Feasibility of roof mounted turbines being applied to football stadiums

AGENDA

Planning

- **Has there been any planning issues or restrictions with your roof mounted turbines currently on existing Quiet Revolution and Proven turbines current and previous projects?**

- **Will a roof mounted application for a stadium roof have to go through planning permission? If so, do you foresee the planning process to be quick for this type of project as oppose to other wind energy district power projects? Is it likely to be permitted?**

Technical

Key issues:

Wind yield – to identify the most suitable configuration of turbines which can interact with the most optimum wind speed at a specific location, to achieve the most optimum wind yield from that specific roof mounted turbine. Avoiding the vulnerability of vibration occurring, and minimising the effects of turbulence and wind shear occurring.

The specific shape of the roof design curved from the outer edge of the stadium roof's bowl to create topography with an incline for the wind flow to enhance its speed (due to the upward curve acting as a wind angular enhancer) and create a more constant attached linear wind flow across the roof (in the form of the coanda effect), - this is the architectural innovation, which could already be existing with an existing stadium roof or can be specifically improved if the stadium roof is designed specifically to create the wind speed up effect and more constant attached wind flow from the start of a new stadium build project.

Aerodynamics - Can an aero-elastic roof potentially create a greater wind yield through a more constant attached wind flow and creating a more speed up effect of the windward flow more so than a normal flat roof, due to the elasticity and the inclined shape of an aero-elastic roof's curved outer edge. Responding positively to wind excitation by moving in unison with the direction of the windward flow moving across the roof by harnessing a more linear wind flow?

Structural engineering - Identify the indicative structural loading parameters of a stadium roof and how the weight of the turbines can comply within these parameters when applied to a roof as a retrofit or as a part of a new build stadium.

Can any of the two types of turbines be susceptible to over-speed and become dangerously unstable under excessively windy conditions? How would you combat this?

Recommendation of the proposed roof mounted configuration

This configuration now proposes: 2 (no. of rows) x 14 (no. of turbines in each row) of 6kW HAWTS on the West side and the same again on the East side, and 1 row x 15 (no. of turbines in one row) of 6 kW VAWTS on the North and South side, which is a total number of 86 turbines in total mounted on the stadium roof.

It can be suggested that this type of turbine can be proposed for the application on the outer edge of the North and South side of the stadium roof.

If both the North and South sides of the roof are 150 linear metres approximately, and each Quiet revolution VAWT turbine needs 3 rotor distances apart (each rotor is 3.1 metres) i.e. approximately 10 metres apart from the centre of each turbine. The hypothetical configuration will be 15 VAWTs approximately positioned in a line near the outer edge of the roof (3-6 metres into the roof surface from the outer edge to avoid the strong vortex and be within the boundary layer of the separation bubble.

In relation to the HAWTs being proposed to be positioned in the centre of the roof of the West and East sides of the stadium's roof, the choice of positioning them in the middle of the roof above the separation bubble is to be able to have enough space over the roof to take full advantage of the 'Coanda effect', which needs enough surface to reattach the flow after the short separation bubble at the outer roof edge.

Proposed roof mounted (retrofit to existing or new build stadiums) – for 86 x 6 kW turbines:

56x6 HAWT turbines @ ((45% (Is the co-efficiency for the turbine free standing from the ground, as quoted by Proven) x 1.2 (due to speed up effect, i.e. 20% increase in co-efficiency than normal flat roof due to innovative application to create laminar flow on long span roof) =54% load factor - ***DOES PROVEN AGREE WITH THIS POTENTIAL INCREASE IN EFFICIENCY ASSUMPTION ?****)) and (100-0.04=99.06% (4 hours of down time per year) utilisation provides load factor @ 99.06% = 336 x 0.54 x 0.9906 x 8760 = 1574 mw hrs*

30x6 kW VAWT turbines @ 42% load factor and assume same as above 99.06% utilisation provides 180 x0.42x0.9906 x 8760 = 656,031 / 1000 = 656 mw hrs.

