Dry Run

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AFAS stadium in Alkmaar

PHOTO: AZ NV

Simulating wind and rain around a stadium determines the best design for keeping spectators dry.

When developing a sporting venue, designers must consider a large number of factors. Two important overall considerations are spectator comfort/safety and how the stadium itself could affect the play of the sport — and each has many facets. Anyone who has attended a sporting event in the rain will understand the dampening effect that this factor can have on event enjoyment.

In semi-open stadium design, two of the greatest challenges are limiting wind on the field to avoid affecting play and protecting spectators from wind-driven rain. Historically, stadium designers largely ignored these factors because they were unable to determine how their designs would perform until after the venue had been built. Simulation is changing that.

A team from Eindhoven University of Technology has conducted 3-D studies of stadium design using ANSYS Fluent computational fluid dynamics (CFD) software to demonstrate the important effects of the architecture on both wind flow and wind-driven rain. Simulation of 12 different stadium configurations showed the precise areas where wind-driven rain would penetrate the seats in each type of stadium as well as the speed and direction of wind on the playing field. These results can be used to improve the design of future stadiums as well as to diagnose and correct problems with existing stadiums — such as using special paint to protect seats that frequently get wet to reduce maintenance costs.

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STADIUM DESIGN AND SIMULATION CHALLENGES

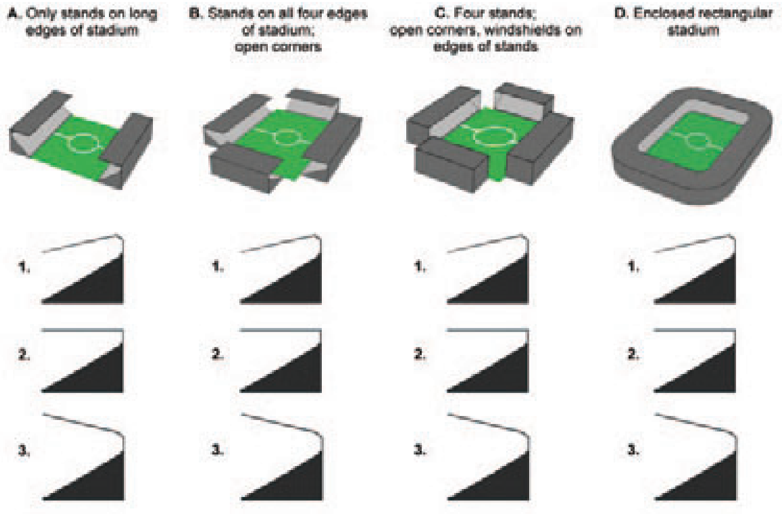
Many stadiums in Europe and elsewhere have an open design in which the roof covers only the stands. In most cases, the roof does not extend farther than the separation between the stands and the field, so wind-driven rain can reach a large area of seating, resulting in spectator discomfort. To the best of the authors' knowledge, the first simulation of wind-driven rain in a stadium was published in 2008 [1]. This 2-D study was not able to capture the important effects of roof and stadium geometry. Simulation predicted the area of the stands that became wet in seven generic stadium designs. The study showed that roof design can strongly influence which areas stay dry and which become wet.

The new Eindhoven study went a step further by using 3-D CFD to capture 3-D flow patterns and provide a more realistic assessment of the effect of roof geometry on the area wetted by wind-driven rain [2]. One of the biggest challenges was modeling geometry that combines a very large computational domain with the need to model certain areas to a fine level of detail. Another challenge was the need to accurately model the wide range of sizes of potential rain droplets.

