Wind energy in urban areas

Concentrator effects for wind turbines close to buildings

One often overlooked alternative to conventional large scale wind farms is to produce wind energy close to where we need it such as in the built environment. In this case we do not need to transport the energy and we keep rural areas untouched. However, the built environment has lower average wind speeds and higher turbulence levels. What means do we have to compensate for this? In this article, Sander Mertens, TU Delft, Holland describes some of the specific technology and design issues in the use of wind energy in buildings.

Wind energy conversion in the built environment can be distinguished from that in rural areas by means of the influence the buildings have on the wind turbine. The influence of a wind turbine based for instance in a field far away from the building will be negligible. However when located close to the building we have to be aware of the interaction of building and wind turbine. In this case the building can speed up the wind velocity at the position of the wind turbine and/or create high turbulence levels. Wind turbines such as this located at the high wind speed zones in buildings are called Building Augmented Wind Turbines (BAWT) because the wind turbine makes use of the building as a concentrator of the wind. The BAWT forms the topic of this article.

When thinking about a BAWT we can distinguish three basic different situations. We can locate a wind turbine: ***between*** diffuser shaped buildings; ***on top of or alongside*** a building or ***in*** a duct through a building (for example see Figure 1). All other possibilities are combinations of these three. The concentrator effect will only be present for small wind turbine dimensions compared to the building dimension since the wind turbine has to be located in high wind speed zones, which only exist close to the building. This limits BAWT dimensions up to 20% of the characteristic building dimension. Therefore, in mid- to high-rise buildings with a dimension of around 100m, the BAWT diameter can only be up to about 20m. This is relatively small compared to 100m rotor diameters found in conventional turbines nowadays. However the wind turbine has to be as big as possible in order to generate an appreciable amount of energy.

The BAWT also needs to be silent. This means a low tip speed of the blades, which brings about a low Reynolds number of the flow on the blades. For a low Reynolds number the blades experience a more viscous flow and the friction of the blades will increase. This is also the case for smaller blade

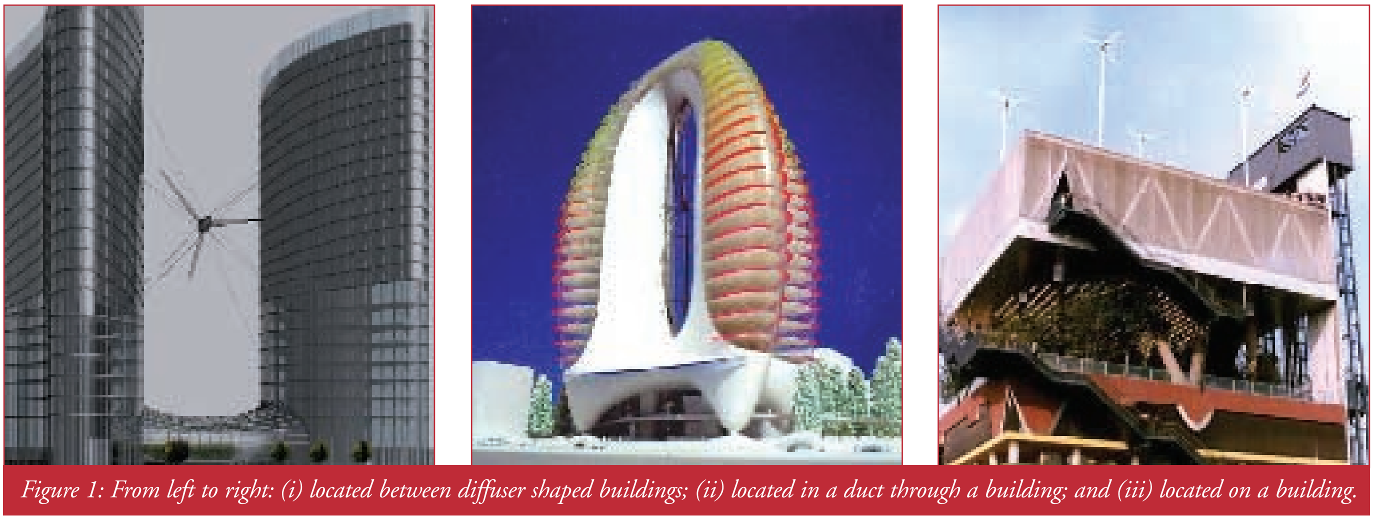

Figure 1: From left to right: (i) located between diffuser shaped buildings; (ii) located in a duct through a building; and (iii) located on a building.

dimensions that are needed for BAWTs. So considering this together with the demand of a low tip speed can be difficult and the Reynolds number of the flow on the blades has to be considered very carefully.

