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A venturi-shaped roof for wind-induced natural ventilation of buildings: Wind tunnel and CFD evaluation of different design configurations

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A B S T R A C T

Wind tunnel experiments and Computational Fluid Dynamics (CFD) are used to analyse the flow conditions in a venturi-shaped roof, with focus on the underpressure in the narrowest roof section (contraction). This underpressure can be used to partly or completely drive the natural ventilation of the building zones. The wind tunnel experiments are performed in an atmospheric boundary layer wind tunnel at scale 1:100. The 3D CFD simulations are performed with steady RANS and the RNG k-ε model. The purpose of this study is twofold: (1) to evaluate the accuracy of steady RANS and the RNG k-ε model for this application and (2) to assess the magnitude of the underpressures generated with different design configurations of the venturi-shaped roof. The CFD simulations of mean wind speed and surface pressures inside the roof are generally in good agreement (10–20%) with the wind tunnel measurements. The study shows that for the configuration without guiding vanes, large negative pressure coefficients are obtained, down to −1.35, with reference to the free-stream wind speed at roof height. The comparison of design configurations with and without guiding vanes shows an – at least at first sight – counter-intuitive result: adding guiding vanes strongly decreases the absolute value of the underpressure. The reason is that the presence of the guiding vanes increases the flow resistance inside the roof and causes more wind to flow over and around the roof, and less wind through it (wind-blocking). As a result, the optimum configuration is the one without guiding vanes.

1. Introduction

Natural ventilation is a sustainable approach to achieve a healthy and comfortable indoor environment in buildings. One of the most important influencing parameters concerning the feasibility of natural ventilation of buildings is the geometry of the building itself. In the past, several studies have been conducted to improve the natural ventilation of a building by modifying the building facades (e.g. wind floors, double-skin facades) or by adding structures on the roof of a building (e.g. wind towers, wind catchers). An overview of wind-driven ventilation techniques is provided by Khan et al. [1]. The present study consists of the analysis of the aerodynamic performance of a venturi-shaped roof that was designed by Bronsema as part of the research project "Earth, Wind & Fire – Air-conditioning powered by Nature" [2] (Fig. 1). The roof consists of a disk-shaped roof construction that is positioned at a certain height above the actual building, creating a contraction that is expected to provide significant negative pressures that can be used to partly or completely drive the natural ventilation of the building.

Analysis of natural ventilation of buildings can be performed using a wide range of methods [3], including: (1) reduced-scale water tank experiments (e.g. [4–6]); (2) analytical and/or semi-empirical formulae (e.g. [4,7–9]); (3) full-scale measurements (e.g. [10–13]); (4) reduced-scale atmospheric boundary layer wind tunnel experiments (e.g. [14–17]); and (5) numerical simulation with Computational Fluid Dynamics (CFD) (e.g. [6,10,13,14,18–20]). Water tank experiments and analytical formulae have generally been applied for simplified configurations and have proved very valuable to gain insight in the process of natural ventilation, such as the combined effects of wind and buoyancy as driving forces (e.g. [5,7]). They are however less suitable for practical applications for specific buildings in specific environments. For such applications, full-scale measurements are very valuable but they are generally time-consuming and expensive and the boundary conditions are often uncontrollable. In addition, full-scale measurements are not an option in the design phase of buildings. Wind tunnel

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