HIGH-RISE WIND TURBINES

By Jens Bennetsen, Project Director, Ramboll Denmark A/S
Copenhagen, Denmark

Photo: Courtesy Yui Law/BFLS.

Photo: Courtesy James Brittain.

The Strata SE1 rises high over London. Positioning of the wind turbines on this unique structure was accomplished with ANSYS fluid dynamics.

Simulation helps to improve the design of the world's first building with integrated wind turbines.

The Strata SE1 residential high-rise building in London pushes the boundaries of innovative construction and sustainable design: It is the first major building to incorporate wind turbines into its structure. Three five-bladed wind turbines at the top of the tower are rated at 19 kW each and produce 50 MWh of electricity per year, about 8 percent of the building's total energy consumption. Ramboll assisted with the wind turbine design, selected because of its experience with the Bahrain World Trade Center, which uses wind turbines mounted on bridges between the building's two towers.

Ramboll engineers used computational fluid dynamics (CFD) software from ANSYS to simulate the operation of the wind turbines under various wind conditions based on the original building design. They determined that a large recirculation zone at the mouth of the turbines would greatly limit the amount of energy that could be generated. The design was modified to improve energy output: The turbines were mounted in a more open structure and moved outward toward the edge of the building.

Ramboll is a leading engineering, design and consulting firm headquartered in Denmark with offices in 23 countries. The Bahrain project, which featured three free-standing wind turbines, was the first project for which the company integrated wind turbines into a building design. The trade center's free-standing design made it possible to achieve a high level of efficiency because the two buildings themselves could be used to create a venturi effect, which accelerates the wind in the area of the turbine. The Strata SE1 project, in which a wind turbine was integrated into the building fabric, was more challenging because there were many more design constraints.

Completed in summer 2010, the 43-story, wedge-shaped building is wrapped in a black-and-white checkerboard facing. It contains 408 apartments on floors two through 43 and retail stores on the ground floor. A sky lobby on the 39th floor features views of central London. That lobby is topped by four three-bedroom duplex penthouses, located just below the three wind turbines.

The building's designers originally considered wind turbines, photovoltaic cells, ground-source heat pumps and thermal heating as potential solutions to the mandated on-site renewable energy target set by the Greater London Authority. They selected wind power because, considering the height and shape of the building, turbines would deliver the greatest energy production. Wind turbines also produce a unique design statement by giving the building a striking profile.

The turbines are mounted in venturi-like tubes that serve to capture lower wind speeds and accelerate them to greater velocity to increase power output from the rotating blades. The tubes are fabricated from 6-mm-thick steel plate bolted to the surrounding steel supporting structure, which in turn is attached to the building's reinforced concrete structural frame. The steel structure was pre-assembled under simulated conditions in a trial run at the steel fabricator's plant before the actual assembly was carried out 148 feet above southeast London.

Each turbine is mounted on a 5 tonne (5.5 tons) inertia base, which is mounted on four anti-vibration dampers to minimize vibration and structure-borne noise. A mechanical brake prevents the blades from rotating at wind speeds and directions that have the potential to damage the turbines. The turbines are connected to a gearbox that converts the relatively slow rotation of the turbine blades into high-speed rotary motion to drive a generator. The generator's output passes through an inverter

When modeling the entire turbine system, ANSYS CFD and meshing tools provided a high level of accuracy while minimizing solution time by varying the density of the mesh in relation to local gradients.

As predicted by the simulation, the turbines run virtually nonstop in a wide range of wind conditions.

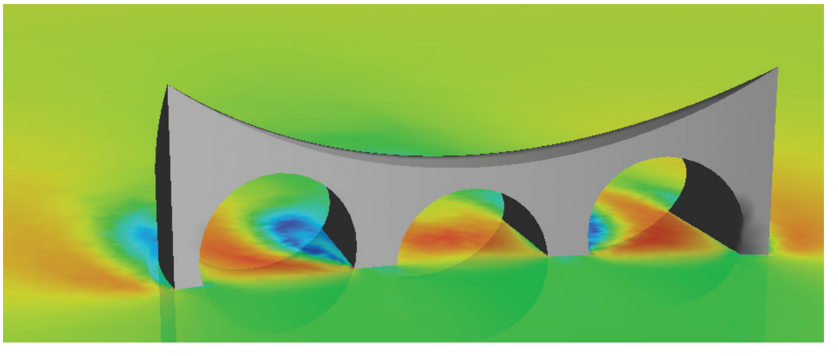
to convert it from direct current into alternating current before feeding it into the building's power supply.

ANSYS CFX and ANSYS ICEM CFD meshing technology are the standard tools used at the Ramboll organization. The primary advantage in this application was the software's ability to efficiently handle large differences in scale. The computational domain extended for several kilometers because the simulation had to incorporate the effects of nearby buildings; at the same time, the mesh needed to resolve fine details in the area of the turbine. When modeling this entire system, ANSYS CFD and meshing tools provided a high level of accuracy while minimizing solution time by varying the density of the mesh in relation to local gradients.