Suitable wind turbine designs

The aerodynamic efficiency of a wind turbine depends upon other things on the way the wind energy is converted (lift or drag type wind turbine). A high aerodynamic efficiency (up to the Betz limit of 59% [1]) can be achieved for lift driven wind turbines. These wind turbines make use of airfoils in order to generate their driving force/lift and have a low material usage. In contrast to the lift driven wind turbines the drag driven wind turbines achieve lower aerodynamic efficiencies (up to about 15%) and have higher material usage. So the lift driven wind turbine is preferable for the BAWT largely for economic reasons. There are several lift driven wind turbines that are possible candidates for the built environment. Among other things, they can be classified with the orientation of the axes of rotation. This classification brings about two different axes orientations. The vertical axes wind turbine (VAWT) and the horizontal axes wind turbine (HAWT). Interesting candidates for the built environment are: the Darrieus (a VAWT); the Wells (a HAWT with symmetrical shaped airfoils), and the normal HAWT.

There are two main Darrieus types: the normal Darrieus (Figure 2, left) and the H-Darrieus (Figure 2, right). The Darrieus has a lower aerodynamic efficiency compared to a lift driven HAWT. This is the result of the airfoils that periodically stall during each revolution. The airfoils only gain energy at the windward and leeward side of the rotor axes. The normal Darrieus has such a shape that pulling forces only occur in the airfoils. However, the parts of the blades close to the axes do not contribute to the energy gain. In the H-Darrieus almost the whole airfoil contributes to the energy gain however, the centrifugal forces in the H-Darrieus can be problematic. Last but not least the Darrieus has the advantage of wind direction independence. In contrast to the Darrieus, the normal HAWT has to be positioned in the direction of the wind. However, a Wells rotor can operate in wind from two opposite directions without pitch because of the symmetrical shaped airfoils. Operating in two opposite wind directions can also be achieved with a normal HAWT by pitching the blades 180 degrees.

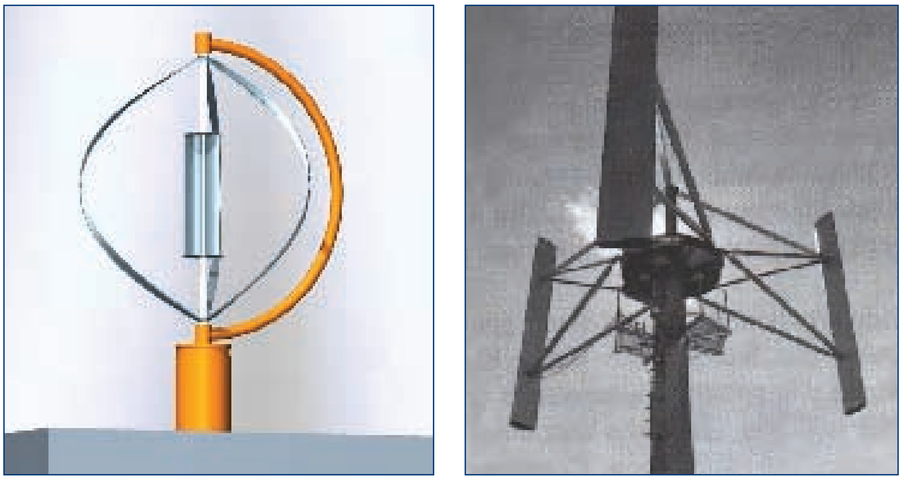

Figure 2: Left: The Globuan Darrieus turbine (a normal Darrieus). Right: a H-Darrieus turbine

Positioning of the turbine

Locating between diffuser shaped buildings

In this case buildings are positioned in such a way that they act as a diffuser for the wind turbine (See Figure 1, far left). In the past there was a lot of interest in the diffuser augmented wind turbine and several tests on the operating conditions and achievable aerodynamic efficiency were carried out. All tests were carried out on horizontal axes wind turbines in ring shaped diffusers. This combination results in a high aerodynamic efficiency compared to other possibilities. The tests of Igra [2] and others [3] confirm the possibility of raising the aerodynamic efficiency in this configuration. However measurements also show the drawback of this configuration. The diffuser needs to be long in order to generate an appreciable gain in aerodynamic efficiency. The common shape of the diffuser augmented wind turbine is not very suitable for the built environment. One can think about much shorter diffuser like buildings that are less wind direction dependent like that shown in Figure 3. This configuration is known as the “short diffuser configuration”. This configuration however does not solely operate as a diffuser but as a combination of “diffuser” and “ duct”.

