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'Towards Zero Energy'
A Case Study of the Pearl River Tower, Guangzhou, China

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Roger Frechette is the Director in charge of sustainable engineering in the Chicago Office of Skidmore, Owings & Merrill LLP. He is a registered professional and mechanical engineer with 20 years of experience.

Mr. Frechette is currently leading the engineering team of the Burj Dubai, which is planned as the world's tallest building, as well as the "zero-energy," high-performance concept Pearl River Tower in Guangzhou, China. His work includes a diverse group of projects, ranging from laboratories, airports, hospitals, academic buildings and corporate offices to government buildings and museums.

Mr. Frechette is a Senior Fellow with the Design Futures Council, a global network of design community professionals. Additionally, Mr. Frechette frequently speaks at a number of educational seminars on "Green Engineering."

Previous accomplishments include his 2001 design of the National Wildlife Foundation Headquarters Building in Reston, Virginia, voted by the American Institute of Architects (AIA) as one of the "Top 10" sustainable buildings in the United States. In 2002, he co-authored a document known as the "Nantucket Principals," which focuses on the trends and issues that will influence green building and sustainable design in the future. In 2004, Mr. Frechette received United States Congressional recognition for his work in building sustainability.

Russell Gilchrist

With more than 23 years of experience in the European architecture industry, Russell Gilchrist recently joined the Chicago Office of Skidmore, Owings & Merrill LLP. In 2000, Mr. Gilchrist was Project Architect for the 88 Wood Street project for Daiwa Securities in London, winner of a RIBA Award, Civic Trust Award and nominated for the Stirling Prize Award for the best building in the UK.

Mr. Gilchrist works in collaboration with SOM Partners and project teams to improve design solutions through the use of building science. He is also responsible for the development of working drawings and construction phase services for several complex projects.

Mr. Gilchrist works with the Director in charge of sustainable engineering to integrate technological and sustainable strategies into all SOM projects. Currently, Mr. Gilchrist is involved in several projects including Pearl River Tower, a 'zero-energy' concept tower in Guangzhou, China, North Bund Jingang Plaza, a mixed-use development in Shanghai, China, the Dallas City Performance Hall, a community theatre with 750-seat music hall and flexible space for theatre and dance, and the University of North Carolina Genome Science Laboratory, a state-of-the-art "green" research laboratory which is planned to be LEED® Gold certified.

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Abstract

Architects and engineers have a significant responsibility to ensure that the design and execution of all new construction projects be of the 'lightest touch' in both energy consumption, real and embodied, to ensure the longevity of the precious natural resources remain on this planet. The goal to achieve 'carbon neutrality' is quite possibly the single most important issue facing architects and engineers today, given the empirical evidence that construction projects far outstrip both industry and transportation as the largest contributors to carbon emissions in the world.

This paper will attempt to both define what is meant by 'carbon neutral' in the context of building design as well as using the case study to demonstrate how such an approach might be achieved it examines the challenges of achieving a net zero energy building, both from an energy consumption perspective as well as the embodied energy of the construction. It discusses the level of control architects and engineers can exert during the process of building procurement and construction as well as examining what post-construction measures can be employed. This latter point is a key issue in validating the design ambitions and provides a useful tool to benchmark and improve upon future projects.

Keywords: tall buildings, sustainability, carbon neutral, energy consumption, embodied energy

Introduction

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. Massive consumption of fossil fuels has sharply increased levels of carbon dioxide (CO2) in our atmosphere resulting in a steady, but rapid warming of the plant. The impact of this man-made environmental shift is not yet fully understood, however, many scientists believe the results may be catastrophic.

There are many contributing factors to that have added to this crisis. Automobiles and industry have had a major impact on CO2 emissions; however, CO2 emissions associated with the built environment exceed both transportation and industry as the single greatest contributor to global warming. It is imperative that architects and engineers find ways to design buildings to decrease the amount of energy consumed in construction and to limit the amount of CO2 emissions generated from these buildings both under construction and when in use.

DEFINING 'NET ZERO'

The Pearl River Tower, Guangzhou, China, designed by Skidmore, Owings & Merrill LLP (SOM) aims to be the most energy efficient super tall tower in the world. The intent of the design is to drive towards "net zero energy" and to pursue carbon neutrality for the project.

A Community may be defined as a city, town, region, neighborhood or any other assemblage of interacting populations. An existing community requires a certain quantity of energy for it to operate properly. This energy is consumed by transportation, industry, utilities and buildings.

We have defined "net zero energy" for a new building as a structure that does not require an increase in the community's need to produce energy. By keeping this power generation capacity stable, or potentially even decreasing this threshold, the city can grow, expand, increase its density and prosper without the need to consume additional fossil fuels, avoiding the potential increase in harmful greenhouse gasses emitted to the atmosphere.

CHINA:

The city of Guangzhou, China experiences some of the worst air pollution on the planet. China's growing economy has increased their energy consumption; this in turn has lead to a rapid increase in carbon emissions. This year China is predicted to pass the United States as the largest emitter of greenhouse gasses in the world. China consumes more than 500 million kilowatts of electricity each year. It is clear that in China, as well as other developing countries around the world, need to find a way to curb their appetites for energy consumption and to find ways to reduce emissions of carbon dioxide by pursuing alternative technologies that are currently commercially and widely available. The World Bank has recently reported that air pollution is the cause for more than 400,000 deaths, each year in China.