Total: 1,574 + 656 = 2,230 mw hrs.

Issue of additional structural weight if applied as a retrofit

6kW Proven HAWT needs to be 3 rotors apart (each rotor 5 metre diameter) i.e. 15 metres apart within a 200 metre linear space on the West and East side of the stadium roof. Then 2 rows of 14 HAWTs can approximately can be positioned in the middle of the roof on both the West and East side of the stadium roof, with 1 row of 15 Quiet revolution VAWTs closer to the outer edge on a 6 metre mast 3 – 6 metres in from the outer edge on the North and South side of the stadium roof.

If this scenario is proposed, then the weight will be 755kg (rotor: 450kg, mast: 305kg) for the VAWT and 500 kg for the Proven 6kW HAWT.

If 1% of the existing structural loading for a typical stadium is 1.5 tonnes in 21 linear metres, advised by Mike Otlet at Atkins, Special Structures group, in Oxford.

The proposed Proven arrangement = 2.72 tonnes

2 x 500kg within a 15 linear metre length + an additional 357kg (calculated as 15 linear length / 21 linear length = 0.71 x 500kg =357kg) to be accounted for within the 21 linear metre length. Therefore the static loading is just under 1% of additional loading for 1 row of Proven 6KW, being 1.36 compared to 1.5 tonnes needed within 21 linear metres. If an additional row is accounted for then this would be approximately 2% at 1.36 x 2 = 2.72 tonnes, as 1.5 x 2 = 3 tonnes at 2%.

This is well within the threshold of maximum excess loading limits of 3% of the existing structural loading allowed, before it is deemed to be not structurally feasible by causing sufficient affect to stress loading on existing structural support. This is 4.5 tonnes (equating to 3%) within a linear space of 21 metres on a typical stadium at 90% stressed load capacity for existing structural framing, as advised by Mike Otlet at Atkins, Special Structures group, in Oxford. Foreseeing, that the 2.72 tonnes is just over half the maximum excess loading of 4.5 tonnes a typical 90% stressed load capacity stadium roof could retrofit, which should suggest that the existing structural framing and foundations should not be at its limit and in danger of over loading the ***static loading****.*

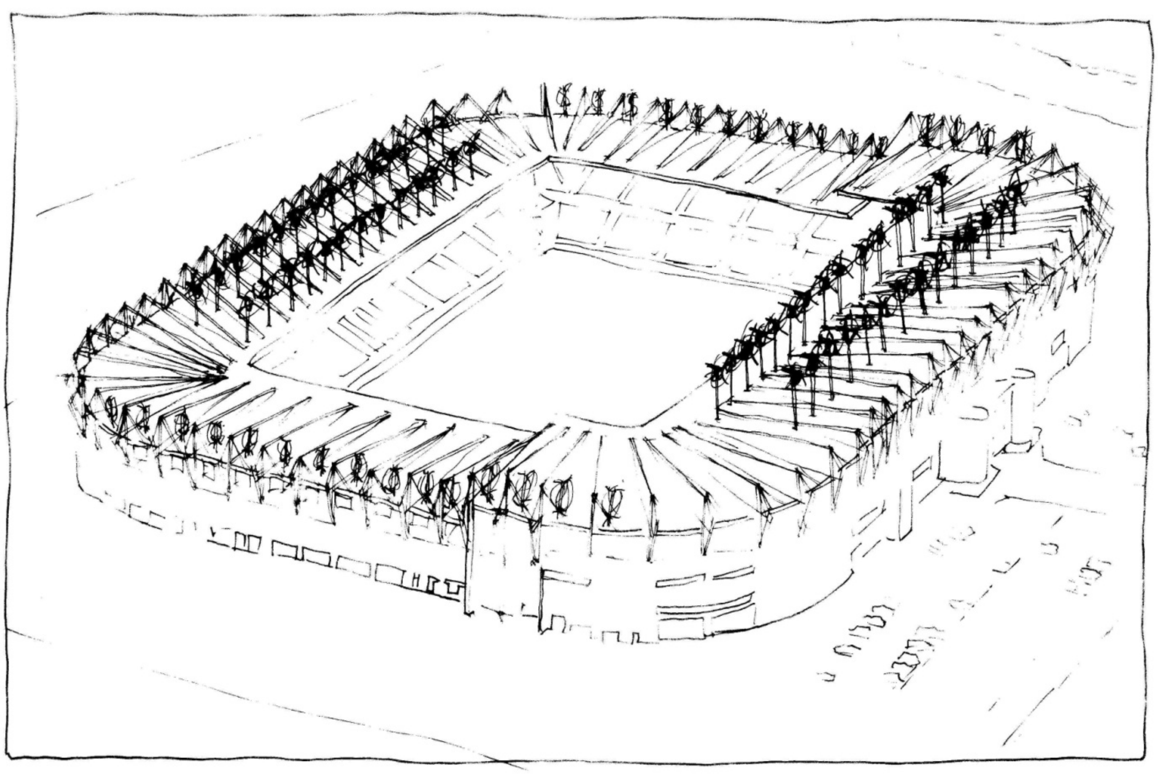
However the issue of ***dynamic and snow loading*** *on the roof will also be a factor.*

