, open and closed apex cases were explored for a variety of cone rise/diameter ratios and apex height/diameter ratios. Monitoring of the air velocity was carried out on a grid of 84 different points for each configuration. Using these results, the possible use of a conic tensile membrane structure's topology and orientation to enhance ventilation rates and airflow velocities within the covered space is discussed. It is concluded that there is a need for further research in this area, in order to fully realise the potential benefits offered by tensile membrane structures for modifying airflows in their vicinity.

## Introduction

Fabric structures have been used throughout history. They were originally used to provide shelter where materials were scarce or mobility was required. There was generally little consideration of their environmental performance. However, nowadays, the issue of resource scarcity applies not only to materials but also to energy and here tensile membrane structures (TMS) have a potential role to play. When adopting fabric membranes as part of the building enclosure it is important that the designer should fully understand the environmental implications implicit in their use. In order to apply the construction technique effectively and to increase their acceptability, their environmental and micro-climatic behaviour should be clearly understood and capable of being predicted by the building design team. One of the ways in which TMS may be used to improve environmental performance is to exploit the form to induce or enhance ventilation and air movement in and around the enclosure.

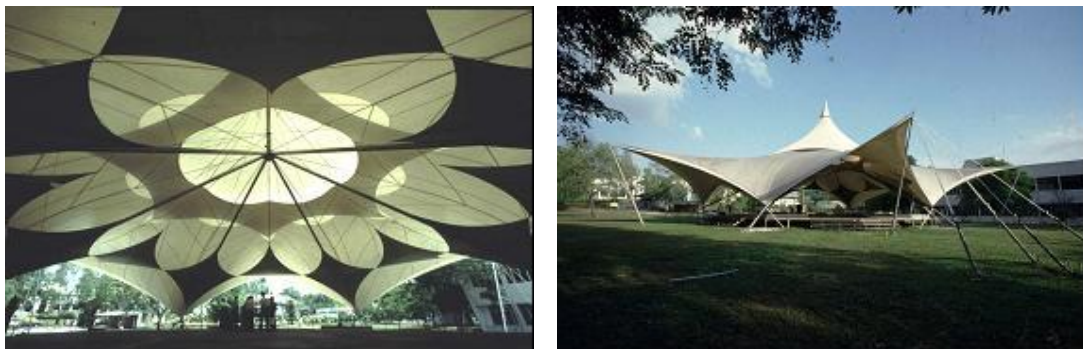


Figure1. Assembly tent in Malaysia (Photo SL-Rasch)

Knowledge of the airflow pattern and rate in and around fabric membrane structures is still relatively unknown compared to that adjacent to more conventional structures.

For designers and engineers, it is important to know the airflow rate and pattern around these structures, in order to assess appropriate comfort levels during the design process. Designers wish to know the airflow rate through the different openings of a structure to size an opening properly, while engineers are interested in the distribution of velocity in different zones of an enclosure to size the ventilation inlets and outlets. Comfort experts are interested in the air velocity values to calculate the convection from or to the human body, while air quality experts are interested in the flow rate, the dispersion of contaminants and the ventilation efficiency.

For instance, the Assembly tent in Malaysia shown in figure 1 used a number of differently oriented openings to induce airflow and ventilation. It is also successfully shows how membrane structures can have an attractive dramatic effect and easily span a large area. In addition to the lighting and shading functions normally associated with tensile membrane structures, the topology of the construction type offers exciting opportunities to lend additional functionality and higher levels of comfort to the enclosure (ElNokaly *et al*, 2002). They can be used as climate modifiers in both hot and cold regions, offering in some circumstances, conditions suitable for human occupation and in others, a protected microclimate within which conventional buildings may be sited and operated in a more efficient manner (Scheuermann and Boxer, 1996).

## **Research Objectives**

The main objectives of this research were to investigate use of TMS to assist in ventilation of enclosed and/or uncovered spaces, or for modifying the air velocity in their immediate vicinity. To facilitate this, a hot wire anemometer was used to measure the airflow under and above a model of a conical membrane structure in order to investigate the effects of the structure's inclination and the shape of the cone itself (e.g. the height/width ratio of the cone, its height above the "ground" surface, etc). In this paper only eight of the cases monitored in the wind tunnel are reviewed. The first is the Straight Closed Apex 17cm high Cone (SC17), the second is the Straight Open Apex 17cm high Cone (SO17), the third and fourth are the Straight Closed and Open Apex 3cm High Cones (SC3) and (SO3), the fifth and sixth are the Inverted Straight Closed and Open 17cm High Cones (ISC17) and (ISO17). The seventh and eighth cases are a reference for all the previous cases, being when there is no structure at all (NC) and with a flat disc roof (FR).