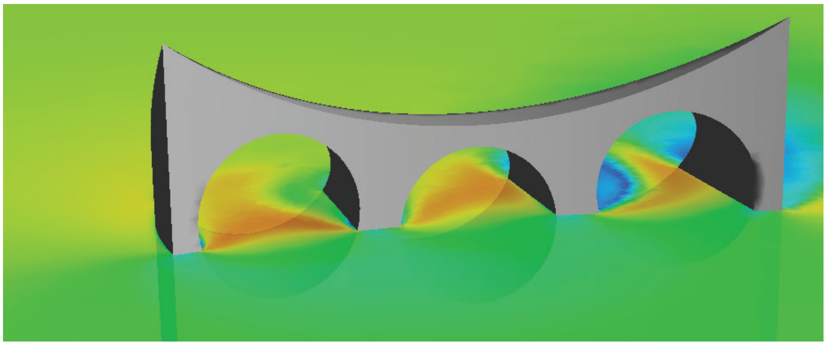
Ramboll began with a graphic information system (GIS) model of the urban area surrounding the new building. They added a CAD model of the initial concept design of the Strata SE1 building. The team created cubic structures representing other buildings to take into account obstructions that affect the airflow in the vicinity of the turbine. Then engineers applied ANSYS ICEM CFD to create a mesh of the open area surrounding the buildings. Engineers used a tetrahedral mesh for the entire domain, while prism elements were used to capture the boundary layers on both the building and turbine surfaces to improve accuracy in these critical regions. The model had approximately 9 million cells and converged in 45 hours utilizing 10 computational nodes on a high-performance computing cluster.

Ramboll engineers used CFD simulation to evaluate the performance of the initial design with different wind directions and speeds. The results identified a large recirculation zone in the entrance to each of the wind turbines that reduced velocity of the wind reaching the inlet. The zone also produced a considerable amount of turbulence that generated stresses on the blade. The team concluded that,

Air velocity with air flowing straight into original design. Low-speed areas shown in blue represent recirculation.



Air velocity with air flowing straight into revised design. There is less recirculation, and wind moves at higher speed through the opening; therefore, this design can extract more energy.



Air velocity with wind flowing at 30-degree angle (from left) into revised design. There is some recirculation in one tube; however, it is considerably less than in the original design.

Air velocity with air flowing at 30-degree angle (from right) into original design. Recirculation puts considerable strain on wind turbine at left.

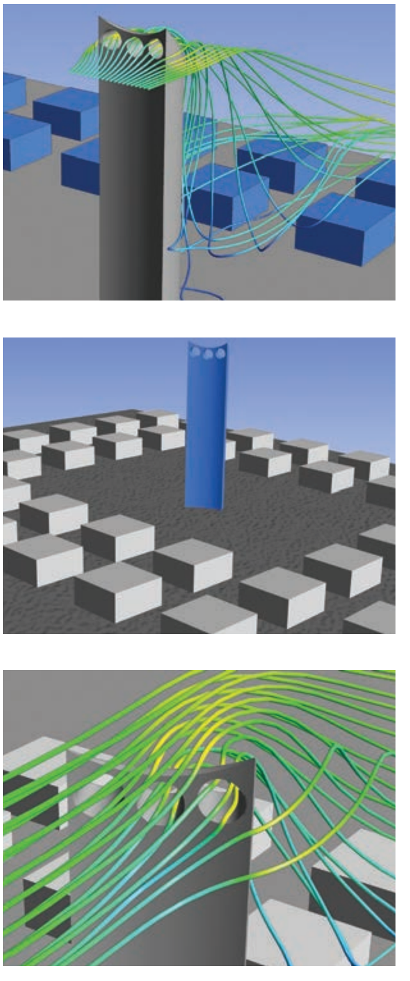
using this initial design, the wind turbine could be operated only under a limited range of conditions; these conditions were expected to occur over only a very small proportion of time.

The engineers modified the model to determine whether the performance of the wind turbines could be improved with design changes. They discovered substantial benefits by moving the wind turbines closer to the edge of the building and pointing them downward, at about 9 degrees, to take advantage of an air current that runs upward along the edge of the building. The team also determined that performance could be further improved with a more open design of the structure surrounding the turbines. After proposing these changes to the Strata SE1 architects, they changed the building design around the turbine to a more open tubular structure and moved the turbines nearly to the edge of the building. The proposal to tilt the turbines downward was not accepted, however, because the architects wanted to maintain straight lines for aesthetic reasons.

Ramboll engineers modeled this new design and discovered that it was considerably more efficient. The stress and wind load on the turbine blades were lower than in the original design. The recirculation zones seen in the initial design were nearly eliminated. The wind turbines could be efficiently operated almost continuously under various wind conditions.

Later, the building architects created a final design with some changes in the curvature of the building. Ramboll engineers modified the CFD model once again and verified that these changes had little impact on the operation of the wind turbines compared to the previous design. CFD analysis determined that the optimum operating range for the turbines is at wind speeds of between 8 meters to 16 meters per second from a southerly direction.

Engineering simulation played a major role in this project, making it possible to determine that the initial building design would provide less-than-desirable performance from a power-generation standpoint. The simulation results provided architects with various ideas for improvements that could then be evaluated from aesthetic and structural standpoints. The CFD-generated graphical output was easy to understand by architects and project managers who are not experts in wind turbine design. Instead of simply stating their conclusions, Ramboll engineers visually demonstrated how the various design alternatives impacted airflow in the area of the turbine under different wind conditions. As predicted by the simulation, the wind turbines run virtually nonstop in a wide range of wind conditions.



The team created blocks to represent other buildings so that airflow for the turbines could be determined as part of a system. ANSYS software's ability to efficiently handle large differences in scale was important, as the computational domain extended for several kilometers.