So if the dynamic and snow loading upon a typical stadium proves to be typically match that of static structural weight, then the additional weight would be deemed to exceed the structural parameters in this case.

Therefore, a Cantilever structural system which is less conducive to dynamic loading unlike that of a cable and mast structure, would be deemed as a more appropriate option, and one row rather than two rows of the Proven 6KW would be recommended to reduce the static loading.

Quiet Revolution

Likewise for the VAWTs at 755kg, the configuration will have 3 x 755 = 2.27 tonnes (due to having each one 10 metres apart), that is 3 within a length of 21 linear metres.



Rationale behind the proposed configuration

Wind velocity as a major factor to increase wind yield

The boundary layers and wind velocity in the vicinity of two different types of roof mounted turbine arrays.

Sander Mertens' analysis of velocity profiles above a roof shows the non-dimensionalised velocity profile above the middle of a flat roof. Findings are similar to that above the separating streamline calculated with free streamline theory, there exists up to 30% higher total velocities, compared to the undisturbed velocity at building height. Higher above the roof this speed up effect becomes bigger.

Proposed type of roughness and type of separation bubble for stadium roof.

Larger roughness will indicate a more consistent speed of flow due to the velocity being parallel with the horizontal roof, thus creating a 0= skew angle. (Mertens, S. 2002)

Which is apt for a small HAWT, roof mounted turbine to perform well in these conditions, as the conditions are more likely to be more undisturbed due to a smaller separation bubble.

Wind energy density on long span roofs

The centre location has the largest energy density for both large and small roughness.

However of equal importance is the value of the skew angle of the wind velocity vector at the corner and edge, which is large compared with the skew angle at the centre location, because of the up-flow at the sides of the building. The corner position is also susceptible to high vortices which will inevitably create turbulence for the rotors of a HAWT in the windswept area. (Mertens, S. 2002)

How complex flow phenomenon and energy density are the key drivers to increasing co-efficiency of roof mounted turbines.

For this reason, and because of the high energy density, the centre location is certainly preferred for operation of a HAWT; moreover, because the large wind speed region at the corner and edge location has a small height (1 metre is only needed to clear the separation bubble), suggesting that there is only room for a small wind turbine.

In contrast to the HAWT, the VAWT shows an increased power output for higher skew angles. For the VAWT, the outer edge position can thus give high energy yields. However, the vertical height of the larger wind speed region is small at the corners and edges of the roof, due to a turbine only needing to be raised sufficiently above the separation bubble (which is 1 metre) to avoid disturbed wind flow, thus reducing the chance of gaining a higher overall wind-speed in metres per second because of the lower height from the roof line to above the separation bubble at the edge and corner positions in comparison to the higher height from the roof line to above the separation bubble in the centre of the roof. Which the HAWT turbine has a better chance in achieving, due to it being mounted at a much higher level in the centre of the roof above the separation bubble to achieve undisturbed wind-flow.