## **Experimental Method**

### *Wind tunnel*

The wind tunnel used for monitoring the airflow around different forms of tensile membrane structures was an open jet wind tunnel based on a small jet tunnel developed for teaching purposes by the Building Research Establishment, described by Clarke (Clarke, 1998). It has a maximum flow velocity of 6m/s and a working section of width 1m, height 0.75m and 2.25m length, as shown in figure 2. Although, the dimensions of the working section are relatively small, this did not adversely affect the size of model that was tested, as the main objective was to obtain qualitative data about the change in air speed due to various geometrical changes. In particular, the geometrical configuration that leads to the greatest increase in air velocity under the structure was sought.

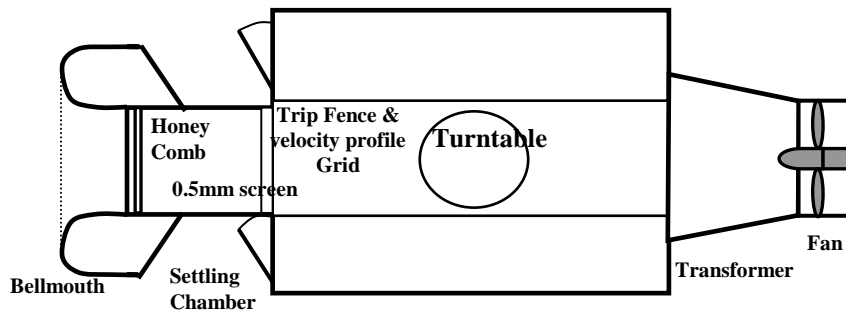


Figure 2. Sketch plan of the wind tunnel

An important part of this research focuses on the visualisation of “airflow patterns” around conical membrane structures, and how they vary with air speed and differing membrane geometry.

*Experimental conditions*

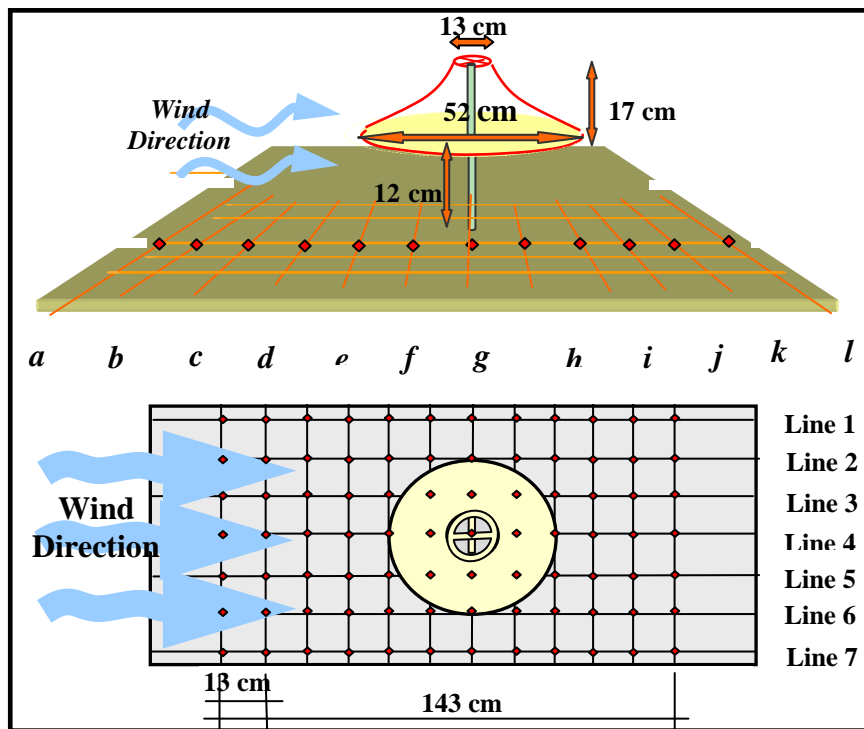


Figure 3. Perspective and plan of the conical membrane structure and the grid of air velocity measuring points.