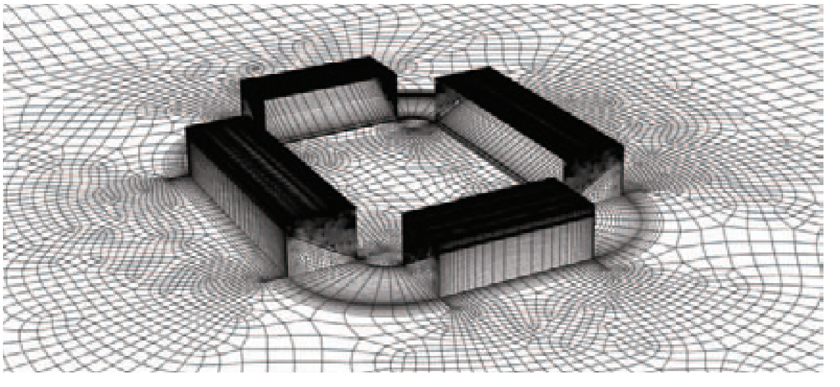
12 DESIGN ALTERNATIVES CONSIDERED

The stadium configurations in this study are based on the AFAS stadium in Alkmaar, The Netherlands, which seats 17,000 people and is the home of the AZ Alkmaar football team. Its exterior dimensions are 176.8 meters long by 138 meters wide by 22.5 meters high; it has a downward-sloped roof with an inclination of 13 degrees. The research team selected this stadium because of its unusual roof, which the architects intuitively chose with the goal of improving shelter from wind-driven rain. The team looked at four different stand arrangements: stands only on long sides of stadium (A), stands on all four sides (B), stands on all four sides with each end of the stands closed off (C), and a closed rectangular stadium (D). Researchers evaluated each stand arrangement with three different roof designs: upward sloped (1), flat (2), and downward sloped (3), yielding 12 different design configurations: A-1, A-2, A-3, B-1 and so on. Configuration D-3 matches the actual AFAS stadium design.

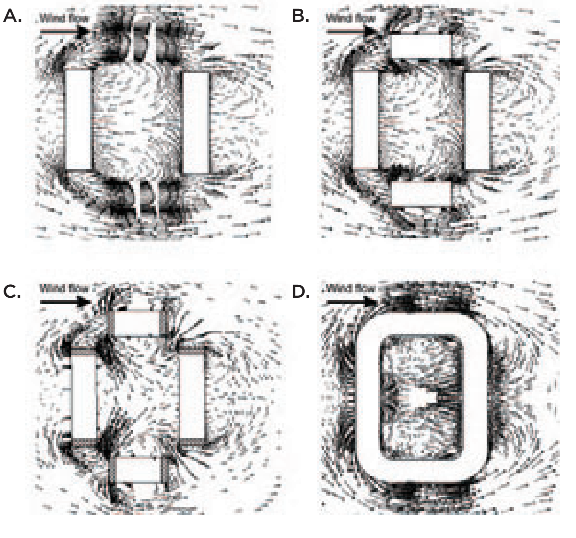
The difference between the largest- (1,100 meters) and smallest- (less than 0.1 meters) length scales in the domain created challenges in producing the computational grid. The Eindhoven team generated the master grid by creating a series of premeshed 2-D cross sections, then using a series of translation and rotation operations. The master grid contained hexahedral and prismatic cells. This approach provides full control of grid quality and resolution. Researchers used higher-resolution mesh at the deck of the stadium, while lower resolution was applied to outside the stadium. They increased the grid resolution in the vicinity of the roof for a more detailed prediction of wind flow. The team deleted designated meshed volumes from the master grid to produce the mesh for each of the 12 different stadium design variants.



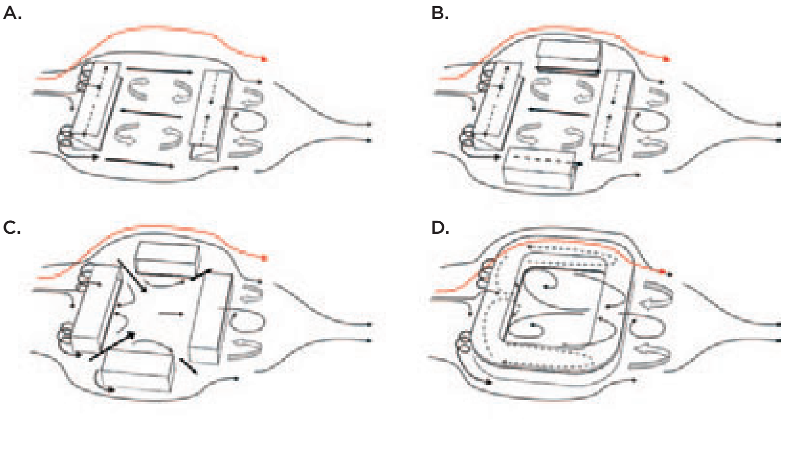
Four different stand configurations were evaluated with three different roof designs, for a total of 12 possibilities.