Conclusions made from reviewing the functional performance and Sander Mertens' case studies

Mertens' case studies showed that the wind conditions at the majority of locations on the roof are very different from the undisturbed wind conditions.

Compared with a HAWT, a VAWT can give a larger energy yield on buildings set in small upwind roughness. This is caused by increased skewed flow wind speed across the roof, which the VAWT will yield due to its tri-dimensional design being able to yield wind from opni-directions. The wind vector at most roofs is not horizontal, but is skewed with an angle to the horizontal roof that varies across the roof. The roof wind turbine has to be suitable for operation in the disturbed wind flow (this is within the separation bubble at a height lower than 5 metres at the centre or lower than 1 metre at the corner and edges. Because of the large power output and energy yield in skewed flow as a result of disturbed wind flow across the roof evidently proven from Sander Mertens' roof top studies, the VAWT seems to be more suitable on roofs at 1 -2 metre height near the outer edge of the roof as compared to the HAWT at the outer edge. The HAWT would be better placed above the 5 metre height of the small separation bubble in the centre of the roof.

However, the wind flow across a flat wide span roof like a stadium's gives a more undisturbed flow, therefore whether the positioning of the turbine is at a level within the separation bubble lower than a height of 5 metres or above the separation bubble, the wind speed will be relatively undisturbed due to laminar flow – i.e. a boundary layer of protective wind flow which doesn't separate when flowing across the flat roof. However, it is still advisable to raise the turbine as high as it can to gain a higher wind speed which is attained at increasing heights within the wind environment.

Whatsmore, it is believed that the average wind speed at the roof due to the laminar flow can create a speed up effect, thus create a higher wind speed than low or high pitched roofs, and has a higher wind speed compared to a relatively low undisturbed wind speed at the same height above the ground in the open surroundings at a specific site. This is substantiated by the wind flow becoming attached to the flat roof using the 'Coanda effect', as oppose to a freestanding yaw becoming susceptible to turbulence and wind shear due to a higher degree of disturbed wind flow coming from different directions and at different speeds, rather than being channelled more effectively across a flat roof.

Nevertheless wind velocities above the roof are still small compared with conventional wind turbines on towers in open surroundings, due to higher windswept area from larger rotors. Therefore, wind velocity is not the main determining key driver in choosing the turbine arrangement, but more the consistency and efficiency of turbine performance relating to increased or sustained load capacity generated by the turbines in kWh per year. So for roof turbines, high buildings are necessary to compensate the small wind speed in the built environment and produce an acceptable energy yield.

The roof mounted turbines being applied to a new build stadium could be an example of both systems and architectural innovation, as they can be integrated more into the design and build of the roof from the design inception. This is more applicable to a PPC 200 form of contract.

Whereas, if the project was retrofit the roof mounted turbines to an existing stadium, architectural innovation will only occur as the turbines are going to be applied to an existing building. This would suggest that a design and build (a less complex route) can be taken.

It is also assumed that if a new build stadium project is used, it could possibly induce higher power from the available wind at a given site due to a higher probability of increasing co-efficiency of wind yield. This can be achieved more so from a new build stadium, as the roof can be designed in such a way from the start of the stadium roof's design to harness the speed up effect of laminar wind flow by creating a more aerodynamic outer edge in the form of a sloped curvature circumference for the outer edge. This would create a speed up effect which in turn will increase the amount of wind yield obtained by enhancing the angular windward flow which impacting the sloped outer edge of roof as the predominant linear flow flows across the stadium roof. The attached flow becomes more constant and consistent in capturing the wind yield by using the principle of the 'Coanda effect' in this way.

- **Please could you offer your views on how you would change the configuration to best suit the most optimum layout for the two types of turbine array, to achieve most optimum wind yield?**