Sustainability

Assessing wind turbines in Korean skyscrapers with Cradle CFD

By Jonas Wirgart, PMM Cradle CFD

The world's tallest artificial structure is the 829.8-metre-tall (2,722 ft) Burj Khalifa in Dubai in the United Arab Emirates and like most such buildings it exists in densely populated urban areas. This has an impact in terms of wind patterns produced around the building and its environmental impact locally. However, such tall buildings also pose an opportunity for planners and designers to potentially rethink designs to take into account sustainability concerns with respect to generating renewable energy in an urban cityscape. Researchers led by the Korea Institute of Energy Research and CEDIC Ltd (ref 1) have done some fascinating fundamental research using computational fluid dynamics (CFD) tools from Cradle CFD on the plausibility of Building-Integrated Wind Turbines (BIWT) in such massive skyscrapers to produce electricity locally and therefore lower carbon footprints. Renewable energy is a very visible symbol of sustainable and eco-friendly energy generation and if it can be integrated into buildings and used at source and is feasible at the design stage, it would be a major sustainability innovation for the future.

The authors (ref 1) first studied the Bahrain World Trade Center which was completed in 2008 and is regarded as the first modern BIWT. It has a 240 m-high, 50-story twin tower complex – a structure with symmetrical triangular-shaped twin buildings whose shape and layout are designed to make use of wind energy beyond the mere integration of a wind turbine in the building (see Figure 1). It is regarded as a Building-Augmented Wind Turbine (BAWT), which is a more aggressive concept than BIWT. As shown in the building photo and on analysis result with Cradle CFD, 3-blade horizontal-axis wind turbines with diameter of 29 m and capacity of 225 kW are installed at the bridges connecting the triangular twin towers, which are symmetrical with an interior angle of about 120°. Since the Bahrain World Trade Center is located near the coast of Arabia, a classical 'venturi' effect occurs in the center of the buildings wherein winds accelerate through the throat made by the twin towers when the sea breeze blows at the building – it was designed to increase the efficiency of wind power generation through this well-known phenomena. The electricity generation per year from the three turbines accounts for 13% of the energy consumption of the building; a capacity factor of approximately 22%.

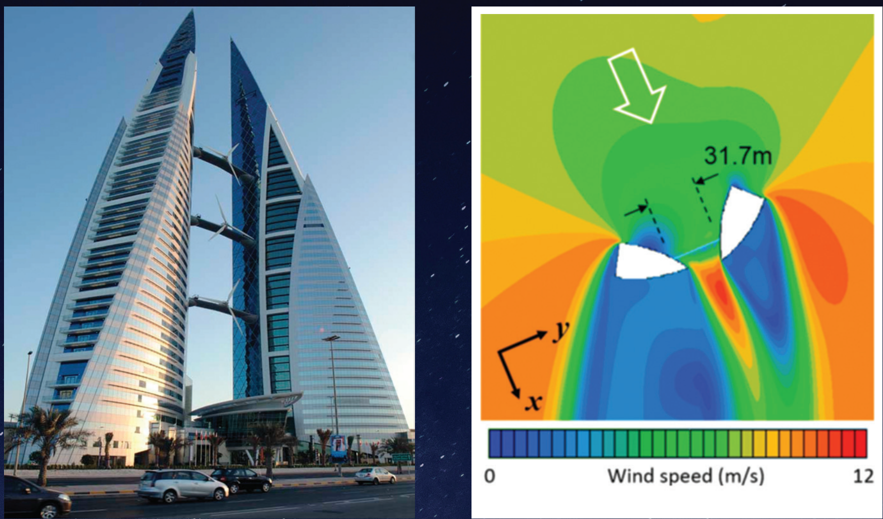

Figure 1. The Bahrain World Trade Center flow analysis: (a) photo from the front of the wind turbines; and (b) contour plot of wind speed on a horizontal cross-sectional plane at 100 m aboveground (CFD from authors)