In response to these great problems, the Chinese government has recently set a goal to reduce their carbon emission by 10% by the year 2010. The central government has made the Guangdong province a major focus of this initiative, and specifically they have indentified the city of Guangzhou. Twenty-six companies in Guangzhou consume more than 180,000 tons of coal each year. In addition China plans to open 400 new coal-fired power stations over the next 10 years a rate of 1 new power plant every 9 days so it is not clear how the reduction in carbon emissions might be achieved.1 In a country that has very little in the way of oil and gas reserves, coal represents the solution to providing 80% of China's electricity demand and continuing economic growth.

The world generally and China more specifically needs to find a new development model that provides a higher living standard whilst reducing the carbon emissions per capita Pearl River Towers passive and active approach as new technologies and reduction strategies in a building integrated high performance way are important ingredients in achieving this end albeit in a country that lacks diversity in its natural resources.

THE PEARL RIVER TOWER DESIGN PHILOSOPHY:

One of the largest companies, in Guangzhou, is the Guangdong Tobacco Company (GTC), which is part of the Chinese National Tobacco Company (CNTC). In 2005, SOM, LLP was hired to design a headquarters building for CNTC on the Pearl River (Fig 1).

The design brief called for a "high performance" tower capable of significantly reducing the "typical" amount of energy consumption from a building of this size and type.

The initial design concept was to develop a super-tall building capable of having a "net-zero" annual energy impact on the city with a view to being the most energy efficient super-tall building in the world. The brief for the Pearl River Tower developed into a 71-story, 310M tall office tower with associated conference facilities, a total gross area of approximately 2.2 million square feet.

As the design of the tower progressed, economic considerations and regulatory challenges resulted in modifications to the initial design, it is no longer able to meet a "net zero energy" standard. However, it will be a high-performance building when completed should be the most energy efficient super-tall tower building in the world. The building concept embraces an all-inclusive design philosophy weaving together a variety of sustainable (both passive and active) measures, to reduce the building's dependency on the city's electrical grid.

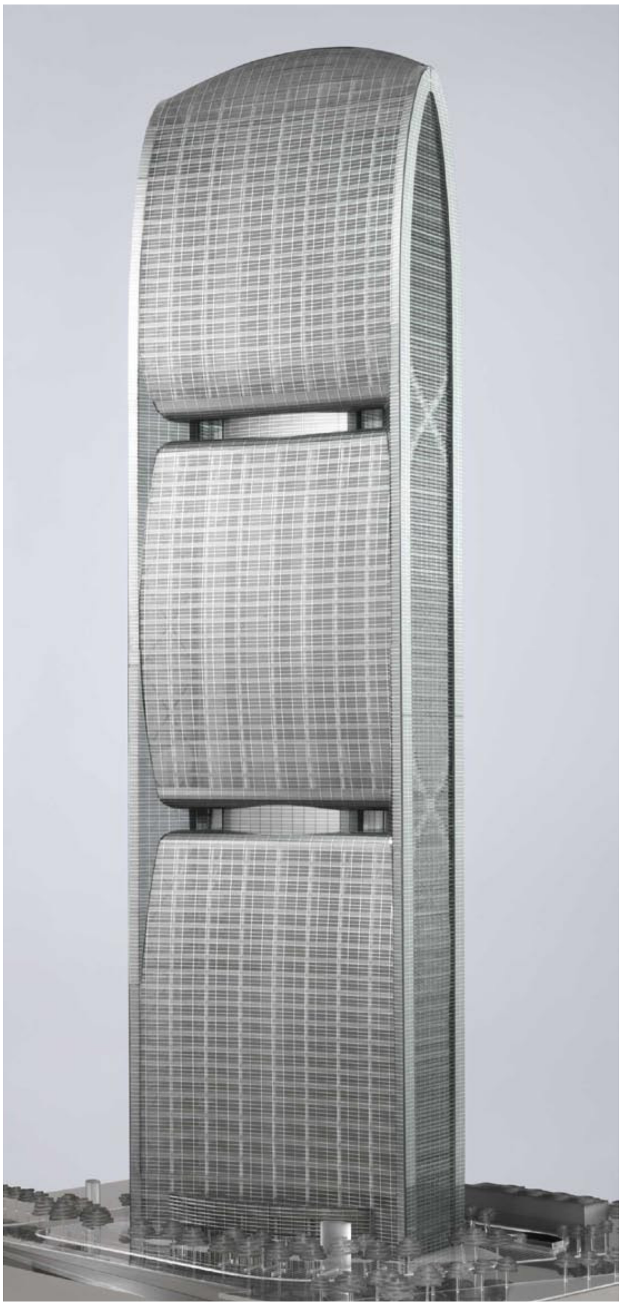

Figure 1: Pearl River Tower, Guangzhou, China

This design process took into consideration the interaction of the whole building structure and systems, and its site location. The key to a successful high performance requires the design team to consider the site, energy sources both active and passive, materials, indoor air quality, and how they might become incorporated into the building form that is more than gestural. These considerations include simple concepts including site analysis, building orientation, wind direction, sun path analysis to more sophisticated approaches and technologies including the use of radiant ceilings, double wall systems, photo-voltaic and wind turbine technology.

