USE OF FABRIC MEMBRANE TOPOLOGY AS AN INTERMEDIATE ENVIRONMENT MODIFIER

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ABSTRACT. This paper describes the pattern of airflow around membrane structures, and how they along with the form of the structure itself affect the ventilation rates within their enclosures or their immediate vicinity. Examples that have successfully used membrane skins in the built environment will be reviewed. The possible use of tensile membrane structures topology and orientation to enhance ventilation rates and natural cooling within the semi-enclosed spaces will be discussed. The use of the indigenous fabric skin to tackle key climatic concerns in a simple, elegant manner is discussed along with the review of the wind tunnel experimental visualisation and measurements carried out by the author. These structures go beyond simply providing shading to illustrate innovative, environmentally friendly fabric Architecture, but if properly understood the fabric's form and topology can play an effective role in the ventilation and natural cooling of spaces in their immediate vicinity.

Conference Topic: Comfort in public open spaces, Materials and building techniques, Design strategies, Methods and tools for design assistance
Keywords: Tensile fabric membranes, natural ventilation, airflow rates, structural form and topology

1. INTRODUCTION

Modern Architectural buildings are becoming more complex, and it is increasingly vital for designers to understand the effect that local wind forces will have on a structure, and how it affects the comfort levels of its occupants.

For successful assessment of design of wind speed data for natural ventilation purposes, through a building, all factors affecting the airflow rate and direction must be taken into consideration. These factors include the speed and direction of the wind, the frequency with which it blows, as well as the form and shape of the building itself. However, there has been little consideration of the effect that the fabric forms have on their immediate environment, from the point of view of human comfort, even for the most basic of shapes. The aim of this research is to point out whether the form of the fabric membrane structure affects the air velocity within the enclosed or semi enclosed spaces, and to which extent the altering of the form itself can be used in order to simulate airflow rates and thus assist in the passive cooling of the space enclosed or semi enclosed by them.

As population increases in hot regions and as energy becomes scarcer and more costly, the demand for passive building design increases. However, it is only a minor contributor to human comfort when compared with conventional heating and cooling methods. Thus, the growing demand will create a large potential market.

Taking advantage of passive and low- energy cooling methods in a hot climate can significantly reduce the costs of conditioning and ventilating buildings. Not only are passive solar buildings expected to fulfil their functions safely and without any harmful health effects, but also at considerable energy savings, in comparison to conventional buildings.

Passive cooling is a system that cools buildings without the help of mechanical devices, or with little use of them. Passive cooling depends on the climate conditions of a region, cultural context and the materials available locally.

2. NATURAL VENTILATION

Ventilation is one of the most ancient means of cooling strategies. Ventilation plays a vital role in providing proper indoor air quality and thermal comfort for the occupants. Natural Ventilation relies mainly on moving air under the natural forces of gravity and wind through a building [1]. Natural ventilation is a necessary strategy that achieves acceptable indoor air quality mainly based on supplying the space with fresh air and the dilution of the indoor pollution concentration [2]. Besides providing acceptable indoor air quality and meeting the comfort needs throughout the full range of climatic conditions, natural ventilation also appears to be very cost effective[1] when compared to the cost of running mechanical ventilation and it does not need any plant room space. The quantity of natural ventilation and air velocity within an enclosure varies along with temperatures and wind conditions. Natural ventilation is driven by wind and thermally generated pressures [3], thus designers must be concerned with harnessing these forces by the careful sizing, orienting and positioning of the structure and its openings.

In the past people relied on natural ventilation in their buildings, which generally provided them with more than satisfactory internal conditions. Nowadays with the vast technological progress, ventilation systems are used to provide much improved reliability and control. Consequently if properly designed and integrated within the building form, it is possible for natural ventilation to enhance the environmental conditions within even quite complex enclosures [3].

3. LEARNING FROM THE PAST

The use of tensile structures sprang out of the human desire, thousands of years ago to have a more adaptable, mobile, easy to erect dwelling. Fabric structures are not as they seem a new modern building construction system. The origin of these structures can be traced back over 400, 000[4] years ago where the earliest known evidence of houses built by man were found. People used stick frames, animal's skin and tree branches for building these houses.