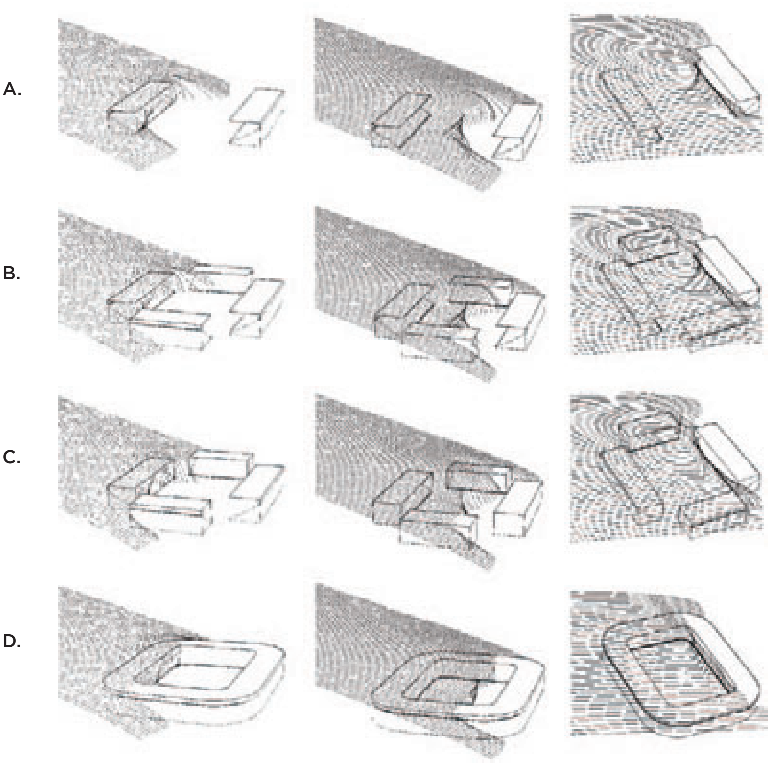
Increased grid resolution in the vicinity of the roof provided a more detailed prediction of wind flow.



2-D wind flow patterns one meter above ground for the four different stand configurations



3-D wind flow for four different stadium stand configurations



Raindrop trajectories for 1 mm raindrops and the same wind speed for four stadium configurations. Each column shows a different injection position for raindrops.

WIND-FLOW PATTERNS

Researchers calculated steady-state wind-flow patterns around the stadiums using the Reynolds-averaged Navier–Stokes (RANS) CFD technique with a realizable k-epsilon turbulence model. They based this choice on earlier extensive validation efforts of wind-driven rain on building facades and over various types of small-scale topography, including hills and valleys [3, 4, 5]. They determined the wind-flow patterns in the field at a height of one meter above ground level (chosen to determine the impact of wind conditions on the game) for each of the four stand arrangements described earlier with a flat roof. The results for configuration A-2 revealed two large counter-rotating vortices between the stands. These vortices are mainly driven by the corner stream shear layer originating at the corners of the upstream stand. Applying fluid flow modeling to configuration B-2 revealed results similar to A-2, except that the velocities in the upstream corners of the stadium are higher. The simulation results show that the stands in the short edges of the stadium have a relatively small influence on the flow because the side flow is not obstructed by these stands and can pass through the area between the stand and the roof. Closing off the sides of the stands in configuration C-2 eliminates the vortices and, instead, shows that streams from two different corners combine to generate two high-velocity jets directed toward the center of the stadium. Configuration D-2 has two vortices, but they are smaller and have a lower velocity than configurations A-2 and B-2 — so the flow pattern inside the stadium is considerably more complex. Additional small vortices exist above the field and underneath the roof.