Figure 3 shows a perspective of the conical membrane model and the grid of measurement points using the letters (a, b, c,...) to denote rows, and the numbers (1, 2, 3,...) to denote columns on the grid. The mast support for the cone is located at grid position **g4**.

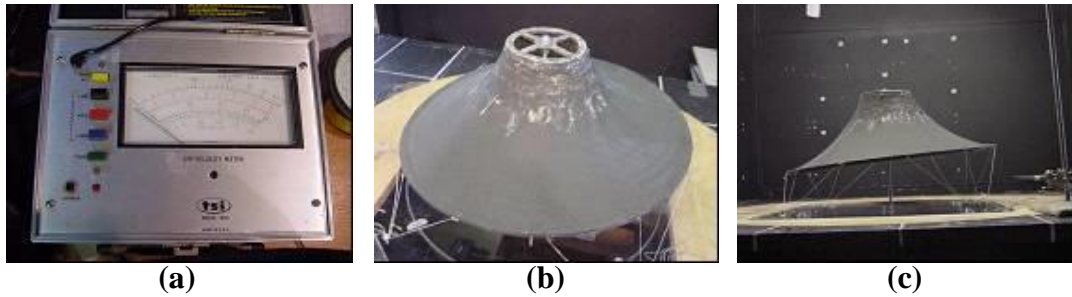


Figure 4. (a) Hot wire anemometer; (b) the conical membrane model; and (c) the model when inclined

Figure 4(a) shows the hot wire anemometer (an Air Velocity Meter, “tsi” Model 1650) used in measuring the air velocities at the grid points at three different heights above the base, low (4.5cm), medium (6.5cm) and high (8cm). However, in this paper, only the medium height is reviewed, as the velocity distribution was similar at each height although the magnitudes tended to be slightly higher at the medium height than the lowest height. Figure 4(b) shows the 52 cm diameter conical membrane model with open apex, as in the second case, SO17. Figure 4(c) shows the same cone inclined away from the wind with the lowest edge at 8cm above the base and the highest edge at 16 cm.

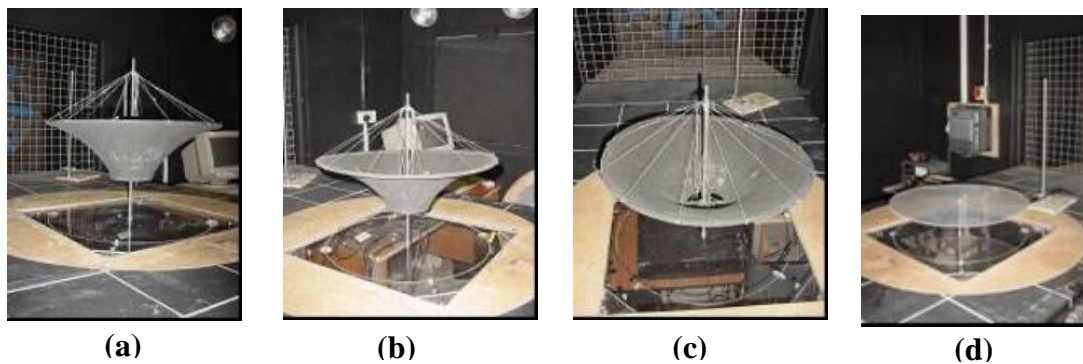


Figure 5. (a) and (b) The closed inverted cone; (c) the open inverted cone; and (d) the flat roof.

Figure 5(a) and (b) show the 17 cm high cone in the inverted position with the smaller ring at 17cm above the base, figure 5(c) shows the inverted same cone with open apex, while figure 5(d) shows the flat disc roof structure, which was also 52 cm in diameter.

#### *Measurement of airflow under and above the conical membrane structure*



Figure 6. Measurement of the air velocity.

In all, for each configuration the air velocity was measured at 84 points using the single probe hot wire anemometer at 6.5 cm above the base. The points were located

on a square grid of 13 cm, this being half the radius of the cone. Seven equally-spaced lines were determined on the wind tunnel table, symmetrically about the centreline in the direction of the wind flow, and the air velocity was measured at 12 equally-spaced points along each of these lines.

*Airflow Visualization under and around the conical membrane*

A smoke generator was used to visualise the trajectory of the airflow as it moved under and around the membrane.



*a.*

*b.*

*c.*

Figure 7: Wind tunnel experiment showing the effect on airflow of a conical membrane with closed apex

As can be clearly seen in figures 7(a) to (c), for a conical membrane with a closed apex, the air tends to be deflected downwards into the occupied zone. This is not so pronounced in the case of the flat surface.