It was important to SOM that this holistic approach did not result in simply an array of solutions that may be compelling at a conceptual level but would not survive the rigours of design development and future value engineering exercises. This demanded a design approach that was not form driven but performance based with all systems having a degree of interdependency to avoid superfluous architectural detailing resulting in a leaner design for the architectural and engineering solutions. All of these strategies combined form the basis of the design approach in an effort to achieve a net zero energy goal.

FOUR STEPS TO NET ZERO ENERGY

The original approach to the design included four interdependent steps, which would lead to the 'net zero-energy' including:

- Reduction
- Absorption
- Reclamation
- Generation

Reduction - The first step to a high performance design is to identify as many opportunities as possible to reduce the amount of energy consumed. These reduction strategies need to focus on the largest consumers within the building, namely the HVAC and lighting systems. The "reduction" strategies used on the Pearl River Tower includes the following;

- The use of an internally ventilated high-performance active double wall façade (N/S façades) with mechanized blinds
- The use of a high performance triple-glazed (E/W) façade
- A building-wide "chilled" radiant ceiling with perimeter chilled beam system for human comfort control.
- A "de-coupled" ventilation system delivered via a raised access floor.
- Dehumidification system which uses heat collected from the double wall façade as an energy source.
- Low energy, high efficient lighting system using radiant panel geometry to assist in the distribution of light.

Absorption - The second step to this high performance design was to include several "absorption" strategies. These strategies are defines as those that take advantage of the natural and passive energy sources that pass around, over and under the building's envelope. The absorption strategies used on the Pearl River Tower include:

- A wide-scale photovoltaic system integrated to the building's external solar shading system and glass outer skin (south façades only).
- The use of fixed external shades and integrated PV's (E/W façades).
- Daylight harvesting using daylight responsive controls integrated with the automated blinds.
- Building integrated vertical axis wind turbines (VAWT's) designed to use the building's geometry to significantly enhance turbine performance.

Reclamation - The third step to a high performance design is to include reclamation strategies. The basis of this collection of strategies is to harvest the energy already resident within the building. Once energy has been added to the building, it can be reused over and over again, Examples Pearl River Tower include the use of re-circulated air for pre heat/cooling of outside fresh air prior to delivery of the occupied Ares depending upon the time of year and outside air conditions, and the use of absorption chillers.

Generation - The concept design of the Pearl River Tower incorporated the use of "micro-turbine" gas turbine generation technology. These micro-turbines offer the ability for the building to produce clean power in an efficient and environmentally responsibility manner. The generation strategy is an important component to the "net zero" energy strategy. Having the ability to generate power more efficiently than what the city's grid is capable of, allows for a "net" reduction in the green house gasses associated with the building's normal operation. A typical electric power utility grid is less than 30-35% efficient by the time the energy has reached the building from the power plant source. 2 The on-site generation plant, designed for the Pearl River Tower, would generate power with an efficiency exceeding 80%. Each turbine is approximately the size of an oversized domestic kitchen refrigerator (Fig 2); it is capable of generating approximately 65 KW of power. These devices can then be connected together in series to deliver the desired capacity to the building.

Micro-turbines are capable of operating on a various types of fuel mediums, such as kerosene, biogas, diesel, methane, propane and natural gas. The micro-turbines are air cooled The hot air can be reclaimed and used as an auxiliary heat source for the building for functions such as water heating or absorption cooling. The safe, low noise and vibration free characteristics of these machines make them ideal for on site installation.3

The original concept for the building was use up to 50 micro-turbines, daisy-chained together to generate more than 3 Megawatts of power. The building's design was altered as the micro-turbines are currently from the project when it was determined that the local utility company, in Guangzhou, China would not allow these devices to be "grid-connected". Without having the ability to sell the excess power back to the utility company, the financial payback of the micro-turbine's premium could not be justified. Although the installation of micro-turbines is not widespread their application in today's climate does make them a compelling component to achievable low energy, sustainable design, so the current design of the basement has reserved a location for them to be retrofitted at a later date should the local Guangzhou infrastructure becomes available.

HIGH PERFORMANCE ACTIVE FACADE:

Interest in the use of highly glazed facades for commercial buildings continues to grow significantly. The deployment of fully glazed facades that are highly transparent, and incorporate numerous sun controls devices are prevalent. These systems have become increasingly popular in Europe, and are now appearing in other regions of the world, including the United States and China. By including a second layer of glass, a double envelope can accommodate venting and solar shading devices within the cavity.

