Wind energy performance of a venturi-shaped roof: analysis based on CFD and wind tunnel measurements

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The depletion of fossil fuels, climate change and the growing environmental awareness have strongly increased the interest in renewable energy, including wind energy. While most research efforts and practical applications of wind energy have focused on large-scale wind installations in remote off-shore or on-shore areas, much less attention has been given to wind energy installations near buildings [1-3]. Campbell and Stankovic [1] distinguish between three categories of possibilities for integration of wind energy generation systems into urban environments: (1) siting stand-alone wind turbines in urban locations; (2) retrofitting wind turbines onto existing buildings; and (3) full integration of wind turbines together with architectural form. Category 2 and 3 are often referred to as "building-integrated wind turbines".

Driven by the concept of building-integrated wind energy systems (category 2 and 3), the present paper addresses the performance of a venturi-shaped roof for integration of a VAWT. This roof was designed by Bronsema in 2005 and later further developed as part of the research project "Earth, Wind & Fire – Air-conditioning powered by Nature" [4]. It 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 significantly increased wind speed in the center of the contraction, where the VAWT is positioned to harvest wind energy. In this paper, the wind flow is analyzed with 3D Computational Fluid Dynamics (CFD). The roof is positioned on top of a 50 m high isolated building. The CFD simulations are performed with the steady Reynolds-Averaged Navier-Stokes equations and the RNG k-ε turbulence model. They are based on grid-sensitivity analysis and successful validation with reduced-scale wind tunnel measurements. A two-stage optimization procedure is performed, focused on the wind speed amplification factor (AF) and the energy enhancement factor (EF). AF is the ratio of the wind speed in the venturi contraction to the undisturbed wind speed at the same height. EF is the ratio of the yearly energy output by the VAWT in the roof to the yearly energy output of an identical stand-alone VAWT at the same height in the undisturbed flow. In this paper, the EF is determined based on the 30-year Eindhoven airport wind speed statistics. The first optimization stage shows that adding vertical guiding vanes does not improve the performance of the roof, but actually cancels its effect and reduces its wind energy performance to values that are equal to or even lower than those of a free-standing VAWT at the same height, which is a counter-intuitive result. The second optimization stage shows that, of the configurations investigated, a contraction ratio of 6.3 provides the largest AF (= 1.3) and EF (= 2.6), although other contraction ratios can give larger absolute energy output due to the larger space that can accommodate a larger VAWT. The paper concludes that the venturi-shaped roof without vertical guiding vanes is a promising design feature for integration of wind energy systems on top of buildings.

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[4] Bronsema B. Earth, Wind & Fire – Towards new concepts for climate control in buildings. CIB W096 Meeting Lyngby, November 2-4, 2005.