# Open Stadium Design Aspects for Cold Climates

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*ABSTRACT: Spectators of any open stadia are exposed to the environmental conditions which may be sever, especially in extreme climatic conditions. The architectural components of the building, such as the stadium bowl and the roof can either augment or attenuate the effect of the environmental factors. Among the prevailing outdoor environmental factors temperature an relative humidity cannot be directly influenced by the means of architecture. However, solar radiation and airflow are affected by stadium morphology and design. A stadium design of protective character is advantageous for cold climates from wind effect point of view, nevertheless from solar radiation point of view, an open character would be suitable. The last depends not only on the form but also the photometric characteristics of the roofing material. A sophisticated equilibrium reached through a compromise of these requirements leads to optimised stadium design solutions. An attempt is made using the results of wind tunnel experiments carried out in one of the boundary layer wind tunnels of the CSTB Nantes, on a stadium model and the existing comfort indices, to support an environmental conscious stadium design in cold climate, focusing on spectators' aerothermal comfort. The impact of the following architectural parameters has been investigated: roof inclination, overhang and façade porosity. Based on the wind tunnel measurements iso-lines of relative air velocity compared to the reference wind velocity in front of the stadium have been defined. It facilitates on one hand to define the critical area of spectators' terrace and their ratio to the whole area, on the other hand to find local corrective measures, such as brise vents. An algorithm has been developed to calculate the seasonal or yearly frequency of comfort indices on the spectator terrace.*
*Keywords: Stadium, aerothermal comfort, wind, wind tunnel, parametric wind tunnel test, cold climate*

## INTRODUCTION

Stadia are multifunctional buildings, hosting not only sport events but also musical, cultural and religious performances. Many of them have been designed by famous architects and have become symbols of towns. They usually attract a lot of visitors. Having a direct effect of "profit-earning capacity", comfortable climatic environment has to be provided for stadium spectators.

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

The creation of a comfortable semi-outdoor space represents a great challenge to architects. The reason for this is that the effect of climatic parameters is hard to control with exclusively architectural means, especially in harsh climates.

Among the climatic parameters, wind velocity and solar radiation can be altered to the largest extent. Temperature and relative humidity can not be significantly modified by stadium architecture.

The wind characteristics in the stadium bowl have been investigated by parametric wind tunnel tests, using a stadium model of variable geometry, in one of the boundary layer wind tunnels of the Centre Scientifique et Technique du Bâtiment de Nantes (CSTB).

The wind tunnel results provide a basis for spectators' comfort aerothermal assessment in stadia in the early state of the design and facilitate in this way to choose a suitable architectural configuration for a given climate, at a given location

## THERMAL COMFORT

Using the existing charts and indices of comfort, in particular the bioclimatic chart of Arens, the Wind Chill Temperature and Index (WCT, WCI) [2] a comfort zone has been established [3]. It indicates the thermal sensation of a person exposed to wind and cold temperatures. Fig. 1 depicts the cooling effect of wind for DBT values ranging from -20°C to +10°C and for wind speeds up to 10 m/s using the new wind chill formula [3]. It is based on a model of the human face and incorporates modern heat transfer theory, i.e. the theory of the heat lost by the human body to its surroundings during cold and windy days [4].

According to the graph the chilling effect of wind on exposed skin is greater in case of lower DBT. When assessing spectator' thermal comfort in stadia, a conventional value of illusory temperature drop of 3K can be defined that illustrates the admissible difference between the actual DBT and the perceived temperature. This difference is on one hand due to thermal tolerance of humans outdoors, and on the other hand, it can be compensated by taking on a pullover or a jacket [5].

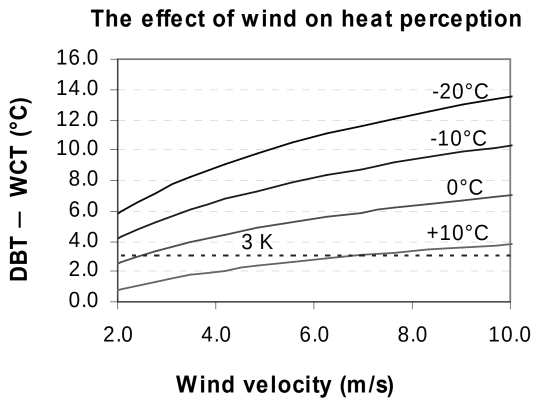


*Figure 1: Illusory temperature drop (DBT-WCT) versus air velocity - using the new wind chill concept*

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 the solar radiation. Both of these factors have influence on thermal and wind comfort of the spectators.