Figure 2: Micro-turbine installation

Figure 3: High Performance Active Façade Detail

These design approaches vary but often provide increased occupant benefits such as thermal comfort and air quality as well as sustainable design associated with day-lighting and energy savings. Driving forces include:

- Desire for transparency from an aesthetic perspective.
- Improved views to outside.
- Greater opportunity to bring useful daylight in to the space.
- Reduced noise transmission from outside of the building to inside.
- Closer control of infiltration of water and air from outside to inside.
- Potential for reduced solar (cooling loads) at the perimeter occupied spaces of the building.
- Improved thermal performance/comfort during winter (cooler) months
-

The exterior enclosure for the Pearl River Tower will be an internally ventilated double wall system (Fig 4) consisting of a double glazed insulated glazed unit with integral spandrel panel in a 3.0 x 3.9m unitized panel. Two hinged 1.5 x 2.8m single glazed leaves are fixed to the back face of the mullion to create a nom 200mm cavity with a small air gap at the base (see Fig 4). Within the cavity is a motorized 50mm perforated silver venetian blind. The blind will always be fully extended within the cavity, however it has 3 modes of operation; open, closed to 45 degrees or fully closed depending on the angle of the sun. The blind position is determined by a photocell that tracks sun position and is connected to the building management system (BMS) which activates the blind position to ensure occupancy comfort from both solar gains and glare. Exterior glazing will be insulated, tempered glass with a low-E coating, the inner layer will be an operable (hinged) clear glass panel and each panel can be opened for maintenance. The wall will be internally mechanically ventilated every floor. Units will be gravity supported (hung) from the top at each level and laterally supported at the bottom.

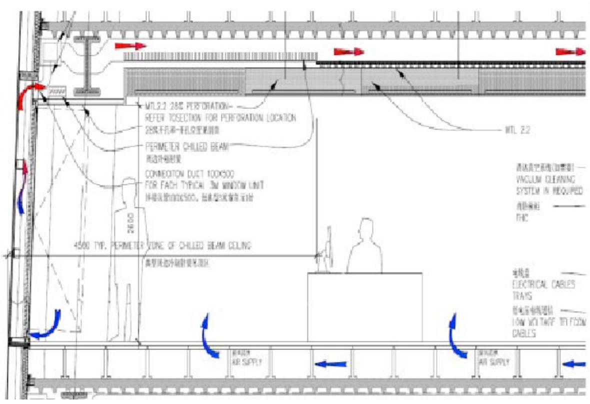

Figure 4: Exterior Wall Air Flow Diagram

This integrated façade assembly provides exceptional thermal performance and high visual transmittance. The increased visual transmittance allows for enhanced daylight harvesting, allowing for a reduction in the amount of electrified (artificial) lighting required in the space, as well as preserving long distance views. Even when blinds are fully closed the perforations allow for good visual transmission to enjoy views beyond. More importantly the ‘double wall’ arrangement is a vital component in maintaining the balance between maximum transparency and achieving a high standard of occupancy comfort by mitigating glare and solar gains. As the sun rays hit the exterior double glazed skin some of the gains resist the low e coating and enter the cavity between the outer and inner glazed layers, the perforated blind will already be activated at the correct angle to provide a further level of defence against solar gains and also contribute to trapping any heat gain in the cavity in turn reducing the temperature of the inside face of the inner single glazed panel adjacent to the occupants. The cavity acts as a natural chimney using the cooler air from the occupied office areas to enter the cavity via a gap at floor level whilst acting as a pressure relief valve to allow more fresh (make up) air to enter the occupied areas. The trapped hot air in the cavity is then extracted through the ceiling void and is used either as a pre-heat or pre-cool depending upon outside air temperatures, i.e. an intrinsic part of our reclamation strategy.

By maintaining a low temperature on the inside layer of glass, closest to the occupants, the mean radiant temperature will be decreased, thus reducing the “operative” temperature of the space. This lower operative temperature will create an environment of improved thermal comfort at the perimeter zones (Fig 5) and should directly improve the flexibility and usability of the area closest to the exterior glazing. It should be noted that the same system is used on both the south and north facades, partly because the northern façade is exposed to solar gains from the west in the late afternoon, but also for glare control.

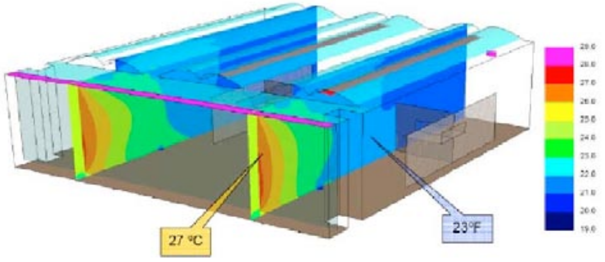

Figure 5: Air Temperature Cross Section at Perimeter Zone

RADIANT CEILING & BELOW FLOOR VENTILATION

A standard system for a sub-tropical, cooling dominated environment, typically achieved by circulating cold air throughout the occupied zone to a desired mixed space air temperature and thus provide occupant comfort. Thermal comfort, however, is influenced by both space air temperature as well as the mean radiant temperature. Additionally, air flow rates, humidity, time of year, and the activity and clothing of the occupants will factor into what is perceived as “comfortable”.

The System proposed for the Pearl River Tower consists of a radiant cooling ceiling (Fig 6) is working in parallel with an under floor ventilation air delivery system. This combination offers an intelligent solution providing improved comfort in all respects, whilst reducing energy demand, maintenance, fewer materials, and reduced capital costs.