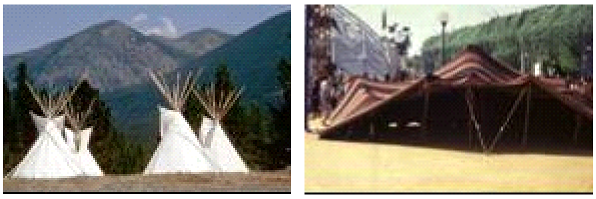

Figure 1: Typees and Bedouin Tent

These traditional stick framed structures were not convenient for nomadic people, as it usually took a day to build them. Therefore, they adopted lighter structures that are portable and can be erected in less than an hour. This resulted in the introduction of tents. Amongst the best-known tent structures still in use today are those used by desert people, such as the Bedouins, Berbers, Baluclas, and Kurds. These structures protected their occupants from the harsh climatic conditions of the deserts.

The proper orientation of the tents, and wetting of its fabric surface were the traditional means of passive cooling of these structures.

4. SUCCESSFUL EXAMPLES OF MEMBRANE STRUCTURES IN THE BUILT ENVIRONMENT

There have been a large number of architectural project trials making use of the unique nature of fabric membrane structures to enhance the environment within the enclosures. Following are some of the examples that used different techniques for enhancing the environmental behaviour of their enclosures

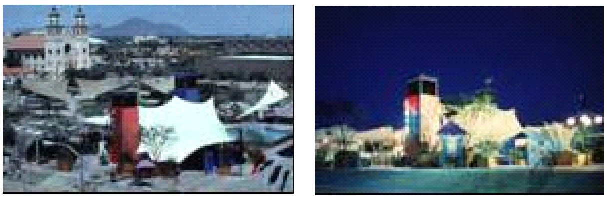

Figure 2: Arizona Solar Oasis

Figure 2 shows the Arizona Solar Oasis, for the 1987 "Summer Invitation". This project displayed several environmental strategies for enhancing the internal climate. A large pre-stressed saddle shaped fabric membrane structure was used as a shade over the exhibition area. The membrane was placed such that its downward curvature oriented east-west, parallel to the suns arc across the sky, it was shaped so as to run from low along the south to high above on the north. This shape provided shade all day long. It also generated a strong warm air current under the membrane surface that drew in ambient air across the south edge, and resulted in continuous cross ventilation. It also used some of the passive cooling techniques used in conventional buildings such as evaporative cooling techniques, which were provided by a nearby fish pond display and an existing fountain. In addition to a mist spray cooling system in the adjacent café, some greenhouse areas, and also two cooling towers. Temperatures in the "Summer Invitation" were cut down by approximately 14°C below the ambient temperature [5].

Figure 3: Foldable Umbrellas at the Cologne Federal Gardens Exhibition, Germany

As these are light and flexible structures there is also potential for folding the fabric membranes to change their function at different time of the day or season of the year. This idea was used by Frei Otto in the design of the foldable umbrellas found at the Cologne Federal garden exhibition shown in Figure 3. These beautiful umbrellas which were simply constructed in 1971, inspired many subsequent projects.

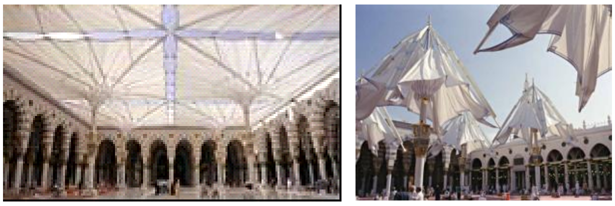

Figure 4: The Foldable Umbrellas at the Prophet's Holy Mosque, Medina, Saudi Arabia

The foldable umbrellas at the Medina Mosque were to provide comfort for the visitors and protect them against the heat of the sun. Designing a fabric structure for this had superior properties, by reflecting most of the sun's heat and also allowing a fresh breeze to enter the Mosque through the openings in between the Umbrellas. The fabric's translucency would make artificial light unnecessary during the daytime, and thus energy was dramatically reduced.

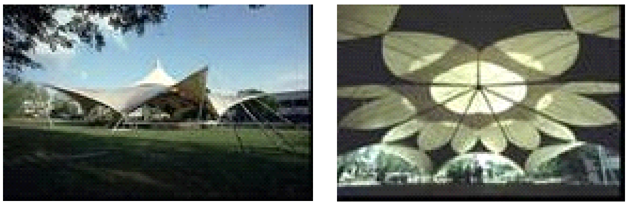

Figure 5: The Assembly Tent in Malaysia

The Demountable Assembly tent in Malaysia designed by Sl-Rasch, shown in figure 5 has a number of differently oriented openings to induce airflow providing a natural breeze underneath the structure. The idea of having a number of openings between the central part and the sides of this umbrella has a two fold benefit one of inducing airflow and the other as a moist filter, thus providing a higher comfort level to its occupants. It also successfully shows how membrane structures can have an attractive dramatic effect and easily span a large area.

