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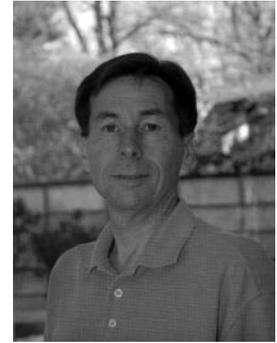
Overview of Sustainable Design Factors in High-Rise Buildings

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His considerable industrial experience includes Skidmore, Owings and Merrill and Sargent & Lundy in Chicago. He has worked as consultant in Canada, Singapore, Saudi Arabia, Bangladesh and the USA. He also worked as consultant with US Army Corps of Engineers. He was the Chairman of Committee 30-Architecture, of CTBUH from 1990 to 1998. Following that he had been a Group Leader of its Group PA-Planning and Architecture until recently and has been a member of its Steering Group since 1998. He has been interviewed on WTC and tall buildings by the New York Times, Toronto Star, Chicago Sun Times, Chicago Daily Herald, The Architectural Record, Milwaukee Journal Sentinel, Discovery Channel, Travel Channel, MSNBC, NPR, IPR, Popular Science, PRI, AP, Rolling Stones, and several others.

Dr. Ali was a TOKTEN Fellow of the United Nations in 1989. He has authored a book titled *Art of the Skyscraper: The Genius of Fazlur Khan*, and edited three books, *Architecture of Tall Buildings*; *Bangladesh Floods: Views from Home and Abroad*; and *Catalyst for Skyscraper Revolution: Lynn S. Beedle--A Legend in His Lifetime*. He has published over 100 papers and articles, and presented numerous papers on tall buildings at conferences and seminars nationally and internationally. His new book *The Skyscraper and the City: Design, Technology and Innovation* co-authored by Lynn S. Beedle and Paul J. Armstrong is scheduled for publication in December, 2007.

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Abstract

This paper examines the critical design factors and strategies that warrant consideration to accomplish sustainable or high-performance tall buildings applying innovative technologies. It shows how “technology transfers” in the aerospace industry have been applied to tall building systems to achieve high-performance. Because the design of tall buildings warrants a multi-disciplinary approach and requires the integration of architectural components, structure, HVAC, and communication systems, an analogy exists between tall building and aircraft, which also comprises complex integrated systems. A few case study building examples are presented which represent the new generation of sustainable tall buildings that are setting trends for future projects incorporating innovations in materials and building systems.

It is concluded that since tall buildings consume massive energy, designers of the next generation of tall buildings will incrementally aim for “zero energy” design. In this approach climate is used to advantage and the building becomes a source of power. It is possible that tall buildings will some day even produce excess energy and transfer the excess to the city’s power grid for use in other ways.

Keywords: up alternative energy, integration, sustainable architecture, tall buildings, technology transfer

Introduction

It is projected that by 2030, 5 billion people will live in urban areas throughout the world (United Nations, 2001). Whereas 30 per cent of the world population lived in urban areas in 1950, the proportion of urban dwellers climbed to 47 per cent in 2000 and is projected to rise to 60 per cent by 2030. Energy shortage, global warming, urban sprawl, air pollution, overflowing landfills, water shortage, disease, and global conflict will be the legacy of the twenty-first century unless we move quickly towards the notion and implementation of sustainability. Survival of the human race depends upon the survival of the cities--their built environment and the urban infrastructure. This will warrant vision, commitment, and action through partnership and commitment of governments, policy makers, experts, and the involvement of citizens. It will require collaboration of urban planners, architects, engineers, politicians, academics, and community groups.

Sustainable Architecture

In 1983, the UN established the World Commission on Environment and Development in an attempt to resolve the conflicts arising out of the aspirations of the developed and developing worlds. In 1989 they published “Our Common Future” or the Brundtland Report (WCED, 1989), which launched the concept of “sustainable development” and was reinforced in 1992 at Earth Summit in Rio. It called for “Development which meets the needs of the present generation without

compromising the ability of future generations to meet their own needs.”

Sustainable architecture is environmentally conscious, energy-saving, and utilizes responsive and renewable materials and systems (Newman, 2001). Ecological and environmental concerns have expanded beyond the issue of the consumption of non-renewable energy sources. Sustainability essentially aims for ecological balance.

The High Performance Tall Building: Environmental awareness extends to both the urban environment and the context in which a tall building is placed as well as its interior environment. The issues of outdoor microclimate and indoor air quality as well as the potential toxicity of materials and chemicals used in building components, systems, and furnishings are also of concern to the building users. In a broad sense the term “green” is often used for a sustainable, which essentially describes design, construction and maintenance practices that minimize or eliminate the negative impact of a building on the environment and on the users.