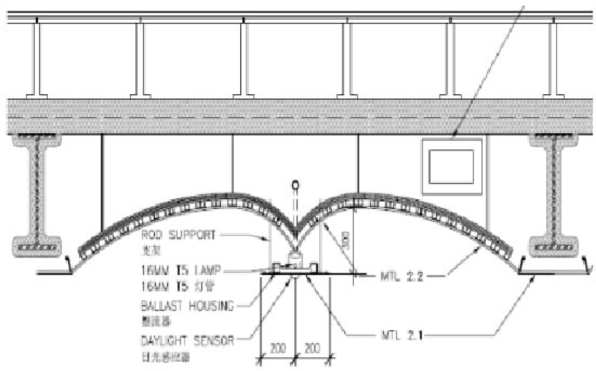

Figure 6: Radiant Chilled Ceiling Panel Detail

On any given day, the office space within the tower will encounter heat gain from a variety of sources. People, only account for only a fraction of this gain, they give off heat in the form of convection and radiation. Ambient and task lighting, computer, and other office equipment are not only end consumers of electrical energy, their convective and radiated heat will directly translate into additional heat gain that needs to be cooled by the HVAC system.

At the perimeter of the building, space heat gains are much more variable and usually difficult to control due to solar energy transmission through the glazing as radiation and conduction driven by the difference between inside temperature and outside air temperature. A radiant cooling/displacement ventilation system addresses each heat transfer mode with the cooling/ventilation system in its constituent separate parts – radiant loads by the radiant system, convective loads by a combination of radiant system and displacement ventilation system, thus optimizing its efficiency when compared with a conventional forced overhead mixing type system which is entirely convective, because water is a far more efficient transfer medium that air, the proposed system results in a significant decrease in fan energy, as compared to the standard VAV system baseline.

In most contemporary office buildings, the largest cooling loads tend to be found at the buildings perimeter, equipment and lighting loads tend to be somewhat uniform for interior and exterior zones, the heavy envelop loads (solar heat gain, window conduction and wall conduction) are realized within the exterior zones. With conventional Variable air Volume (VAV) systems, the warmer air temperatures, associated with the return air system, can increase the loads within the building interior as this air migrates to return air grilles located throughout the floor. The Pearl River Tower design uses the exterior double-wall enclosure as the return air plenum. The return air within the perimeter zone is drawn to the buildings exterior minimizing the impact on the interior zones. The “de-coupled” ventilation system provides improved indoor air quality and improved air change effectiveness which is very important in China.

This mechanical approach allowed us to reduce the building’s “floor-to-floor” height from 4.2 meters to 3.9 meters (equivalent of saving five stories of construction). This allowed the design the ability to offer the owner additional floor area without compromising floor-to-ceiling height and reducing the exterior envelope costs and other benefits beyond energy conservation. The energy savings associated with reduced airflow and the radiant ceiling system is arguably the most sustainable aspects of the Pearl River Tower design.

In addition to reducing the building section we were able to optimize the plan layout. The elimination of fan rooms and the reduction of air shaft sizes has resulted in the core area being reduced thus optimizing the net to gross on each and every floor increasing the buildings revenue potential. It should also be noted that this decrease in fan equipment enabled the area on the mechanical floors to become the wind portals for the wind turbine system. A conventional system would have required too much area to make this approach possible.

BUILDING INTEGRATED PHOTOVOLTAICS

The integration of photovoltaic’s (PV’s) in building design, where the PV elements become an integral part of the building envelope, often serving as the exterior weather skin, is growing worldwide. Building Integrated Photovoltaic’s (BIPV’s) is the integration of PV’s into the building envelope rather than as an applied extra feature. The PV modules on the Pearl River tower serve the dual function of building skin (spandrel panels) and power generator. By avoiding the cost of conventional spandrel panels, the incremental cost of PV’s is reduced and its life-cycle cost is improved. BIPV systems often have lower overall costs compared to PV systems requiring separate, dedicated, mounting systems.4

The solar radiation on the Pearl River Tower was carefully studied (Fig 7). It was determined that the use of PV cells could be productive if used on certain portions on building’s envelope. The distribution of the BIPV’s directly correlates with where they would optimize the solar power offered by the sun. You will see (Fig 8) that they are asymmetrically located at roof level in order to achieve best performance rather than non specific architectural criteria.

The system not only provides an electrical supply for the building, it also functions a solar shade for that part of the building most susceptible to the negative impacts of direct solar radiation.