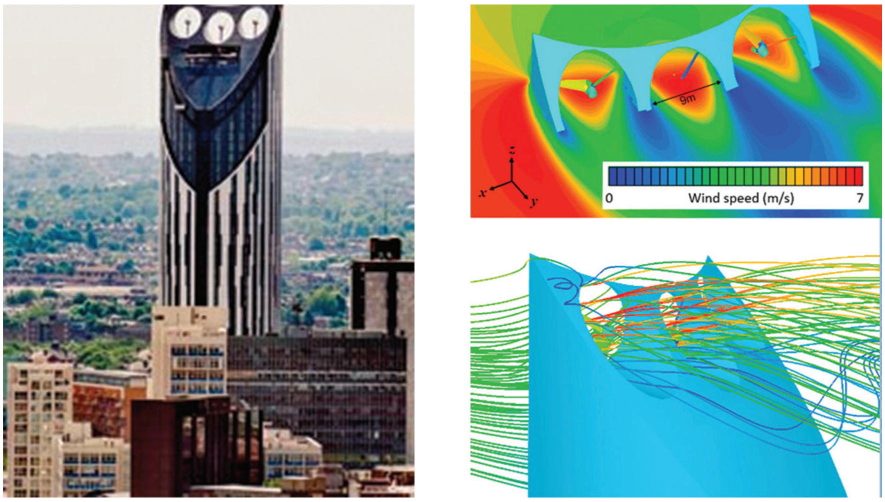

Figure 2. The Strata SE1 Apartment flow analysis: (a) photo from the rear of the wind turbines; and (b) contour plot of wind speed on a horizontal cross-sectional plane (top) and streamlines passing through holes (bottom; CFD by the authors).

Another fluid flow analysis using Cradle CFD of the Strata SE1 building in London, England, and built in 2011, which is a 148 m-high, 43-story residential building with three rooftop horizontal-axis wind turbines of 19 kW capacity integrated into the building was also carried out (Figure 2). The building is iconic looking and has been awarded several architectural design prizes. However, the press British were not impressed with it claiming that the wind turbines rarely rotated and although citizens believe the wind turbine should work continuously, the wind speeds are generally low in London and it has not been as much of a success as expected because of the terrain in which it was situated.

The team's main CFD study was based around a new high-rise building constructed in Seoul as the eighth tallest freestanding structure in the world, the Lotte World Tower. Seoul is one of the largest metropolitan cities in Korea, has a population of 10 million but has an inland location as well as weakened winds compared to Korean cities on the coast. The researchers therefore needed wind resource assessments to evaluate the potential performance of this 555 m high-rise BIWT in the center of the city. At such a height it is very complicated to perform in-situ measurements. Hence, ground-based remote sensors such as LIDAR and SODAR needed to be employed to perform wind resource assessment. Furthermore, a numerical weather prediction (NWP) model and measure-correlate-predict (MCP) method needed to be devised to extend short-term data measured via remote sensing to yield multi-year wind data. A three-dimensional geographical information system (GIS) database and Cradle CFD were then employed to predict the effect of the building on the prevailing winds and the feasibility of BWITs. The team's workflow is shown in Figure 3 and complete details can be found in the original paper of what they did (Ref 1).

The remote sensing campaign in this study lasted for two months due to various constraints. The second step they took was to create a wind resource map to show the spatial variability of the wind resource at the installation area on the tower to determine the turbines' layout. For wind resource mapping, wind flow fields at the target area by wind direction were simulated using CFD first. In this instance, a total of 16 wind directions were simulated. The third step was to select a type of wind turbine and to determine an optimum layout. Although energy production can be maximized if a wind turbine is installed at the highest wind power density location, wake losses also needed to be taken into account. The wind flow field around the Lotte World Tower distorts flow in the region once the building is completed. The wind flow field was simulated using the Reynolds-Averaged Navier-Stokes (RANS) CFD software SC/Tetra v12 from Cradle CFD. It is a flow solver based on finite volume method and employs the SIMPLEC algorithm for pressure-velocity coupling and the 2nd-order QUICK upwind scheme for convection terms. A 90 million unstructured hybrid mesh for the computational domain was created to cover a 6 km × 6 km × 2.5 km domain around the Lotte World Tower. For validation, the main wind direction (WNW) with/without the Lotte World Tower was simulated. The CFD analysis employed the modified production k–ε turbulence model, which predicts flow separation in the cubic block structures as urban streets.

