



## 3D CFD simulations of wind flow and wind-driven rain shelter in sports stadia: Influence of stadium geometry

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### ABSTRACT

Sports stadia are increasingly used to host a wide variety of activities that attract large attendances, ranging from sports matches to concerts, festivities and conferences. One of the crucial aspects of spectator comfort in open stadia is protection from wind and rain. However, in many stadia this part of spectator comfort is insufficiently taken care of. The main reason is that stadia and stadium roofs are often designed with only vertical rainfall in mind, neglecting the influence of wind that can sweep the rain onto the stands. This wind-driven rain (WDR) can reach a large area of the stand underneath the roof, resulting in discomfort for the spectators in this area. For stadium design, it is important to understand the interaction between wind and rain in different types of stadium geometry and its effect on wetting of the stands.

This paper presents 3D Computational Fluid Dynamics (CFD) simulations of wind flow and WDR for twelve different generic stadium configurations that are representative for a wide range of existing stadia. The wind-flow patterns are determined by steady-state Reynolds-averaged Navier-Stokes (RANS) simulations. The WDR trajectories are calculated using Lagrangian particle tracking, yielding the wetting pattern on the stands. This study demonstrates the influence of both overall stadium geometry and roof slope on the area of the stand that is wetted by WDR. It shows the importance of taking into account WDR in the stadium design process, and it provides some design guidelines to avoid this type of spectator discomfort.

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### 1. Introduction

Since the first stadium was built in ancient Greece, sports stadia have always been impressive works of building engineering [1]. For contemporary stadium designs, spectator comfort is an important design parameter. One of the most important aspects of spectator comfort in open stadia (where only the stands are covered by a roof) is the protection from weather influences such as wind and rain. However, the majority of stadia are built with only vertical rainfall in mind, neglecting the influence of wind that can sweep the rain onto the stands. This wind-driven rain (WDR) can reach a large area of the stand underneath the roof, resulting in discomfort for the spectators in this area. The statement that stadia are usually only built with vertical rainfall in mind is supported by

the fact that the roof generally does not reach further than the separation between the stands and the field. Ignoring the influence of the wind and WDR during stadium design can give rise to discomfort for the spectators that are seated in the lower regions of the stand, due to insufficient protection from WDR.

The construction of many new (semi-) open stadia has incited research on spectator comfort in these stadia. Szűcs et al. [2] assessed the visual comfort of spectators in a generic stadium configuration by numerical simulations using a daylight program. This study focused on the influence of roof inclination angle on the daylight distribution on the pitch. Szűcs et al. [3,4] studied the effect of wind flow on thermal comfort in generic stadium configurations by wind tunnel measurements. Among others, they analyzed the effect of facade porosity and roof inclination angle on the wind-flow pattern inside the stadium and concluded that the wind velocity in the stadium can be altered significantly by design changes to the stadium facades and roofs. Bouyer et al. [5] coupled the results of climatic, airflow and thermo-radiative modules in an Enriched Virtual Environment (EVE) to predict the thermal comfort level in the Atatürk stadium in Istanbul, Turkey and the Stade de France in

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