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

- wall situated at the ends of the tribune, acting as a windbreak and protecting from driving rain
- spectators terrace covered by roof, providing shelter from rain and snow

Fig. 2 illustrates a stadium protected by a windbreak at the end of the tribune.

In cold climates stadia with high protecting capacity against rain and wind are advantageous. Nevertheless, the design should facilitate the daylight and sunshine penetration in order to ameliorate the thermal comfort of spectators.

Another example, on Figure 3 shows a stadium with a transparent roof constructed at a geographical location with a cool and humid climate.

*Figure 2: Transparent windbreak on the side of the Fredrikstad Stadium in Norway.*

The stadium architecture cannot modify climatic factors, such as relative humidity or outdoor temperature, however has a significant influence on air movement. The effect of some architectural parameters on the airflow characteristics in the stadium bowl have been tested on a scale model in a boundary layer wind tunnel.

*Figure 3: Licorn Stadium in Amiens France with a transparent roof.*

The results of the parametric wind tunnel tests show that the following architectural parameters have particularly strong impact of the airflow:

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

The challenge resides in finding the architectural solution that provides comfortable aerothermal environment for the spectators and also suitable aerodynamic conditions for the undisturbed course of the different sport events.

## WIND TUNNEL EXPERIMENTS

The airflow has been studied in one of the boundary layer wind tunnels of the CSTB Nantes. The wind tunnel is about 13 meters long, 4 meters large and 2.5 meters high. The maximal air flow velocity in the wind tunnel is 12 m/s. A model of variable geometry has been constructed whose the following architectural parameters have been modified based on the outcome of the morphological study of modern stadia: length and direction of roof overhang, roof inclination, façade porosity and stadium length.

The morphological elements of a stadium are the roof and the spectators' terrace. The tendency shows that modern stadia have large continuous roofs running all around the perimeter covering the entire spectators' terrace. That is why for the investigation of the air flow pattern a stadium scale model of compact geometry has been built with both the bowl and the roof symmetric and continuous. The model, shown has a variable geometry that permitted to change the stadium configuration within a short period of time.

The scale of the stadium model of variable geometry is 1@300 and represents a stadium with a volume of 236m x 326 m x 42-78 m (the height changes with the roof inclination), for about 80 000 spectators. The model represents about 2% of the wind tunnel section.

A series of parametric wind tunnel tests have been carried out in order to investigate the airflow characteristics, in particular the wind velocity and its standard deviation on the spectators' terrace, at the height of the spectators. The wind velocity has been measured in a horizontal plane, by a hot wire anemometer.

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 [6], and has been modeled by obstacles placed into the entering airflow. The wind speed has been measured by a hot wire anemometer with a vertically positioned wire in order to measure wind speed fluctuations at the horizontal plane.

The measured data have been expressed by a dimensionless parameter, named $\Psi$ and introduced by J. Gandemer et *al.* [7]. The $\Psi_i$ defines the turbulence and the average wind speed at a given *i* measurement point relative to those measured at the reference point.

$$\Psi_i = \frac{\overline{U}_i + \sigma_i}{\overline{U}_{ref} + \sigma_{ref}}$$

*where*

$U_i$ is the average wind velocity at a point *i*;

$\sigma_i$ is the standard deviation at a point *i*;

$U_{ref}$ is the average wind velocity at the reference point;

$\sigma_{ref}$ is the standard deviation at the reference point.

The later is situated at 2 meters height (real scale) in an obstacle free zone, in front of the stadium. In other words, $\Psi$ characterizes the wind velocity in the stadium bowl compared to that measured without the presence of the stadium. In this way, the obtained relative wind velocity values permit to calculate the absolute wind speed at each measurement point of the studied configurations. Moreover, the wind environment and spectators' aerothermal comfort in stadia, not tested during the parametric wind tunnel study, with a resembling geometry to those tested in wind tunnel, can be predicted up to a certain extent.