Tall buildings are massive consumers of energy. They are the dominant elements in urban architecture due to their scale and purpose, and should be the focus of sustainable design. A high performance tall building is one that achieves the peak efficiency of building functions while meeting the requirements of optimum performance employing green technologies. These technologies and innovations offer radical changes to the built environments in terms of energy usage, structural

performance, and environmental effects. In other words, a high performance tall building warrants an optimal approach to design for maximum sustainability. Designing a sustainable tall building, therefore, requires a 360-degree view of the entire building enterprise considering the local and global environment, the availability of renewable and non-renewable resources, community impact assessment, and the collaborative input of architects, planners, engineers, social scientists, behavioral scientists, and other community-based groups. Clearly, the design process is significantly complex since the designer has to understand the building performance in terms of different design factors and variables and under differing conditions. Some overall benefits of high performance design are: energy efficiency, design flexibility, resource conservation, indoor environmental quality, etc. (Donaldson and Lippe, 2000).

The Design Factors

The principal design factors that are crucial for achieving a high performance tall building are site context, environment, structure and use of materials, energy consumption, use of water, ecological balance, community development, etc. Because of these diverse aspects of design for tall buildings which have enormous scales as a building type, the amount of information that guides the design is often very complex, and shared by professionals of different disciplines. Further, the design factors assume different forms, such as conceptual, schematic, physical, economic, environmental, and socio-cultural. This demands smart design and integration, which hold the key to high performance buildings. The design team comprising different professionals must aim for the common goal set early on that “the building will offer optimum performance” and must have a respect and understanding for each other’s mission. This goal must have clarity and be performance oriented, attainable, and mostly measurable.

For high performance buildings, the full integration of architecture and engineering is crucial. A well integrated high performance building may incur a slightly higher cost than a regular one which is however offset by lower operational cost (Ali and Armstrong, 2006).

An integrated process is necessary because of their scale and the fact that green design affects so many different elements of a building, such as daylighting, which in turn concerns siting, orientation, building form, facade design, floor-to-floor heights, interior finishes, electric lighting controls, and cooling loads, among other things. A green or vegetated roof, with its impact on storm water runoff, building structure and form, thermal insulation, and plantings, is another example where integration must be considered (Malin, 2006).

Integration among the hardware components of building systems is approached with three distinct goals: Components have to share space, their arrangement has to be aesthetically resolved, and at some level they have to work together or at least not conflict with each other (Bachman, 2003). Bachman lists three types of

integration: physical integration, how components share space or fit together; visual integration, how they achieve visual harmony; and performance integration, how they share functions with other components and systems. The Hong Kong and Shanghai Bank Building, designed by Foster and Partners, in Hong Kong is an example where the visual expression of the physical systems and components of the building creates a powerful aesthetic impact.

Integration Web: The Tall Building System Integration Web (see Figure 1) is a tool to assist architects and engineers in the decision-making process at critical stages by clearly defining the relationships of all physical systems and subsystems of a tall building (Ali and Armstrong, 2006). While all buildings require integration, sustainable tall buildings require a greater level of integration at the early stages of the design process because they require coordination of complex, interdependent systems. However, over-emphasizing integration at the conceptual phase of a project can also be a drawback especially when considering LEED (Leadership in Energy and Environmental Design) credits. The checklist of LEED points can be helpful in identifying measures to pursue, many of which benefit from an integrated approach. But focusing on individual credits too early in the design process can also get in the way of design integration producing a “point-chasing mentality,” which drives up project expenses by causing people to forget how the points work together. During initial meetings, it is more useful for a team to focus on sustainable goals and opportunities on a broader level (Malin, 2006).

Technology Transfer

“Technology transfer” refers to the process whereby the techniques and materials developed in one creative field, industry, or culture are adapted to serve another (Pawley, 1990). It is a synergistic process through which the research and development effort of the donor field is exploited in order to lighten the cost-burden of the pre-production phase of the receptor field. One example that has been applied to building construction is the automatic assembly line, which originated in the automobile industry, where building a complex mechanism in large numbers and on a scale that required robotics and machine production methods (Giedion, 1948). Like buildings, it required the coordination of machines, materials, and labor in interdependent processes regulated by time.

New developments in aeronautical engineering, production and assembly methods, and new materials often find their way to the building construction industry. The design of a jumbo jet, for example, can be compared to a building in terms of scale, integration of complex systems and intelligent technology, structural engineering to resist wind loads and create an efficient, aerodynamic design, and the development of new materials to increase strength and reduce weight and drag. Like tall buildings, aircraft are self-contained environments with their own