**Results**

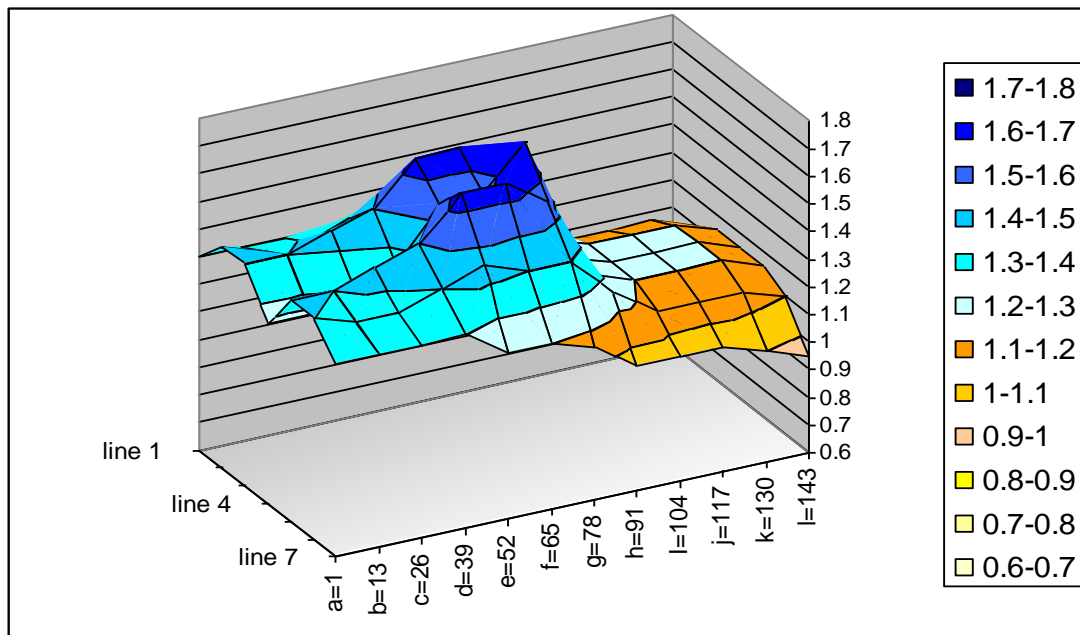


Figure 8. Air velocities (m/s) around the IC17 cone at a height of 6.5 cm above the base shown as a 3D surface (wind from the left).