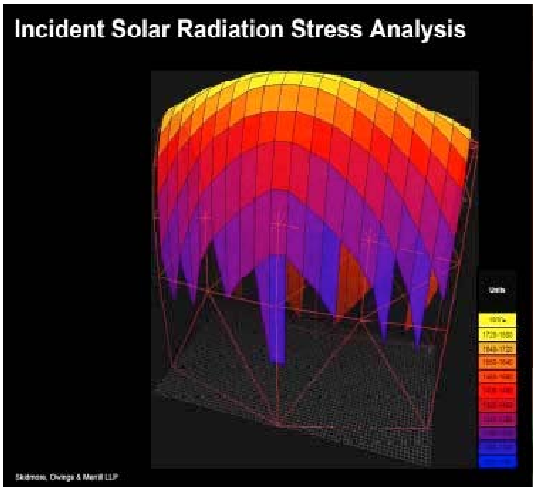

Figure 7: Incident Solar Stress Model of Pearl Tower

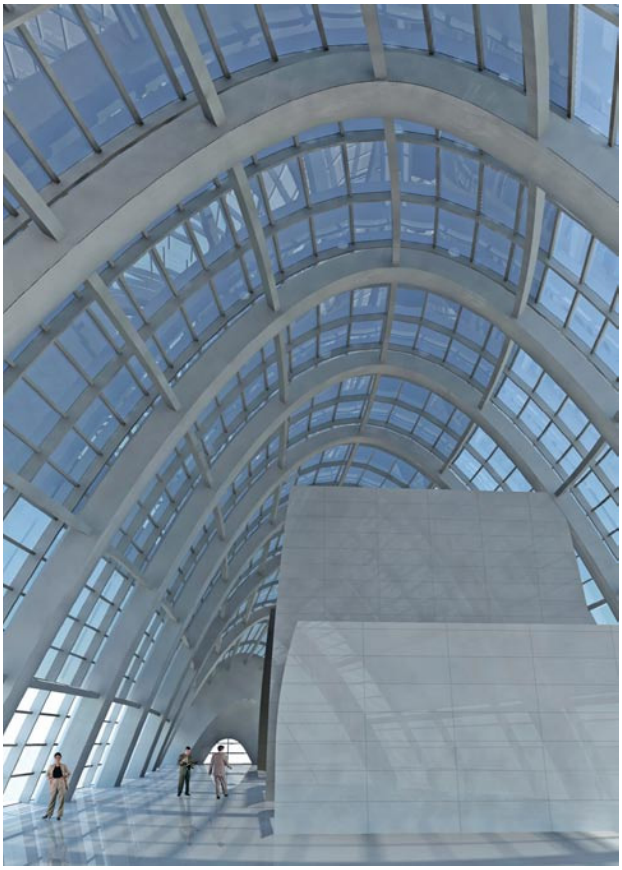

Figure 8: Building Integrated Photovoltaic’s

WIND TURBINES:

Wind energy offers many advantages and is the fastest-growing renewable energy source in the world. Wind energy is a clean fuel source and doesn’t pollute the air unlike power plants that rely on combustion of fossil fuels. Wind turbines don’t produce atmospheric emissions that cause acid rain or greenhouse gasses. Wind energy is also a constantly renewable power source, making it one of the lowest-priced renewable energy technologies available today. More recent developments in this technology have allowed wind turbines to be utilized in building design. Consistent with the high performance approach to building design, the use of wind turbines on the Pearl River Tower is significantly enhanced by their integration with building architecture.

Wind has a large impact on the design of tall buildings. The wind causes a large build-up of positive pressure on the windward side of the building. Vortex shedding, around the sides and over the top of the building, creates a large pocket of negative pressure on the leeward side of the building. In allowing air to pass through the building, the differential pressure from front to back is reduced and the forces on the building are, in turn, reduced. This approach is sustainable from a structural standpoint in that it allows for a reduction in the quantity of steel and concrete to maintain the building's stability.

The building incorporates four large openings, approximately 3 x 4 meters wide (Fig 9). The façades are shaped to decrease the drag forces and optimize the wind velocity passing through the four openings. These openings function as "pressure relief" valves for the building. This strategy maximizes the wind power potential at these four locations as the power potential from the wind speed is a cube function of wind velocity, therefore a small increase in velocity can translate to a larger increase in power potential.

$$P=V^3$$

The Pearl River tower will implement vertical axis wind turbines (Fig 10), as they are capable of harnessing winds from both prevailing wind directions with minor efficiency loss.

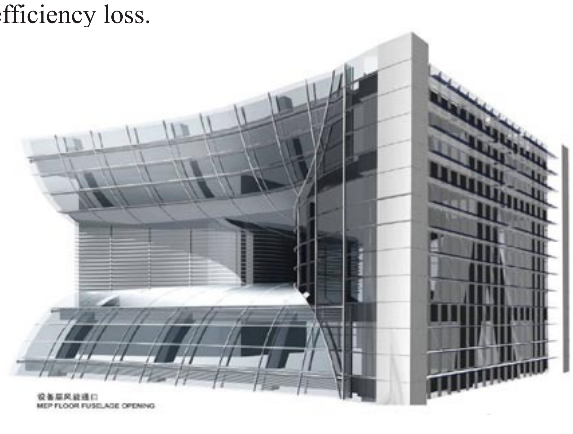

Figure 9: Wind Portal Located at Pearl's Mechanical Floor

The building design capitalizes the pressure difference between the windward and leeward side of the building and will facilitate air flow through the four openings located adjacent to the mechanical floors within the building. At the windward side there is a stagnation condition that causes the locally increased pressure to be higher than the undisturbed pressure approaching the building. At the leeward side of the building a low pressure exists that is induced by the high velocity flow at the sides and roof of the building.

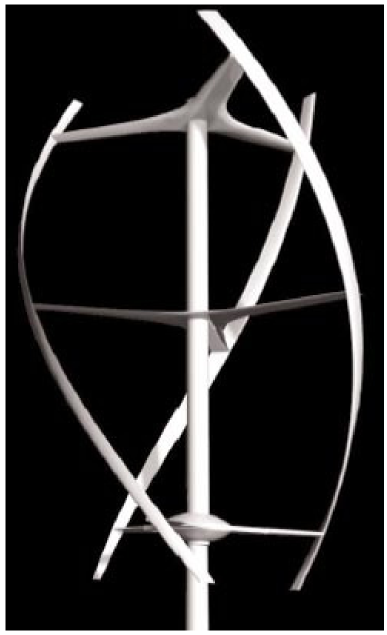

Figure 10: "Quiet Revolution" Vertical Axis Wind Turbine

The effect of the wind traveling through these openings was carefully studied in a wind tunnel testing rig. A scaled model of the Pearl River Tower was assembled and tested. Airflow measurements were taken of wind speeds as they approached the building along with the corresponding air velocities within the building's 'wind portals'. The building was then rotated within the tunnel to simulate wind approaching from all possible directions. As the air passes through the openings, acceleration takes place and an increased velocity is realized.