In a duct through a building

The pressure difference between the windward and leeward side of the building initiates the flow through the duct in the building. At the windward side there is a stagnation condition that causes the locally increased pressure to be higher than the undisturbed pressure far before the building. In contrast, at the leeward side of the building there exists a low pressure that is induced by the high velocity flow at the sides and roof of the building. From the latter it can be concluded that there are few advantages of rounding the building at the sides as this can cause lower separating velocities at the sides that cause the pressure difference across the building to become less. So the basic design of this concentrator can look like a flat plate with a duct through the building and can be described as a flat plate concentrator (Figure

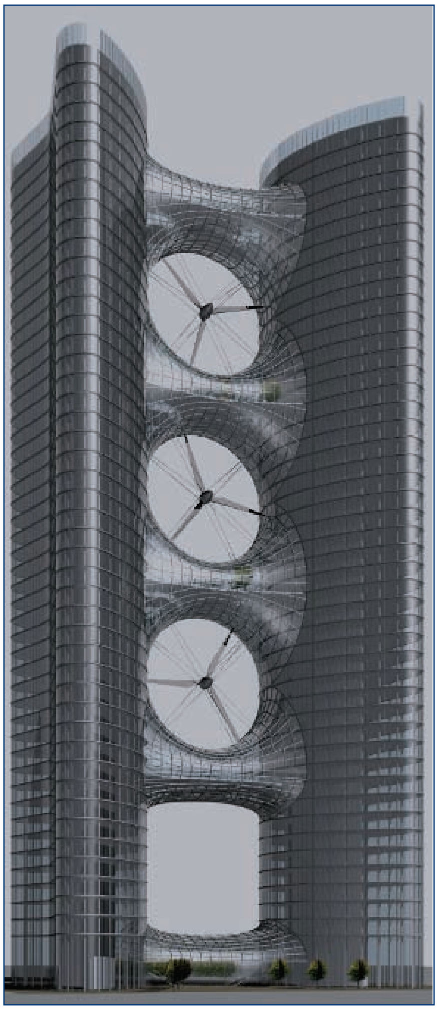

Figure 3: The short diffuser configuration

Figure 4: Flat plate concentrator

4) [4]. For flow at angles not perpendicular to the front, rounding the edges has some advantages for the inlet flow. In this case the flow will be more "smoothly guided" to the entrance of the turbine.

The existence of the pressure difference between windward and leeward side is not very sensitive to changes in wind direction and as a result the aerodynamic efficiency of the rotor is not sensitive to changes in wind direction. The wind turbine has to operate in two opposite flow directions. Suitable configurations are therefore: a Darrieus turbine; a Wells turbine, or a HAWT with the possibility of 180 degrees pitch of the blades.

- A Darrieus will have the disadvantage that it extracts energy at the windward and leeward side of the rotor axes in the region of the lower velocity in the duct. So the Darrieus will not take advantage of the higher wind speeds in the duct.
- The Wells turbine can use the higher wind speeds at the outer part of the duct and research has to be carried out to verify the suitability of the Wells rotor. A disadvantage of the Wells turbine could be the potential noise problems.
- The HAWT does not have the disadvantage of the Wells but requires a 180 degrees pitch mechanism and a generator that is able to operate in two different directions.

Figure 5: The Turby, a H-Darrieus specially designed for roof applications

On top of or alongside a building

Wind turbines on the roof or alongside a building operate in the higher wind speed area close to the building. This wind speed will be about 20% higher than the undisturbed wind speed further away from the building [5],[6]. For a small wind turbine the entire stream tube where the energy extraction takes place can be located in the higher speed region.

For locating on the roof it has to be kept in mind that the flow separates at the leading roof edge and has an angle of about 45 degrees to the horizontal roof. For a Darrieus this effect will be less important. For common tip speeds the blades will experience an almost horizontal flow. On a HAWT the tilt will have a larger influence. The airfoils will stall, the aerodynamic efficiency will decrease and the rotor load will be non-uniform. So the Darrieus seems preferable for locating on the roof. Considerations about the flow at the roof led to the design of Turby (designed by TU Delft), a Darrieus type wind turbine with twisted axes (Figure 5). Due to the separation at the leading roof edge the location on the roof has to be chosen well. A wind turbine close to one edge of the roof will suffer from turbulence from wind coming from the other roof edge.

Conclusion

Wind turbines for the built environment that exploit higher wind speeds around buildings have to be designed for different types of flow and low noise emission. Low noise emission is coupled to a lower tip speed of the airfoils, which brings about a more viscous flow and therefore a higher drag at the blades. A low tip speed together with small airfoil dimensions can be very demanding and the airfoil design has to be considered carefully. Considering the necessary modifications of the building to encourage good flow properties for the wind turbine the most attractive option is to place the turbines on top of or alongside a building. In this case no modifications of the building are needed and the aerodynamic efficiency is very high. As a second option locating "in a duct through a building" is promising. The aerodynamic efficiency is also very high but the building will generally need several adaptations. The flat plate concentrator type is the basic design of this concentrator. The locating "between diffuser shaped buildings" option is not very promising. The aerodynamic efficiency is low and the drastic adaptations of the building to reshape it into an aerodynamic body are large.

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