The Pearl River Tower, in Guangzhou, China, has been designed to be the most energy efficient of all the world’s supertall structures. Although the design team’s original goal of constructing a “net zero-energy” building that would sell its excess power to the local electrical grid is unlikely to be achieved, the structure is expected to consume nearly 60 percent less energy than a traditional building of similar size and could serve as a model for future “carbon-neutral” towers.

**By Roger E. Frechette III, P.E., LEED AP, and Russell Gilchrist**

The industrialization of the world has led to great innovation, great technological advances, and powerful national economies. It has also resulted in an incredible appetite for energy, most notably energy generated through the use of fossil fuels. This massive consumption of fossil fuels has sharply increased the levels of carbon dioxide (CO₂) in our atmosphere, resulting in a steady but rapid warming of the planet. The ramifications of this man-made environmental shift are not yet fully understood, but many scientists believe the results could be catastrophic.

Many factors have contributed to this crisis. But while...
The city of Guangzhou experiences some of the worst air pollution on the planet, the city and its province, Guangdong, are a major focus of this environmental initiative. The Pearl River Tower project, which features both active and passive approaches to limiting carbon emissions through new technologies as well as reduction strategies, could play an important role in developing a new model that will both provide higher living standards and achieve important environmental goals.

The structure of this wide but narrow tower is based on a composite system that utilizes both structural steel and reinforced-concrete elements to resist gravity and lateral loads. The primary lateral-load-resisting system features an interior reinforced-concrete core and a series of composite megacolumns that are linked by a large, multistory system of structural steel X braces on the narrow edge facades of the building. The perimeter columns are linked to the reinforced-concrete core walls and the corner megacolumns by a system of two-story outrigger and belt trusses at the major mechanical levels. Engaging the perimeter columns with the outrigger trusses increases the effective moment mechanism of the lateral system while the belt trusses work to equalize the loads in the perimeter columns. Structural steel moment frames also are provided on the broad faces of the building for additional resistance. Inherent redundancy and robustness are achieved with the addition of the belt trusses and perimeter moment frames.

The thicknesses of the core walls range from 700 to 1,500 mm over the height of the building. The megacolumns consist of large built-up structural steel I sections that are up to 900 mm deep by 700 mm wide; these I sections feature 100 mm thick plates surrounded by reinforced-concrete encasements that are 3,000 by 2,700 mm for the bottom half of the tower and 2,500 mm square for the top half. The structural steel X braces located between the megacolumns also are formed of built-up I shapes that typically are 600 mm deep by 600 mm wide and have plates that are 50 to 100 mm thick. Each system of X braces is roughly six stories tall. The perimeter columns generally are built-up shapes below the uppermost outrigger and are built-truss systems and rolled sections above that point. The perimeter columns for the lowest third of the tower consist of built-up I shapes 600 mm deep by 600 mm wide with 100 mm thick plates; there are also 50 to 100 mm thick cover plates on and between the flanges because of the loads from the lowest outrigger and belt truss system. The middle third of the tower consists of built-up I shapes 500 mm deep by 500 mm wide with 75 mm thick plates and 25 mm thick cover plates, again because of the loads from the lower outrigger and belt truss system.

The(Project) Name: Pearl River Tower

Location: Guangzhou, China

Status: Under construction (scheduled for completion in 2010 and expected to be the most energy efficient of all the world’s supertall structures)

Design Firm: Skidmore, Owings & Merrill LLP

Project Description:

The Pearl River Tower project, designed by Skidmore, Owings & Merrill LLP, is envisioned as a “high-performance” tower that would consume significantly less energy than is typically needed by a building of this size and type. The design team interpreted “high-performance” to mean a structure whose energy-saving systems and strategies would work together in an integrated fashion to consume nearly 60 percent less energy than does a more traditional building.

The result was SOM’s design for the 71-story Pearl River Tower, which includes associated conference facilities that increase the total floor area of the building to approximately 204,000 m². Although the initial goal was to construct a building that would not require any additional energy on its behalf, modifications to the original design arose from economic considerations and regulatory challenges made this goal unachievable. But thanks to an all-inclusive design philosophy that worked together a variety of measures designed to reduce the building’s dependency on the city’s electrical grid, the Pearl River Tower is expected to come as close as possible to that goal.

Such a high level of performance requires a design team to consider a host of issues, among them the structure, the passive and active energy sources available, the types of building materials to be used, and the desired indoor air quality. The team must also determine ways of integrating these issues into the building design in a substantive manner rather than including them in a way that is purely for show. It is thus necessary to determine such basic elements as site conditions, the building’s orientation, the local wind speed and direction, and the path of the sun in the region and to draw on such sophisticated approaches and technologies as radiant ceilings, double-wall systems, photovoltaic devices, and wind turbines.

It was important to SOM that this holistic approach produce an array of solutions that would be compelling at a conceptual level and would survive the rigors of design development and future value engineering exercises. This demanded a design approach that looked not to form but to performance. In this way, superficial architectural detailing was avoided by ensuring that all of the systems possessed a degree of interdependency.