Figure 4 shows the comparison of simulation results of the main wind direction case, revealing horizontal wind speed variability at the pedestrian level and vertical cross-sectional wind speed variability along the main wind direction (WNW) before and after the construction of the Lotte World Tower. The CFD analysis results considering only the Lotte World Tower and including all surrounding buildings show that the rooftop of the Tower is impacted by surrounding building groups to a low degree (less than 3% of wind speed), although the pedestrian level wind speeds are largely augmented by the Lotte World Hotel (about 75% of area; left contour plots in Figure 4). This can also be seen in the wind speed variability at the right vertical cross-sectional plots in Figure 4. The computational load in the simulation can be significantly reduced by excluding the surrounding buildings. The team were able to create

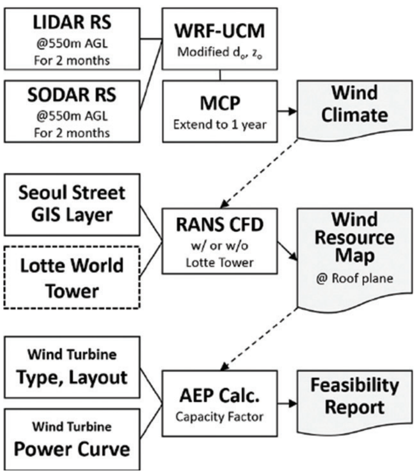

Figure 3: Procedure for wind resource assessment for a high-rise BIWT by using RS–NWP–CFD.

individual wind maps for a total of 16 wind directional sectors using CFD and then weighted the predictions using the wind climate data. Good agreement between the CFD results and the LIDAR measurements were achieved. However, when the study was carried out with various configurations of turbines on the roof of the Tower, the CFD predictions did not show very good electricity generation abilities. Even with assessments involving changes in the building shape, the best the study could predict was a capacity factor of only 7%, thus the BIWTs were not considered economically feasible. The tower was built without integrated wind turbines.

The researchers' findings meant that BIWTs were not considered at the Lotte World Tower. However, they established a powerful procedure for wind resource assessment for high-rise BIWTs by combining RS, NWP, and Cradle CFD. They showed that the data recovery rate of ground-based remote sensing decreased dramatically, and it is very important to perform a reconstruction of full wind climate data for at least one year using long-term correction via NWP and MCP methods. Moreover, they anticipated the need to perform longer remote-sensing measurements to mitigate uncertainties caused by seasonal variation of wind climate. Their study showed that wind conditions can change considerably depending on the building shape, and CFD simulation is therefore needed to analyze the effect of building shape accurately. Modifying the building shape did show predictions of up to 30% improvements in the power density and large changes in spatial variability around the tower. The bottomline, however, was that they discovered that the wind resource around the Lotte World Tower in Seoul is very poor despite its high altitude (555 m) because it is located well inland on the Korean Peninsula. However, it should be noted that they discovered that the surrounding buildings of the Lotte World Tower did not directly influence the wind speed at 555 m according to the CFD simulation.