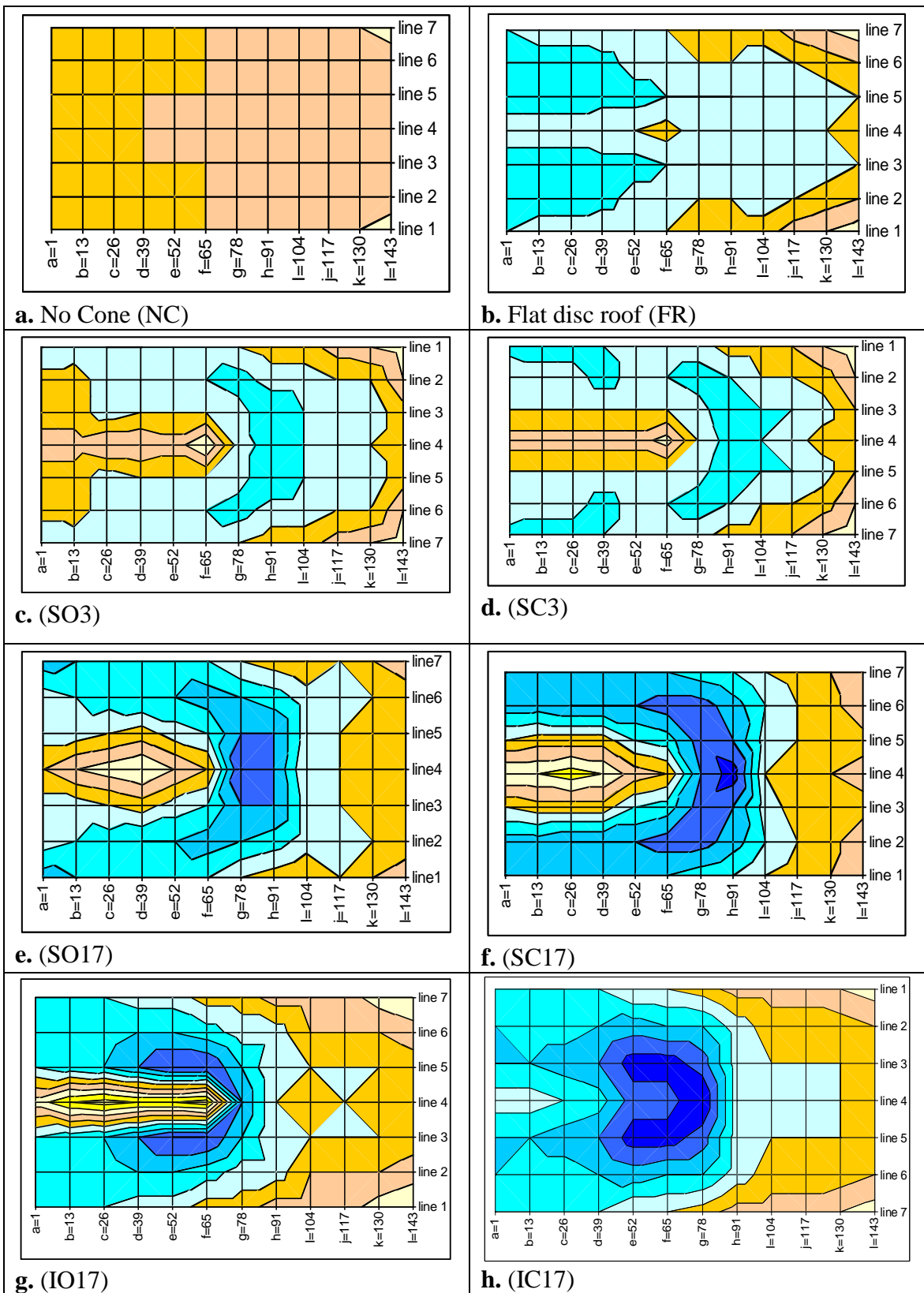


Figure 9. Airflow patterns at a height of 6.5 cm above the base for (a) no cone; (b) the circular flat disc; (c) straight open cone at 3cm; (d) straight closed cone at 3cm; (e) straight open cone at 17cm; (f) straight closed cone at 17cm; (g) inverted open cone at 17cm; (c) inverted closed cone at 17cm. (Key as Fig 8.)

In figure 8 the airflow pattern around IC17 at a height of 6.5 cm is shown three-dimensionally as a surface. Figure 9 illustrates the variant air velocity pattern around and under the conical structure in the eight cases referred to earlier in this paper. As seen in figure 9(a), when there is no cone at all the airflow remains steady and stable at almost all points (on average between 1.2 and 1.1 m/s to windward, decreasing slightly to 1.1 to 1.0m/s at positions remote from the wind). Figure 9(b) shows the air velocity under the circular flat disc, which has the same radius as the tested conical structure. It is clear from figures 9(b), 9(c) and 9(h) that although the airflow velocity is increased with a presence of the circular flat plate, the velocities are higher when the conic membranes are present.

In the case of SO3, Fig 9(c), it can be seen that the air velocity tends to be lower than control case (NC) to the windward side around the centreline of the cone and increases to a maximum of 1.3 to 1.4m/s immediately to the leeward. Air speed tends to be unstable at the windward side in almost all the open apex cases. In these cases an average reading is taken of the air velocity at that point. This fluctuation does not occur at the leeward side of the cone. Figure 9(d), case SC3, shows a slight change to the above as air velocity increases towards the outer edges of the area monitored and a drop of air velocity occurs at the point **f4**, which decreases to 0.9m/s.

In case SO17, air velocity tends to decrease on the mid axis of the cone as in SO3, and then increase again as it passes the centre point of the cone to the leeward half. Also the highest air velocity is reached in the middle of the leeward half of the cone along the mid axis where air velocities reach 1.6-1.65m/s as seen in figure 9(e). Airflow around SC17 tends to decrease more to the windward side just in the middle of the structure than in the open case and then increases significantly on the leeward half of the surface as seen in figure 9(f).

The greatest variations in air velocities are seen to occur in the cases IO17 and IC17, as shown in figures 9(g) and 9(h). In the case of IO17 as in most cases of opened apex cones high levels of fluctuation of air velocity was monitored all along the mid axis of the cone and till the centre point of the structure. After that air velocity increases in the leeward half of the cone. In the IC17 case the highest air velocities are measured. It is clear in fig. 9(h) that air velocity reaches its highest levels under the conical structure where the velocities increase significantly, and then the air velocity starts to decrease as we move away and towards the leeward.