## RESULTS AND DISCUSSION

**Effect of porosity** Porosity means the proportion of the openings on the façade related to the entire surface of the façade. Porosity can be represented by horizontal or vertical openings situated between different spectators' terrace levels, between the roof and the bowl, between the playground level and the bowl, at the bowl corners or at the vertical borders of the different spectators' terrace zones.

These structural openings can be distributed on the façade in a regular or an irregular manner.

The first investigated configuration has an opening situated between a horizontal roof and the bowl. The airflow entering between the roof and the bowl is accelerated by the reduced flow section due to the mutual position of the structural elements, and results in an intense airflow in the higher rows of the spectators' terrace. In contracts, the lower zones of the spectators' terrace, situated close to the pitch level are well protected and the airflow velocity is 2-3 times lower than in the higher zones of the tribune. In consequence, the spectators close to the pitch are exposed to lower wind speeds but are less protected from precipitation (e.g. driving rain), since the roof layout and the spectators terrace layout are identical. Spectators, sitting in the higher rows of the stadium are exposed to stronger wind, however they are better protected from rain and snow by the roof.

The configuration with a completely closed façade, without any opening between the roof and the bowl, results in homogeneous airflow fields and contains few zones of more intense ventilation.

The velocity in the zones of intense ventilation equals about the 60% of that measured at the reference point – situated in front of the stadium at an obstacle free zone, at a height of 2 meters. The air velocity is very low at the higher zones of the spectators' terrace, on the windward and lateral sides. These zones are very protected since there is no opening between the roof and the bowl.

An interesting phenomenon has been observed during the investigation of this configuration: the airflow is relatively intense on the leeward side of the bowl, in the higher rows of the spectators' terrace, directly next to the wall closing the gap between the roof and the bowl.

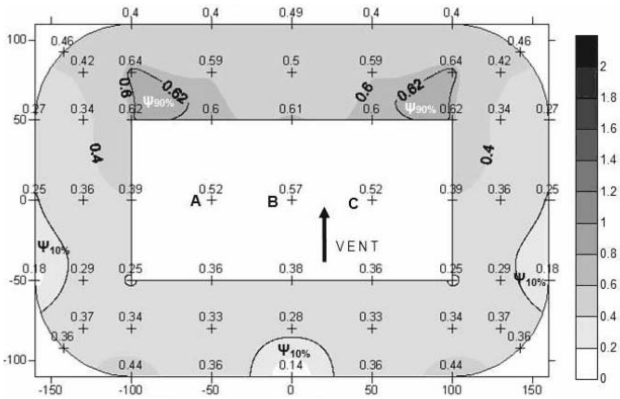


*Figure 4: Iso-Ψ lines representing wind velocity for a stadium configuration with no opening between the horizontal roof and the stadium bowl, in case of transversal wind*

The pressure on the windward side of the bowl, protected by the roof and the façade is lower than in the zones exposed to the entering airflow, through the oculus (central opening of the roof) of the stadium. In consequence, a bilateral airflow is created, from the higher rows of the central part of the exposed spectators' terrace zone towards the protected, low-pressure zones, situated on the windward and lateral tribunes, directly next to the wall situated between the bowl and the stadium roof.

In this manner, in case of transversal wind (Fig.4) the spectators sitting in the higher rows of the lateral spectators' terrace will experience an airflow opposite to the wind direction.

A configuration with closed corners between the roof and the bowl promotes the formation of calm zones on the corners. Nevertheless, in case of diagonal wind, the airflow that passes around the wall closing the gap between the roof and the bowl, results in zones of intense ventilation situated at the top of the bowl.

## CONCLUSION

In cold climates the principal task when designing an open stadium, is to find the configuration which gives the maximal wind protection to the building users, in particular to the spectators who can spend more hours seated. That is why a compact design with closed façades is preferred from wind comfort point of view.
From daylight and visual comfort point of view, a transparent structure would be ideal, however neither the spectators' terrace nor the spectators can not be "designed" transparent. The only way to provide maximal daylight penetration is to use transparent, translucent or opalescent roofing material. A translucent material has more advantageous photometric properties than a transparent one, since it diffuses light uniformly, towards all directions of the space. In this way, a relatively good illumination level can be reached in case of adequate meteorological conditions [8]. Opalescent and translucent materials help to provide homogeneous daylight conditions, ameliorating in this manner, the visual comfort of spectators.

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