Reference

Hyun-Goo Kim, Wan-Ho Jeon and Dong-Hyeok Kim, "Wind Resource Assessment for High-Rise BIWT Using RS-NWP-CFD" Remote Sensing Magazine, Vol 8, 1019, 2016

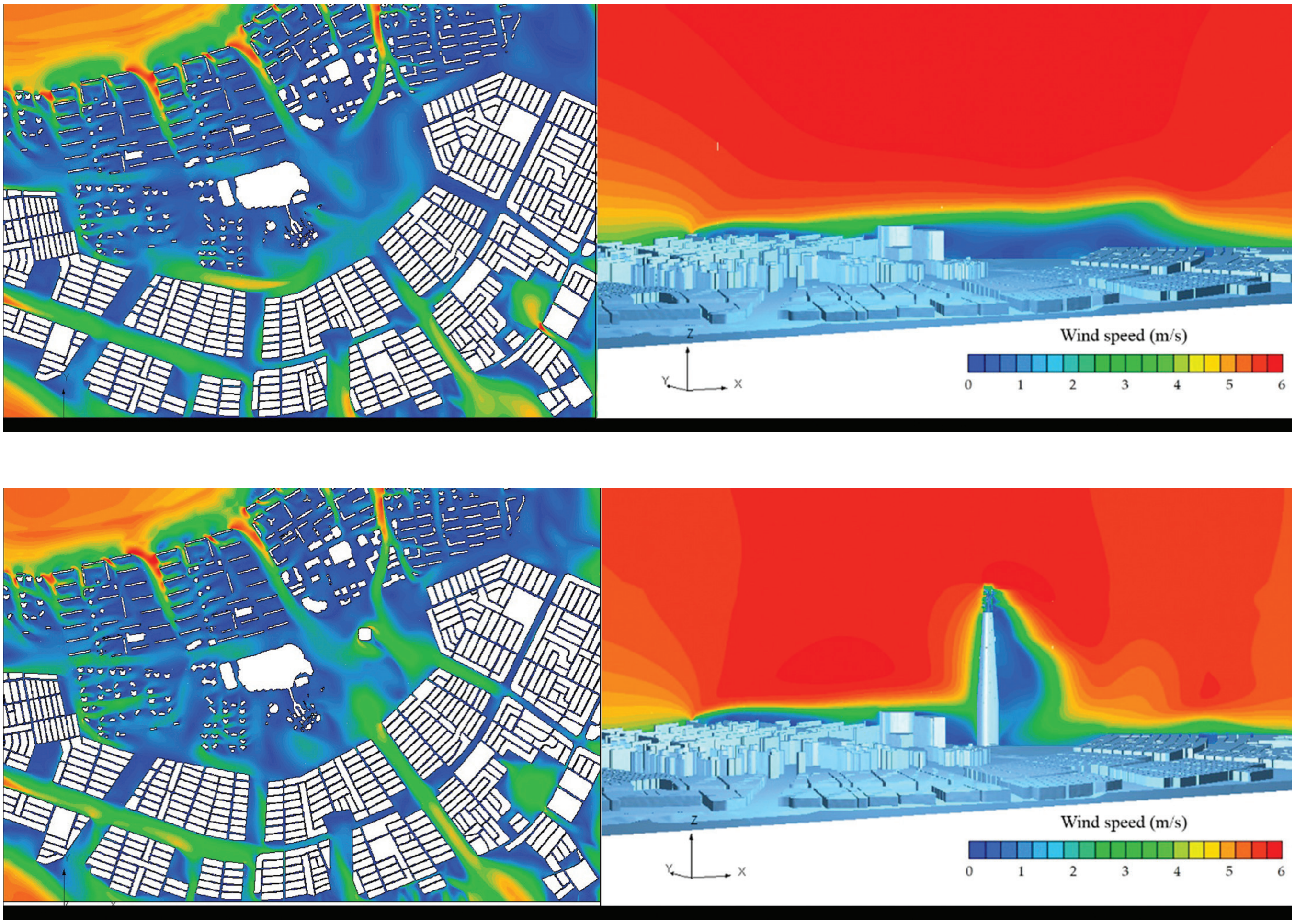

Figure 4. Computation results of pedestrian-level wind speed around the Lotte World Tower: horizontal (left column); and vertical (right column) cross-sectional wind speed variability: (a) without the Tower; and (b) with the Tower.

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