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Aspects of stadium design for warm climates

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ABSTRACT

The airflow pattern on the spectators' terrace in stadia is affected by numerous architectural factors, such as form, size, permeability, i.e. the morphology of the building. A stadium design not taking into account the prevailing environmental parameters can result in unpleasant thermal and aerodynamic environment in the stadium bowl.

The present article focuses on the airflow modifying effect of some architectural parameters, such as the overhang of the roof, the ratio and disposition of the openings on the stadium façade and the roof slope. The airflow that spectators are exposed to, has a significative aerothermal comfort modifying effect both in warm and cold climates. In warm climates the aim is to provide homogeneous and intense ventilation complying on one hand, the threshold of mechanical nuisance and on the other hand that of the athletic records' certification.

The analysis provided by this article is based on the results of a series of parametric wind tunnel experiments carried out in one of the boundary layer wind tunnels of the Centre Scientifique et Technique du Bâtiment de Nantes (CSTB). The results have been analysed using mathematical statistical methods in order to characterise the average airflow conditions and those belonging to the most and less intensely ventilated zones of the spectators' terrace.

1. Introduction

Modern stadia are multifunctional buildings hosting sport, cultural and religious events. Many of them became symbols of towns and attract lot of visitors. The spectator comfort in stadia became a prevailing issue, so that great care should be taken on stadium design that affects the comfort of the users to a great extent.

Stadia are classified as semi-exterior spaces by Spagnolo and de Dear [1] – they are both open and covered, representing a transition between indoor and outdoor. That is why the environmental factors, namely the wind, the temperature and the solar radiation have important effect on the quality of the environment in the stadium bowl. The stadium bowl signifies the space outlined by the spectators' terrace and the roof.

The effect of the wind has been investigated through parametric wind tunnel tests carried out in one of the boundary layer wind tunnels of the Centre Scientifique et Technique du Bâtiment de Nantes (CSTB), using a stadium model of variable geometry. The wind tunnel results provide a base for spectators' comfort aerothermal assessment in stadia in the early state of the design and facilitate in this manner the choice of a suitable stadium configuration for a given geographical location with a given climate.

2. Aerothermal comfort in stadia in warm climates

The stadium spectators are exposed to natural climatic conditions which can be altered by building elements, such as a roof acting as a shading device or a wall providing wind shelter. These elements provide *some* protection against the outdoor conditions but cannot completely eliminate their effect.

Among the climatic factors, the stadium architecture can modify to a great extent the effect of wind and solar radiation. Both of these factors have influence on thermal and wind comfort of the spectators.

Some examples of modern stadia designed for warm climate show climate responsive features, such as

- roof promoting airflow and providing shade
- spectators' terrace divided by horizontal or vertical openings intensifying airflow in the stadium bowl

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Fig. 1. Sketch of King Fahd Stadium Riyadh, designed by Ian Fraser, John Roberts and Partners.

Fig. 1 illustrates a stadium protected by a large white membrane roof having the following functions:

- shading and reflecting solar radiation
- promoting airflow in the bowl

The white coloured membrane facilitates to avoid the overheating of the roof reflecting solar radiation. Its tent-like structure containing regular triangular-shaped openings allows the wind to create airflow inside the stadium bowl independently from the wind direction.

Fig. 2 gives another example with a spectators' terrace divided by vertical openings in order to intensify air movement and also to separate the supporters (security aspect) [2,3]. Shading is provided by a light coloured canvas roof.

In warm climates the comfort of stadium spectators can significantly be improved by shading and intensifying the air movement. A study on the spectators' thermal responses in the Stadium Australia of Sydney carried out by Fiala et al. [1] reveals that the photometric characteristics of the stadium roof affect the thermal state of the spectators. Their simulation results for a typical hot summer afternoon indicate that the temperature of the semi-transparent roof surface exposed to intense direct solar radiation could rise up to 50 °C in the higher zones of the spectators' terrace, whose environment is significantly moderated by the roof. In case of an adverse wind, i.e. counteracting the buoyancy forces, air movement would be restricted and the air temperature could increase to about 11 K above the ambient air temperature, generating severe hot stress conditions for the spectators [1]. It can be avoided

- by using an opaque roof
- by intensifying the air movement on the upper tiers of the seats

The design details of the semi-outdoor and outdoor spaces can modify the actual levels of the ambient air temperature, solar radiation and wind at a particular location [4]. Such details may include the provision of shading elements, materials and colours of the surrounding hard surfaces, the "openness" to the wind, placement of windbreaks and the provision of planted areas [4,5].