The tower is composed of a core system that includes the reinforced-concrete core wall and the corner megacolumns also are formed of built-up I shapes that typically are 600 mm deep by 600 mm wide and have plates that are 50 to 100 mm thick. Each system of X braces is roughly six stories tall. The perimeter columns generally are built-up shapes below the uppermost outrigger and are built-truss systems and rolled sections above that point. The perimeter columns for the lowest third of the tower consist of built-up I shapes 600 mm deep by 600 mm wide with 100 mm thick plates; there are also 50 to 100 mm thick cover plates on and between the flanges because of the loads from the lowest outrigger and belt truss system. The middle third of the tower consists of built-up I shapes 500 mm deep by 500 mm wide with 75 mm thick plates and 25 mm thick cover plates, again because of the loads from the lower outrigger and belt truss system.

Cross Section of Air Temperatures at Perimeter Zones

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>19°C</td>
<td>9.0%</td>
</tr>
<tr>
<td>20°C</td>
<td>19.5%</td>
</tr>
<tr>
<td>21°C</td>
<td>29.0%</td>
</tr>
<tr>
<td>22°C</td>
<td>38.5%</td>
</tr>
<tr>
<td>23°C</td>
<td>48.0%</td>
</tr>
<tr>
<td>24°C</td>
<td>57.5%</td>
</tr>
<tr>
<td>25°C</td>
<td>67.0%</td>
</tr>
<tr>
<td>26°C</td>
<td>76.5%</td>
</tr>
<tr>
<td>27°C</td>
<td>86.0%</td>
</tr>
<tr>
<td>28°C</td>
<td>95.5%</td>
</tr>
</tbody>
</table>

40

41
Reduction meant finding as many opportunities as possible to reduce the amount of energy consumed.

tower consists primarily of built-up I shapes that are 600 mm deep by 600 mm wide and have 50 to 75 mm thick plates. Below grade, the perimeter columns are encased in concrete to simplify the construction interface with the basement levels, which are generally made up of concrete slabs reinforced with steel bars. These slabs extend approximately 28 m below grade level.

footings under each of the perimeter columns. All foundations are designed to handle the superimposed loads and to provide composite action with the slabs. The maximum floor thickness of 160 mm. The shear studs are welded to the beams supporting a deck slab of concrete on metal with a total thickness of 50 to 100 mm.

bear on rock and extend approximately 28 m below grade level. The outrigger and belt truss elements also are built-up I shapes that are 600 mm deep by 600 mm wide and plate thicknesses of 50 to 100 mm.

The initial goal—designing an edifice that would not require energy to power the building—was designed to take full advantage of the building’s geometry. The third concept—reclamation—relied on strategies to harvest the energy that would already be resident within the building. Once energy has been added to the building, it can be reused repeatedly.

The Pearl River Tower was designed to use thermoelectric modules to generate clean power in an efficient and environmentally responsible manner. Indeed, the original plan was based on the projected ability to generate enough electricity within the structure to sell the excess to the local electrical grid. Having the ability to generate power more efficiently than can be achieved by the city’s grid would result in a net reduction in greenhouse gases associated with the building’s normal operation. For example, a typical electric power utility grid is less than 30 to 35 percent efficient by the time the energy has reached the building from the power plant source, according to “Energy Efficiency in the Power Grid,” a white paper produced by am. Inc., of Zürich, Switzerland, in 2007. By contrast, the on-site generation plant that was designed for the Pearl River Tower was expected to generate power with an efficiency exceeding 80 percent. The original concept for the building involved linking as many as 50 microturbines—each approximately the size of a large kitchen refrigerator and powered by such fuels as kerosene, biogas, diesel, methane, propane, or natural gas—to create a generating capacity of 3 MW.

Unfortunately, these plans were placed on indefinite hold when the Guangzhou utility decided that it would not connect the microturbines to the local electrical grid, which is often unreliable. Because the tower would not be able to sell its excess power to the utility, the cost of the microturbine system could no longer be justified. Moreover, the elimination of this technology meant that the goal of achieving a net zero-energy building was unattainable. But the potential benefits of the microturbines were so compelling that the building’s basement has been designed so that it can be retrofitted to accommodate the devices should the local utility ever change its stance.

The Pearl River Tower will feature an internally ventilated double-wall system made up of double glazed, insulated units integrated into the building’s envelope. The exterior glazing will take the form of insulated, tempered glass with a low-emissivity coating; the inner layer will be an operable clear glass panel that can be opened for ventilation and laterally supported at the bottom.

The facade of the Pearl River Tower will feature an internally ventilated double-wall system made up of double glazed, insulated units integrated into the building’s envelope. The exterior glazing will take the form of insulated, tempered glass with a low-emissivity coating; the inner layer will be an operable clear glass panel that can be opened for ventilation and laterally supported at the bottom.