WIND-DRIVEN RAIN PATTERNS

Researchers determined raindrop trajectories by injecting raindrops of different sizes in the calculated wind-flow motion and solving their equations of motion. Raindrops with diameters of 0.5 mm, 1 mm, 2 mm and 5 mm were considered. The raindrops were injected from the top of the domain with the local wind speed as horizontal injection velocity and terminal velocity as vertical injection velocity. Raindrops of 0.5 mm diameter represent the median diameter for drizzle (rainfall intensity of 0.1 mm/h), 1 mm diameter represents the median diameter for a rainfall intensity of 1 mm/h (common Dutch rain), 2 mm diameter represents 10 mm/h (heavy shower), and 5 mm diameter is the largest raindrop in heavy rain showers. The areas of the stadium receiving rain were calculated based on the calculated raindrop trajectories for each stadium configuration. For configurations A and B, the large vortices between the upstream and downstream stand cause part of the upstream stand to be wetted, especially for smaller raindrop diameters that are more sensitive to the wind-flow pattern and can be more easily swept underneath the roof. On the other hand, with configuration C, the wetting of the two

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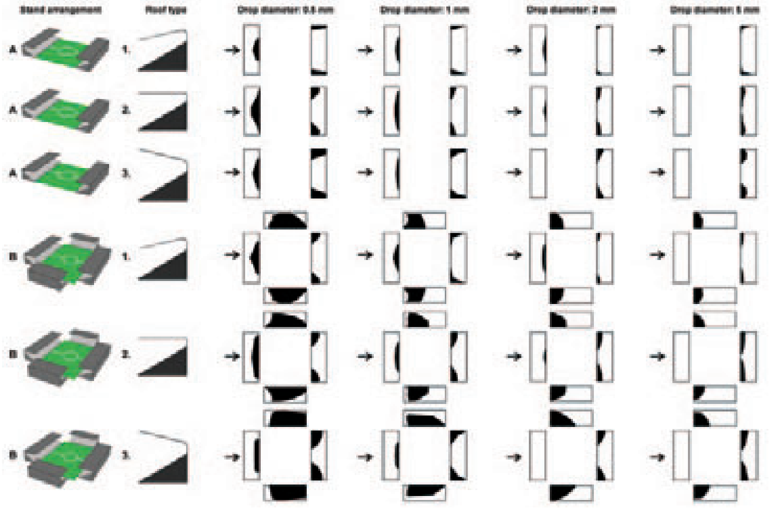
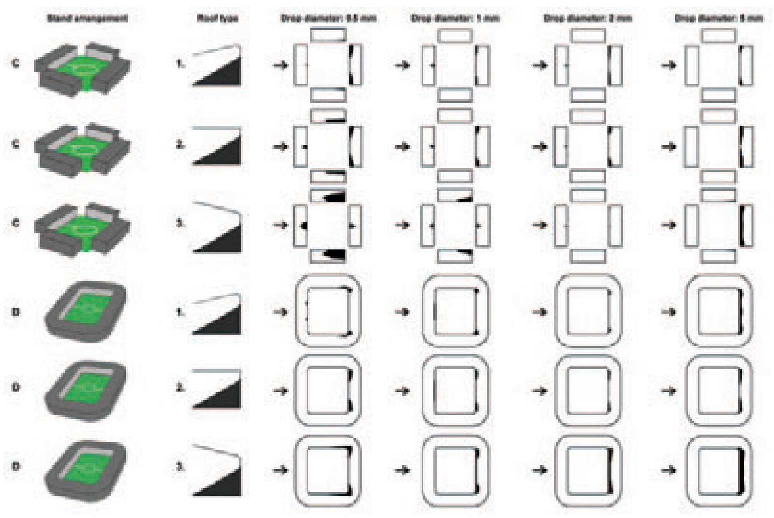


Overview of wetted stand areas for stand arrangements A and B with three different roof types



Overview of wetted stand areas for stand arrangements C and D with three different roof types

stands is limited, especially for the downward-sloping roof. The closed ends of the stands effectively shield the stands from rain, especially for upward-sloping and flat roofs. Configuration D provides only limited wetting at the rows of the stands closest to the field.

Wind flow and wind-driven rain affect spectator comfort and fair competition, but until recently stadium designers have had no way to determine the performance of design alternatives based on these conditions. This study demonstrates that CFD can provide detailed insight into wind-flow patterns and wind-driven rain distribution in a wide range of stadium configurations. Much further work remains to be done, such as applying design optimization to determine the ideal roof angle to maximize the comfort level of the spectators.

References

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