A Retrospective of Wind Turbine Architectural Integration in the Built Environment

Stefano Degrassi, Marco Raciti Castelli and Ernesto Benini

Abstract—Since the European renewable energy directives set the target for 22.1% of electricity generation to be supplied by 2010 [1], there has been increased interest in using green technologies also within the urban enviroment. The most commonly considered installations are solar thermal and solar photovoltaics. Nevertheless, as observed by Bahaj et al. [2], small scale turbines can reduce the built enviroment related CO_2 emissions. Thus, in the last few years, an increasing number of manufacturers have developed small wind turbines specifically designed for the built enviroment. The present work focuses on the integration into architectural systems of such installations and presents a survey of successful case studies.

Keywords—Wind turbines, architectural integration, wind resources, urban areas, built enviroment, renewable technologies.

I. Introduction

THE dramatic increase in rotor size and technological know-how, coupled with economy of scales from fast growing production volumes have greatly reduced the cost of wind power. According to Chandler [3], wind turbines are highly reliable, with operating availabilities of about 98%.

The power generated by wind turbines is proportional to the cube of the wind velocity and to the swept area of the rotor. Therefore, the two main issues to be considered for the wind energy conversion in the urban environment are the wind speed and the required space utilization.

A. Wind Speed inside the Built Environment

Wind speed in the built enviroment is only a fraction of that blowing in rural areas, due to the presence of obstacles. Siting wind turbines on the roof of buildings appears to be the most obvious solution: such installations also allow to take advantage of the local increment of the unperturbed wind speed, due to the well known ”hill effect” (up to 20% of unperturbed wind speed, depending on both the incoming wind direction and the orientation of the building).

The turbulence generated from the buildings presents some challenges due to the rapidly varying wind direction, producing extra stresses on the turbine blades and decreasing the global energy production.

Fig. 1: Olympic Park, London (United Kingdom): Qr5 wind turbines [4]; Street lamp, Bristol (United Kingdom): WS-4B wind turbines [5]; Cijin wind power park, Kaosiung (Taiwan)

B. Rotor Dimensions

The wind turbine for the built enviroment is limited in rotor size: in fact, huge wind turbines operating in turbulent winds would need to be robustly manufactured, in order to cope with blade-buffeting, thus increasing rotor weight and, therefore, cost. Moreover, a larger rotor usually yields to increased noise. However, noise from rotor blades can be reduced by paying attention to the aerodynamic design, while noise from the electrical generator can be minimized with good sound insulation within the turbine head. Generally speaking,

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vertical-axis wind turbines (VAWTs) are less noisy, due to the lower tangential velocities of the blade sections.

Fig. 2: Greenway Garage, Chicago (Illinois) (from: [7] [8])

II. ARCHITECTURAL INTEGRATION STRATEGIES

As observed by Campbell et al. [6], three main integration strategies are registered:

- Landscaping stand-alone wind turbines in urban locations (Fig. 1);
- Retro-fitting wind turbines onto existing buildings (Fig. 2);
- Full integration, such that the wind turbines drive the architectural form (Fig. 3).

Campbell and Stankovich [10] observed that the cumulative potential energy contribution from introducing sensitively sited stand-alone turbines would probably be the greatest of the three generic options, but could only be assessed once test cases had entered the planning systems of several member states.

Concerning both retro-fitting and full integration options, Mertens [11] focused on the design of buildings that maximize wind harvest, studying the optimal wind turbine positioning on the roof or side of buildings, between two airfoil-shaped buildings and in ducts through buildings. As a result, both ”on the roof of buildings” and ”in ducts through buildings” are the most promising configurations in order to maximize wind energy production.

III. WIND ENERGY SYSTEMS AND BUILT APPLICATIONS

Wind turbines for the built enviroment should be relatively small, in order to harvest the wind energy from frequently changing wind directions and profit from the small region on top of buildings characterized by accelerated flow. Still, the lift-driven horizontal-axis wind turbine (HAWT) is favorable only if the shape of the building grants a nearly constant wind direction at the turbine installation point. Yet, VAWTs are not only the best option in the built enviroment in general, but especially in the skewed flow above the roofs of sharp-edge buildings.