This integrated facade assembly provides exceptional thermal performance as well as good visibility through the glass, and it should allow for the enhanced use of natural lighting. In turn, this should make it possible to reduce the amount of artificial lighting required
The Pearl River Tower will implement vertical-axis wind turbines that are capable of harnessing winds from both prevailing wind directions with only a minor loss in efficiency. The system also enabled the design team to optimize the plan layout by eliminating fan rooms and reducing the size of air shafts. This, in turn, resulted in a reduction of the total quantity of steel and concrete required to power fans than in a standard variable air volume system. With a conventional air volume system, the warmer air, typically the layer closest to the occupants—the mean radiant temperature in the space while preserving the excellent views—via the perforated return grilles located over the top of the building. The emissions and should provide power year-round. Therefore, the Pearl River Tower incorporates four large openings approximately 6 by 6.8 m, one on either side of the mechanical floors at levels 24 and 27. The distance between these four openings. In particular, the broad sides of the structure will be aligned perpendicular to the prevailing winds, which for most of the year are from the south, to create a positive pressure on the windward side and a negative pressure on the leeward side. But if the air is allowed to pass through the building, the difference in pressure from front to back is reduced, as are the forces on the building. Moreover, such an approach confers environmental benefits structurally in that it reduces the quantity of steel and concrete that is required to maintain the building's stability.

The Pearl River Tower incorporates four large openings approximately 6 by 6.8 m, one on either side of the building's exterior as depicted in the figure on page 41. This lower operative temperature will create an environment of improved thermal comfort at the perimeter zones and should directly improve the flexibility and usability of the areas closest to the exterior glazing. A similar system is used on both the southern and northern facades, in part for controlling glare but also because the northern facade is exposed to solar gains from the west in the late afternoon.

The Pearl River Tower, as mentioned above, will also feature a decoupled radiant cooling ceiling that works in conjunction with an under-floor ventilation air delivery system. This combination should provide improved comfort in all respects while simultaneously reducing the building's energy demand and maintenance costs. Furthermore, by requiring less material, it will also reduce the structure's capital costs.

The Pearl River Tower incorporates four large openings approximately 6 by 6.8 m, one on either side of the mechanical floors at levels 24 and 27. The distance between these four openings. In particular, the broad sides of the structure will be aligned perpendicular to the prevailing winds, which for most of the year are from the south, to create a positive pressure on the windward side and a negative pressure on the leeward side. By contrast, most buildings are typically aligned so that the positive pressure on the windward side is counteracted by the negative pressure on the leeward side, a stagnation condition causes the wind to approach the building, the difference in pressure between the windward and leeward sides of the building and should facilitate airflow through the four openings. On the windward side, a stagnation condition causes the locally increased pressure to be higher than the undisturbed pressure approach the building. On the leeward side, a low-pressure area is induced by the high-velocity flow at the sides and roof of the building.

The effect of the wind traveling through the four openings was carefully studied in a wind tunnel testing rig that featured a scale model of the Pearl River Tower. This testing took air flow measurements of the wind speeds as the wind approaches the building, and also measured the corresponding air velocities within the building's four openings. The model was then rotated within the tunnel to simulate what would happen when the wind approached from all possible directions.

The results indicated that as the air passes through the openings, the wind accelerates and the velocity increases. If the wind strikes the building at a perpendicular angle to an opening, the velocity will drop. But from almost every other angle, the increase in wind velocity will exceed the ambient wind speeds. In most cases, the velocity increases should be more than twice the ambient wind speeds. Thus, placing one vertical-axis wind turbine within each of the four openings of the building will take advantage of the increased power potential of the airstream. These wind turbines are low-vibration, low-noise units that operate within a wide range of wind directions and should provide power year-round. Therefore, the Pearl River Tower not only should realize structure-related cost savings as a result of adding the four openings but also should be able to avail itself of relatively free energy by harvesting the accelerated winds that will pass through these openings.
The cumulative benefit of all the environmentally beneficial strategies included in the design of the Pearl River Tower will significantly reduce the amount of energy needed to operate the building.

The cumulative benefit of all the environmentally beneficial strategies included in the design of the Pearl River Tower will significantly reduce the amount of energy needed to operate the building. The cumulative benefit of all the environmentally beneficial strategies included in the design of the Pearl River Tower will significantly reduce the amount of energy needed to operate the building.

The facade will feature an internally ventilated double-wall system that incorporates a motorized venetian-blind system controlled by a photosensor that tracks the movement of the sun. The exterior glazing will take the form of insulated, tempered glass with low-emissivity coating; the inner layer will be an operable clear glass panel that can be opened for maintenance.

The energy consumption of the building has been modeled and compared with that of a hypothetical baseline building. Ground was broken for the project in August 2006, and construction of the Pearl River Tower proceeded through 2007 and 2008. The highest portion of the structure should be erected during the fourth quarter of 2009, and the building should be completed by October 2010.

In developing the design for the Pearl River Tower, the design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.

The design team has learned numerous lessons from this project, including the critical fact that attempting to design and build a tower that does not require the utility to change its stance. Although ultimately for these reviews is understandable, such assessments tend to be based more on theory than on practical experience. As a result, it was sometimes difficult to convince other project team members of the viability of the proposed solutions. Moreover, efforts to address the concerns of the Chinese clients by using examples from projects in the West often were not successful.