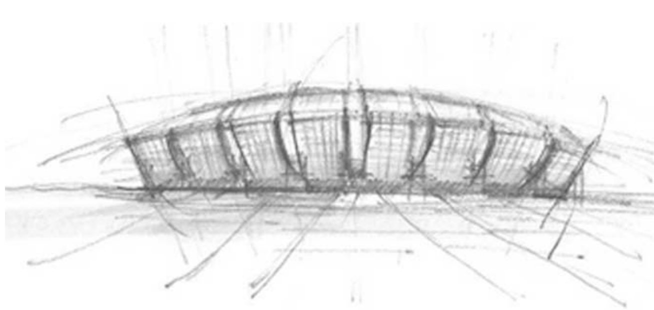

Fig. 2. Sketch of Saint Nicolas Stadium Bari, designed by Renzo Piano.

Studies carried out by Bouyer et al. [6] point out that stadium geometry has a prevailing influence on spectators' thermal comfort. They carried out thermal comfort assessment using the index PET (physiological equivalent temperature) in two stadia and the results of previous wind tunnel tests. Significative differences have been found in terms of PET values in case of a stadium with a roof, covering half of the spectators' terrace and in case of a continuous roof running all-above the entire spectators' terrace. Besides the stadium geometry, the impact of direct solar radiation, long-wave radiation and the photometric characteristics of the roofing material on thermal comfort have been underlined.

Air movement in the stadium bowl can be modified by architectural means. The effect of some architectural parameters on the airflow characteristics inside the stadium bowl has been tested on a scale model in a boundary layer wind tunnel. The results of the parametric wind tunnel tests show that the following architectural parameters have particularly strong impact on the airflow:

- roof overhang
- roof inclination
- façade porosity (ratio of the openings on the façade relative to the total façade surface)

The challenge is to find the architectural solution which provides comfortable aerothermal environment for the spectators and also suitable aerodynamic conditions for the undisturbed course of the different sport events.

In warm climates homogeneous and intense ventilation is advantageous for maintaining the aerothermal comfort of the spectators. However, the mechanical threshold of 3.6 m/s used as a conventional value in the CSTB Nantes should not be exceed [7–9] so that mechanical nuisance is avoided (blowing off of personal objects such as hats and hair). According to the Beaufort scale this value is associated with the first discomfort events: the wind is perceived on the face and the hair is disturbed [10]. On the other hand, strong wind is not desirable as it can obstruct the rectification of athletic competitions' results and it can disturb ball games by altering the trajectory of the ball [8].

The air movement reduces human thermal load in two ways even in case of no change in air temperature:

- by convective heat loss, if skin temperature is higher than the ambient air temperature
- by accelerating evaporation if the relative humidity of the ambient air is relatively low

Based on the existing comfort indices and charts a comfort zone of flexible outlines has been defined that indicates the effect of air movement on thermal comfort, hence the denomination "aerothermal" comfort. It shows admissible air movement in case of low DBT and required air movement for high DBT for an RH of 60%. The outlines of the comfort zone can be adjusted for different RH values or if additional solar radiation is present [8,9].

3. Wind tunnel tests

The parametric wind tunnel experiments have been carried out in one of the boundary layer wind tunnels of the CSTB Nantes. The wind tunnel is about 13 m long, 4 m large and 2.5 m high. The maximal airflow velocity in the wind tunnel is 12 m/s. The measurements have been taken with a wind velocity of 6 m/s. Farmland has been chosen as roughness category according to the Eurocode classification [11], and has been modeled by obstacles