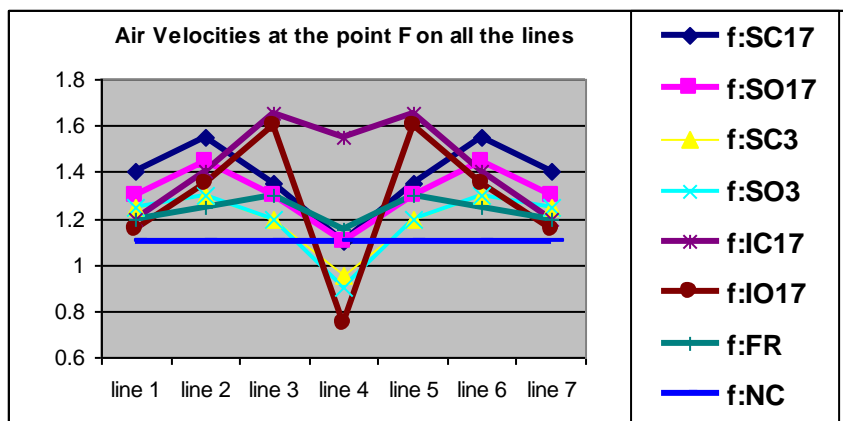


Figure 10: Air velocities on row **f** of the cone

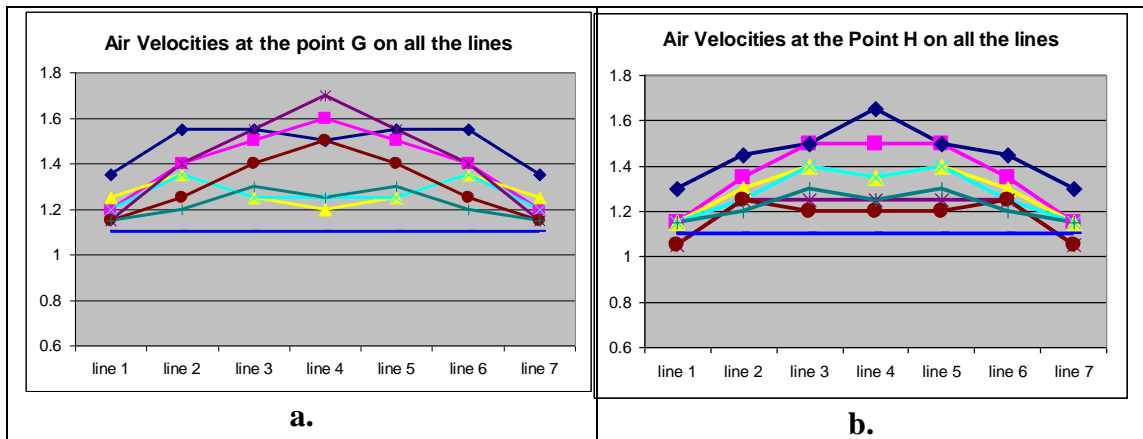


Figure 11: (a) Air velocities on row **g** the central cross section of the cone; (b) Air velocity on row **h** of the cone

Figures 10 and 11 show the air velocities at three of the rows in the central cross-section of the cone (rows **f**, **g** and **h**) for the 8 cases considered. It is clear from the graph that the NC generally gives the lowest air velocities and flat response across the section. Figure 10 clearly illustrates the significant drop in air velocity at the windward side on the centreline of all cones except IC17, where air velocity decreases only slightly. The SC17 case tends to be fairly uniform under the cone at rows **f** and **g** then seems to increase significantly at the leeward side (row **h**).

## Conclusions

Simple wind tunnel testing has shown that topology and orientation of a simple conical membrane structure may influence considerably the wind environment in its immediate vicinity. The results lead to the following conclusions:

- Airflow velocity generally tends to be lower in the vicinity of an opened apex cone when compared to a similar closed apex cone.
- The possible use of the fabric's topology and orientation in conical fabric structures, particularly to enhance ventilation rates and airflow velocities within the covered space and around buildings in its immediate vicinity has been demonstrated.

However, this qualitative study has revealed the need for further research in this area in order to fully realise the potential benefits offered by these structures, as microclimate modifiers.

## References

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