5. USE OF FABRIC TOPOLOGY TO MANIPULATE THE INTERNAL ENVIRONMENT

Fabric membranes can be merely used as a filter for creating an intermediate climate or meso-climate, which acts between the external climate and the environmentally controlled interior of the building to moderate and regulate them, rather than shutting it out completely. The topology and form of the tensile structure can be used to alter the quantity and direction of the solar absorption into the enclosure. The structure can be easily shaped and oriented such that to allow maximum solar radiation in winter by using the low angle of the sun. The orientation and form of the fabric membrane itself can be used to drive in higher speeds of air velocities and to allow a fresh breeze to enter, providing higher comfort levels. This method is used in more conventional buildings, but should be easier in tensile membrane buildings due to the high elasticity of the material used. In summer the form of the building can provide shade by screening solar radiation from the higher overhead arc of the sun. In sunny parts of the world, the shape of the structure can also be oriented such that it is parallel to the sun arc across the sky; this creates shade the whole day.

The membrane form and orientation and the associated thermal mass (walls, floors, terraces, water pools, fountains, etc.) can be designed to suit different seasons and climates. For example, in winter the structure should be designed to maximise the absorption of solar energy, and transmit it into the enclosure. At night it should be sufficiently air tight to prevent the escape of the heat to the night sky. In summer, the opposite should occur, as the fabric structure should absorb and transmit the minimum of solar heat, and work in conjunction with thermal mass distributed within the enclosure to stabilise temperatures. It should be designed with a number of different openings so that the internal heat finds a place to escape at night, or it could also be folded at night, so as to encourage cross ventilation and escape of the heat that is stored during the day to the night sky.

A number of traditional passive cooling systems can be effectively used along with fabric membranes, such as evaporative cooling by having water cascades, mist sprays or fountains, cooling towers, stack effect and self shading. All of these strategies can be used to enhance the benefit of tensile membrane structures in hot climates. Some different effects are shown in the next examples

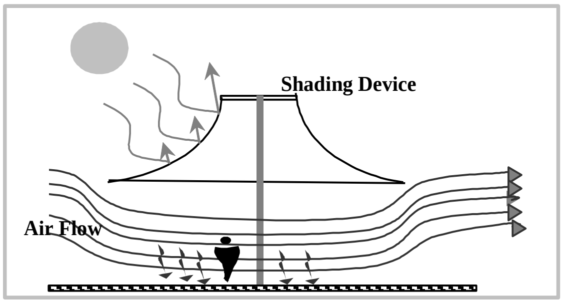

Figure 6: A retractable conic membrane umbrella

Using a retractable structure to provide screening by reflecting most the sun's radiation can prevent unwanted heat gains in summer. At night the structure is closed to expose the interior to the night sky for cooling. This idea has been successfully applied in the Holy Prophet's mosque in Medina in Saudi Arabia shown in figure 4, and has proved to be effective.

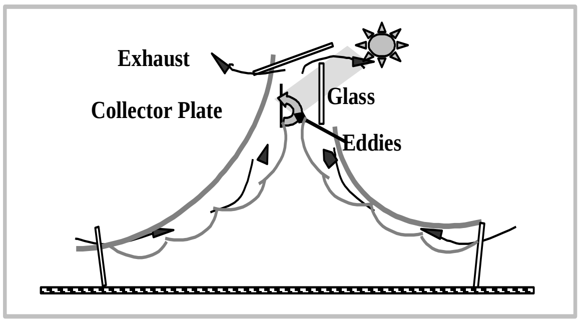

Figure 7: A solar chimney incorporated to a fabric membrane structure

A solar chimney can be incorporated into a tensile structure using the stack effect as seen in Figure 7. The temperature inside the chimney needs to be higher than that of the outside air, to create a pressure difference between the inside and the outside and facilitate the exhaust [6] . A collector plate within the chimney, which gets heated up by the solar radiation, easily assists this. This heats the air, making it buoyant, thus forcing an upward flow of hot air from the enclosed space to the outside keeping the inhabited area cooler. If used in conjunction with transparent insulation it reduces excessive heat gains into the enclosure thus preventing overheating in summer.

