Bahrain World Trade Centre: Harnessing Wind Energy – a post-occupancy evaluation

Ian Milne, Senior Design Director, Atkins
Bahrain World Trade Centre

- 50 story 240m twin towers.
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- **Worlds first large scale wind turbines on a tall building**
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- Designed by multi-disciplinary Atkins team
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Sail reference
Bahrain, like the other nations of the Persian Gulf has a history closely linked with sea and maritime trade.
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Onshore sea breeze
Bahrain and Saudi Arabian land masses heats up during the early hours of the morning, creating uplift and cool sea breeze replaces it resulting in a consistent onshore sea breeze.

Bahrain Wind Rose
The Sea breeze effect creates a consistent North Westerly onshore breeze.
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Wind turbines
The two 50 storey sail shaped office towers taper to a height of 240m and support three 29m diameter horizontal-axis wind turbines.

Funneling effect of towers
The elliptical plan forms act as aerofoils, funneling the onshore breeze between them as well as creating a negative pressure behind, thus accelerating the wind velocity between the two towers.
CFD analysis of air flow

These diagrams show the air flow around the tower when the wind originates from 315°, 345°, 360° and 15° from north.

Conclusion

This CFD and later wind tunnel testing confirmed how the shapes the towers sculpt the airflow, creating an “S” flow whereby the center of the wind stream remains nearly perpendicular to the turbine within a 45° wind azimuth, either side of the central axis. This increases the turbines’ potential to generate power whilst also reducing fatigue on the blades to acceptable limits during wind skew across the blades.
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Wind Dynamics

Vertically, the tapering of the towers reduces the funnelling effect at higher levels. At the same time the wind increases in velocity with height.

This, creates a near equal wind regime on each of the three turbines.

This is a key factors that has allowed the practical integration of wind turbines in a commercial building design cost effective.

It resulted in:-
- Reduction in R&D
- Simplified risk analysis.
- Each turbine produces similar energy
- Turbines rotate at the same speed
Lessons learnt

The wind climate in the Arabian Gulf with its dominant sea breeze characteristic is conducive to harnessing wind energy and allows designers to move away from omni-directional solutions and consider uni-directional wind turbine options that in many respects, lend themselves to the large scale integration in buildings.
Lessons learnt

Research by Atkins has shown that the large scale integration of turbines into buildings mostly fails because of the excessive cost (up to 30% of the project value) associated with the adaptation of the turbines to the building’s design, and also as a result of high research and development costs for special turbines.
Lessons learnt

From the outset this project had as its primary basis of design the utilization of conventional technologies and the development of a built form that would be sympathetic to receiving wind turbines. As a result the premium on this project for including the wind turbines was less than 3% of project value.
Wind turbines

The turbines are able to operate for wind directions between 270° and 360°, however, caution has been applied and turbine predictions and initial operating regimes are based on a more limited range of between 285° and 345°.

At all wind directions outside of this range the turbine will automatically adopt a "standstill" mode.
Wind turbines

Nacelles have been designed to sit on top of the bridge, rather than within it, to portray the functionality of the turbine. The turbine is a simple and robust “stall controlled” type. The stall control is a passive way of limiting power from the turbine. The rotor blades are bolted onto the hub at a fixed angle and the profile has been designed to ensure that the moment the wind speed becomes too high. It creates turbulence on the leeward side of the rotor blade and prevents lift, stalling the blade so that the power output stabilizes at a maximum output.
Wind turbines

The full power of about 225kW will be achieved at 15 to 20m/s (Fig. 4.) depending on air density. In the event of extremely high wind speeds under operating or standstill modes, the tip of the blade extends (Fig. 5.) by centrifugal force and rotates to act as a self regulating governor brake, through the exertion of a drag force.
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Bridges

The bridges are ovoid in section for aerodynamic purposes and are relatively complex structures because they incorporate maintenance free bearings where they connect to the buildings to allow the towers to move 0.5m relative to each other.

In addition, the bridges that span 31.7m and support a nacelle with a mass of 11 tonnes have been designed to withstand and absorb wind induced vibration and vibrations induced by both an operating and “standstill” turbine.

Analysis by the designer has been undertaken to estimate the natural frequency of the bridge and to ensure it does not conflict with the frequency of exciting vibrations of itself or the building.

Further precautions were included in the design to allow the bridge to be damped, if in practice vibrations are found to be problematic during commissioning. These precautions include the facility in the design to add spoilers to the bridge and to adjust the tuned mass damper.
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**Issues addressed by validation team**

- Remote sensor viability
- Power outage impact
- Electricity board acceptance
- Cooling system availability
- Maintenance viability
- Rain water thrown off blades
- Exciting vibrations
- Bridge resonant frequency
- Construction tolerance
- Bridge resonant frequency
- Bridge vortex shedding
- Source / sink coincidence
- BMS reliability
- Lightening strike
- Blade loss

- Tip break off
- Blade penetration
- Blade / bridge strike
- Blade fall
- Climate Sand ingress
- Bird strike
- Operation outside of azimuth range
- Availability
- Reliability and maintainability
- Operability and durability
- Performance of proposed turbine
- Operating and control strategy
- Unusual flow and fatigue life
- Dirt build up on blades
- Galloping vibration at standstill
- Maximum twisting moment for a blade
- Noise emitted from blades / generator
- Shadow flicker
- Reflection of blades through windows
- Electromagnetic interferance
- Electrical flicker
- Electrical harmonics
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Energy Yield

Turbine # 1  400 MWh/year
Turbine # 2  430 MWh/year
Turbine # 3  470 MWh/year

Total  1,300 MWh/year

Fuel Type  Equivalent Carbon Emission

UK basis  55,000 kgC p.a.

Energy generated:

15% of electricity used by the towers
Final lesson

It should be appreciated that this was a fast track design and construction programme. The integration of large scale wind turbines was only achieved by adapting the building form to fit current turbine technology, rather than expecting to develop turbines to fit the building's design.
Other sustainable measures

Aside from the wind turbines a number of other design features that are of interest and reduce carbon emissions when compared to other buildings in the Middle East..

- Buffer spaces between the external environment and air conditioned spaces
- Deep gravel roofs in some locations that provide kinetic insulation;
- Significant proportion of projectile shading to external glass facades;
- Balconies to the sloping elevations with overhangs to provide shading;
- Glass is used with low shading co-efficient to minimise solar gains;
- Low leakage, openable windows to allow mixed mode operation in winter months;
- Enhanced thermal insulation for opaque fabric elements;
- Dense concrete core and floor slabs presented to the internal environment
- Variable volume chilled water pumping that will operate with significantly less pump power;
- Low pressure loss distribution for primary air and water transport systems.
- Total heat energy recovery heat wheels of fresh air intake and exhausts.
- Energy efficient, high efficacy, high frequency fluorescent lighting with zonal control.
- Dual drainage systems that allows grey water recycling to be added at a later date;
- Connection to the district cooling system.
- Dual flush WC and electronic taps with excess water flow restrictors.