If the wind strikes the building perpendicular to the opening, there is a drop in portal velocity. However, from almost all other angles, the wind velocity increase exceeds the 'ambient' wind speeds. In most cases the velocity increases are more than twice the 'ambient' wind speeds. Figure 11 illustrates the results from the wind tunnel testing for one of the four portals.

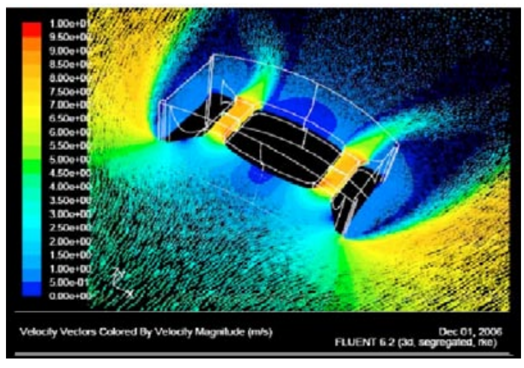

Figure 11: Wind Velocity Vectors at Pearl's Mechanical Floor

The smaller circle represents wind velocity measurements taken at 10 degree directional increments for the air approaching the building.

The graph shown in blue (Fig 12) shows the corresponding wind velocities measured within the wind portal. When the wind is flowing at a right angle to the building, the portal conditions approach a stagnant condition.

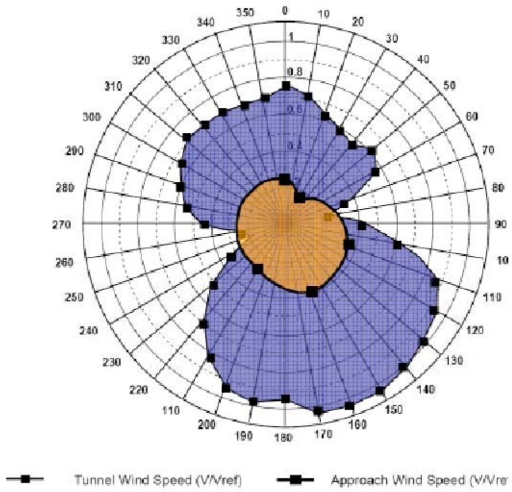

Figure 12: Wind Tunnel Test Data at Pearl's Wind Portal

By placing vertical axis wind turbines, one inside each of the four openings of the building, the increased power potential of the air stream can be leveraged. These wind turbines provide power year round. They are low vibration, low noise units which operate given a very wide range of wind directions. Therefore, not only does the building realize structural savings with the openings, the accelerated winds through these openings can be "harvested" to produce free energy. One interesting and surprising point was that the two lower openings yielded a similar amount of energy. We would have expected the 2 higher placed turbines to generate more energy due to increased wind speeds approaching the building at a higher altitude. Although not fully explained both the wind testing and CFD analysis recorded this phenomenon which may be due in part to the lower turbines receiving some downdraught from the façade above to supplement the approaching wind.

CONCLUSIONS:

The cumulative benefit of all these sustainable strategies included in the design has led to a significant reduction in the amount of energy needed to operate the building. The most notable are the reductions associated with the mechanical systems of the building; measurable savings will be realized in the cooling systems, lighting systems and the air and water delivery systems.

The energy consumption of the building has been modeled and compared to a hypothetical "baseline" building of the same geometry, but without the sustainable measures included and relying on the more established strategy of using air to cool the building rather than a (water based) radiant ceiling system The baseline case has been compared to the Pearl River Tower "design" case.

Figure 13 below is a summary of the comparison between baseline and design cases. The expected performance equates to roughly 58% reduction of energy consumption on an annual basis.

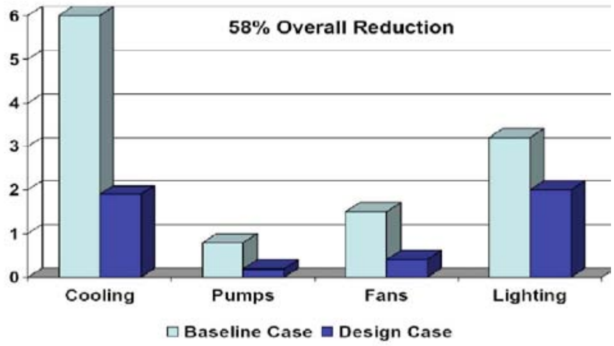

Figure 13: Pearl River Tower Annual Energy Consumption

LESSONS LEARNED:

Attempting to design and build a "net zero energy" building can be a very difficult proposition. The challenges of high performance design in a super-tall tower in a humid climate can be daunting. Some building owners are willing to take perceived risks on smaller scale projects, but it is unusual in a high rise large scale office building. Attempting unconventional strategies on a 2.2 million ft2, 1000-foot tall tower takes a courageous owner. Despite the best attempts by the design team, there were several strategies required to get to "zero energy" that ultimately were unachievable.