Considering small VAWTs, whose typical dimensions are around 10 or 20% of the characteristic building height, as a good solution, Van Bussel and Mertens [12] considered the Savonius rotor not particularly suited for urban installations, due to a fairly low power coefficent. Also standard Darrieus wind turbine was rejected, due to its too high noise level, while the modification of the Darrieus concept characterized by twisted blades was considered the best solution for application on existing buildings. Nevertheless, drag-driven VAWTs present some advantages in the urban enviroment: as suggested by Manwell et al. [13], drag-driven machines register a relatively low construction cost, which makes them less expensive than comparable lift-driven devices, thus allowing an initial saving in micro wind project economics. Moreover, considering a low-wind urban area, Raciti Castelli and Benini [14] presented the results of a comparison between the annual energy outputs of a Darrieus architecture and a Savonius one. The total amount of annual energy production resulted quite similar for both turbines, the drag-driven concept performing better for low winds (up to 8 m/s), while the lift-driven turbine produced most of the annual energy thanks to high winds and its higher rated power.

A. *Large Systems*

The architectural integration for large wind energy conversion systems requires strong decisions in the earliest phases of the project.

The site, shape and orientation of the building are fundamental choices. As observed by Mertens [11] and Campbell [6] [10], placing the wind turbines inside the building/concentrator produced considerably more power compared to conventionally mounted installations at the same height. For a multi-turbine twin tower building, the integrated turbines could provide at least 20% and up to 100% of the annual electricity demand.

Fig. 3 b) and c) show the WTC building of Manama (Bahrain). The two towers are linked via three skybridges, each holding a 225 kW wind turbine, totalizing 675 kW of nominal wind power production. Each of these turbines measures 29 m in diameter and is aligned north, which is the direction from which air from the Persian Gulf blows in. The sail-shaped buildings ensure that any wind coming within a 45° angle to either side of the central axis will create a wind stream that remains perpendicular to the turbines, which are expected to provide from 11% to 15% of the total power consumption of the building. Fig. 4 a) and b) show the Strata Tower in London (United Kingdom). The building exceeds current UK building regulations on sustainability by 13%. The tower houses 408 apartments and energy costs per flat are envisaged to be up to 40% less than Britain typical housing average.

Fig. 4 c) and d) show the Pearl River Tower in Guangzhou (China). The building is intended for offices and presents four wind tunnels where a 5 m high Windside [5] turbine is installed, producing about 5% of the building total energy needs.

Fig. 3: a) Airfoil shaped building proposed by Campbell and Stankovich (from: [6]); b-c) WTC of Bahrain (from: [9])

Fig. 4: a-b) Strata Tower [15], London (United Kingdom); c-d) Pearl River Tower [16], Guangzhou (China).

B. *Small Systems*

Horizontal and vertical-axis turbine integration are fairly established for small-scale machines and easily available as a retrofit solution.

Fig. 5 a) shows the Arizona State University's Global Institute of Sustainability [17]: the bulding was outfitted with six AeroVironment [18] parapet turbines. Fig. 5 b) shows four Windside WS-0,30B [5] turbines on Viikki "Eco-Building" in Helsinki (Finland). Fig. 5 c) shows the Adobe [19] headquarters in San Jose (California), whose 20 Windspire [20] VAWTs were installed on the parking garage on top of the complex. Fig. 5 d) shows the Canton Tower in Guangzhou (China), while Fig. 6 shows the "Kinetica" building in Ramsgate Street, London (United Kingdom) [21].

Fig. 7 a) shows the Oklahoma Medical Research Foundation building, which represents an excellent example of how a roof top wind farm can be successfully implemented. The installation is designed to cut carbon emissions by approximately 2 million pounds yearly. Fig. 7 b) and c) show the Mercy Housing SRO in the city of Chicago (Illinois). This installation features eight 520H Aeroturbines [22] mounted horizontally with respect to the roof of a 96-unit single-resident housing development. The building is a fine example of building-integrated wind energy technology: the geometry and orientation of the building was designed specifically to increase the speed of the wind as it flows over the roof.

IV. CONCLUSIONS

The exploitation of the wind resource inside urban areas is a relatively recent idea. The roughness of the urban environment causes turbulence in the wind, thus reducing the energy production of many commonly used small wind turbines. Nevertheless, siting wind energy conversion systems on top of building roofs or integrating them inside the architecture of the buildings allows designers to take advantage of the local increment of the unperturbed wind speed, due to both the "hill effect" and the "concentration effect". On the other hand, the motivations for integrating renewable energy sources with buildings are not only driven by environmental issues: architecture has always reflected society trends and one of those trends nowadays certainly concerns the need to use green energy.

Fig. 5: a) Architectural Wind [18]; b) Viikki Eco-Building, Helsinki (Finland); c) Adobe [19] headquarters in downtown, San Jose (California); d) Canton Tower, Guangzhou (China).

Fig. 6: Kinetica Building in Ramsgate Street [21], London (United Kingdom)

Fig. 7: a) Oklahoma Medical Research Foundation Building, (Oklahoma); b-c) Mercy Lakefront SRO, Chicago (Illinois).

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