6. 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.

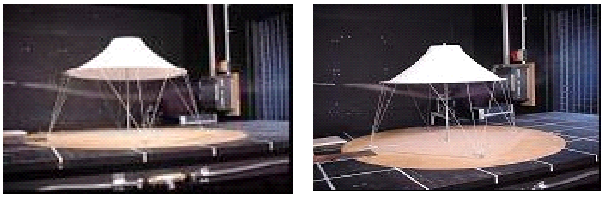

Figure 8: Visualization of airflow around conic membrane structure (wind tunnel experiment)

As can be clearly seen in figure 8, 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. This phenomenon can be used in favour of the enclosed space in order to withdraw air in the occupied zone of the enclosed or semi-enclosed space.

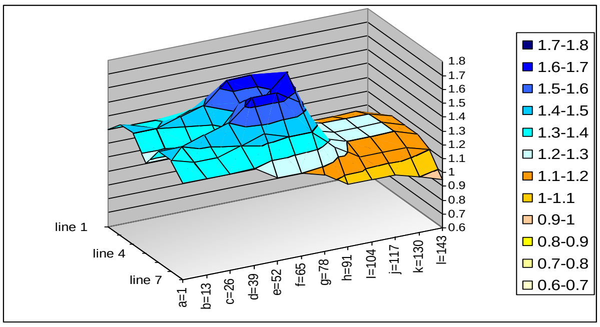

Figure 9: Air velocities (m/s) around the IC17 cone at a height of 6.5 cm above the base shown as a 3D surface (wind from the left).

In figure 9 the airflow pattern around IC17 (Inverted closed apex 17 cm high cone) at a height of 6.5 cm is shown three-dimensionally as a surface. It is clear that air velocities tends to be higher under the cone (covered area by the cone from d=39 to h= 91)

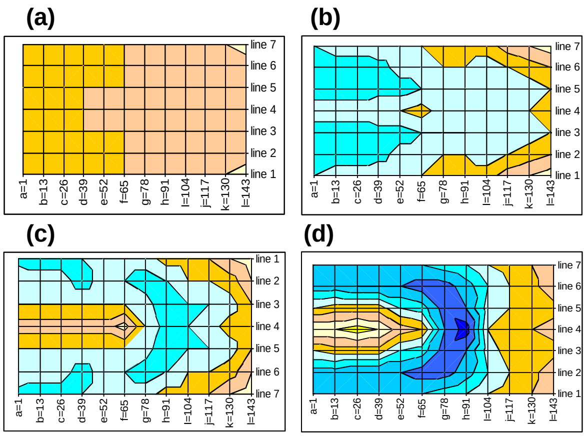

Figure 10: Airflow patterns at a height of 6.5 cm above the base for(a) no cone; (b) the circular flat disc; (d) straight closed cone at 3cm; (f) straight closed cone at 17cm high;

Figure 10(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 10(b) that although the airflow velocity is increased with the presence of the circular flat plate then in the case of no cone (Figure 8(a)), still the velocities are higher when the conic membranes are present as shown in fig. 10 (c & d). The figures also show that the air velocity increases under the cone with the increase of the height of the cone itself. Increasing the air velocity under the structure can cool down the temperature and lead to a higher comfort level in hot climates if properly integrated within the design stage of the building enclosures.

8. CONCLUSIONS AND FUTURE RESEARCH

The paper explored how the unique nature of the tensile membrane structures topology can be effectively designed to achieve better environmental performance. Features like topography, local climate, sun and site orientation and wind should all have a significant role in the form finding of a tensile structure. The possibility of using the fabrics topology to enhance the ventilation rates and the climatic performance of the interiors along with the employment of a number of architectural strategies commonly applied to conventional buildings were discussed.

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 when the height of the cone decreases or in the case of flat disc, when compared to similar closed apex cones with higher heights.

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 in the immediate vicinity of the buildings around it has been demonstrated.

The results of wind tunnel testing 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. Preliminary results of the investigation show that higher airflow velocities are achieved within the enclosure under certain conditions, for instance when the cone is inclined towards the prevailing wind direction. This improved ventilation may enhance the comfort of occupants of the membrane enclosure, particularly in hot climates and reduce the demand for mechanical cooling systems (and consequently energy consumption). Detailed results and conclusions will be presented in a future paper.

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