The most notable change to the design was the elimination of micro-turbine power generation from the project. The use of this technology would have led to a significant decrease in carbon emission associated with the Pearl River Tower. The micro-turbines would have provided a reliable source of power in a city with a notoriously unreliable electric grid. he micro-turbines could have provided a free source of domestic hot water to the tower.

However, the business case for incorporating micro-turbines relied of the ability of the owner to sell power back to the utility company during evening and off-pear hours of the year. Unfortunately, the utility company in Guangzhou, China does not currently allow such an arrangement for commercial buildings. Hence, the micro-turbines and there associated benefits were removed from the project. Without the use of this technology, the "net zero energy" target was out of reach.

APROACHING 'NET ZERO' ENERGY:

Although the aforementioned progression of the design has led to a final design not realizing 'net zero' energy, the process has provided strong analytical evidence, that a "net zero" energy super-tall tower is clearly within our grasp.

Figure 14. Aerial perspective of Pearl River Tower

The use of a water based cooling system has reduced the cost of tenant fit-out and future retrofits due to the absence of fan coils, VAV boxes, filters, ductwork, insulation and other items typically requiring tenant-specific alterations. There is an expectation of improved human performance, improved occupant health and increased human productivity as a consequence of the enhanced thermal comfort, natural lighting, ventilation and acoustics in the space.

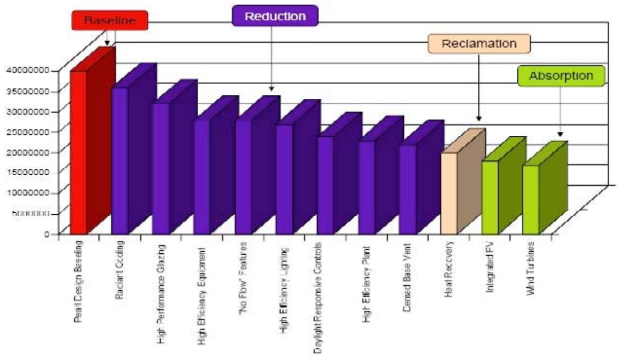

Figure 15: Overall Energy Savings for Sustainable Strategies

Figure 15 illustrates the final relevant reductions associated with each of the large-scale sustainable strategies used in the Pearl River Tower design. It is expected that the tower will consume at least 58% less power than an energy code compliant equivalent building.

In developing the design for Pearl River Tower it is interesting to understand some of the practical problems associated with the design process from initial (competition) concept through to the completion of the project. SOM have enjoyed a 'full' appointment of services up to and including detailed design (DD) on the Pearl Tower project namely their scope of services includes Architecture, Structural and MEP Engineering whilst working with a Local Design Institute (LDI) to ensure that all local and statutory approvals are obtained with respect to planning and zoning as well as building code approvals. At the time of writing this paper, SOM had completed the DD phase of the project and were awaiting a review set of Construction Documents (CD's) from GZDI the Local Design Institute (LDI) who are assisting SOM through the remaining phases of the project. The project is currently under construction, the construction of the substructure concrete (basement) due to be complete in early 2008.

It is accurate to say that the on-going dialogue with the LDI to further develop the aforementioned strategies particularly with regard to the MEP systems (but also other aspects of the building fabric including exterior wall and superstructure), it has been difficult to describe and develop the design intent to the full degree. The strategies and their attendant technologies are not new in building technology but they are emerging technologies in China and the reliance of performance criteria for projects in the USA or Europe is not so easily transferable to this part of the world. This is not only because the strategies are not prevalent in China but also there is a reluctance for the Chinese to import existing technologies or manufacturing from other parts of the world. In addition SOM's work to date has been subject to peer reviews (quite rightly) from leading experts from all over the Chinese mainland, however assessments tend to be theoretically based rather than from practical experience for obvious reasons. This can present a dilemma when convincing other project team members of the viability of the solutions proposed. Designers are used to inviting clients and others to look at earlier buildings employing such strategies as precedents to alleviate their concerns it can often have the reverse effects when the examples suggested are located in North America or Western Europe.

These concerns will continue through the construction stages of the projects particularly in the development of full size mock-ups (both visual and full testing) for the exterior wall and other building components such as the radiant panel ceiling systems. Pearl River Tower would be a challenge were it located in London or Chicago and this is certainly the case in Guangzhou where the performance of the exterior wall in a humid climate will be critical and its inter-relationship with the radiant cooling and fresh air systems and the associated control system required are of paramount importance if all is to function successfully. Conversely it can be safely assumed that most if not all the building components will be sourced from the Chinese mainland thus substantially reducing the amount of 'embodied' energy that has become so prevalent with construction projects in the western hemisphere.

However, we should not forget that currently the Chinese building code is more stringent than that of ASHRAE 90.1 its American equivalent. In addition SOM are fortunate to have a client, The Guangzhou Tobacco Company (GTC) who have requested a highly energy efficient building, when complete we are sure these earlier concerns will be academic as China will be leading the way in delivering super high rise energy efficient buildings.

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