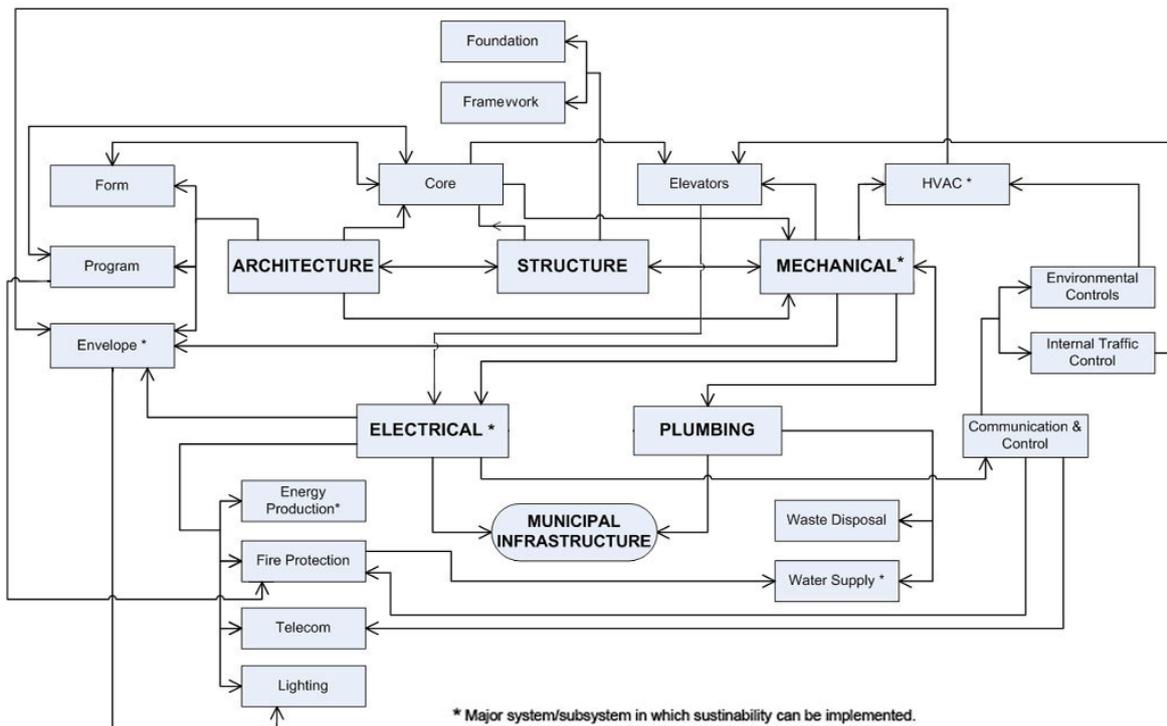


Figure 1: Tall Building System Integration Web

micro-climates. Because they often fly at high altitudes, their interiors must be pressurized to withstand external air pressures and to maintain comfortable pressure levels within for occupants to maintain proper sensory response. Like a tall building, they are designed and assembled on a large scale, which requires careful planning, coordination, and integration of complex systems. This integration begins at the earliest stages of design to avoid costly mistakes during fabrication and assembly.

Composite materials have been developed for fuselages to increase strength and reduce weight. Carbon fiber is light-weight material that can be laminated to produce an extremely strong cladding material for the exterior surfaces of jumbo jets. The manufacturing process of carbon fiber is very expensive, however, and involves nano-scale technology. Hence, there is only one major manufacturer of carbon fiber materials in the world today. The aircraft industry has recently used carbon fiber reinforced composite material for the latest 787 jumbo jets. Although carbon fiber composite materials have not been widely used in tall buildings to date, they hold great promise in reducing the weight and mass and increasing the structural strength of columns, girders, trusses, and beams of supertall buildings in the future. A 40-story multi-use “carbon tower,” designed by architect Peter Testa, has been proposed as a visionary project (Beedle *et al.*, 2007).

Strategies for Achieving Sustainability

Since the beginning of the industrial age in 1830, building technology has advanced from monolithic structures with marginally controlled passive

environments to glass-enclosed skeletal frames with intelligent robotic servicing. Much of this change occurred after 1940 with proliferation of mechanical, electrical, and plumbing systems (Bachman, 2003). The obvious influence of industrialization has been first, the progression of advanced materials that performed better and lasted longer; and second, has been the standardization of building components that could efficiently be produced by machines. Modern technical solutions now may come as well-ordered or totally preconfigured systems designed by other professionals facilitating fast construction.

LEED Rating System: The U.S. Green Building Council has developed the LEED Green Building Rating System to promote sustainable design. This is a voluntary program under which building owners can have their building rated for environmental impact in levels ranging from regular certification to silver, gold, or platinum. The rating system measures building performance on the basis of comprehensive criteria that are grouped under the following six parameters: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor air quality, and innovation and design/build process. While the LEED rating system offers a checklist for typical green commercial buildings it does not address high-rise residential construction and does not explicitly cover all aspects of green design that would yield a bioclimatic built form, such as structural practice, ecological impact, infrastructure, social systems, and community development.

While engineers view sustainability in terms of energy conservation through innovations in mechanical

systems, architects look upon it through the prism of building configuration, passive measures and improved façade design. Collaborating with building energy specialists and structural framework planners, they have designed projects that utilize sophisticated engineering to allow buildings to be responsive to their climatic contexts.

The following are a few strategies that can be adopted to accomplish sustainable tall buildings.

Passive Solar Gain: Tall buildings are less constrained than low-rise buildings by the geometry of the site or the layout of the streets. Because of their verticality, more of the ground area can be freed up and allocated to public uses and amenities in the form of plazas, shopping and recreation spaces. Maximum advantage can be taken of daylight by shaping the plan arrangement of a building to suit the activities within. The fabric of the façade and the area assigned to windows is of ultimate concern in gathering sunlight. The orientation of the building in relation to the seasonal paths of the sun across the sky has a significant impact on the thermal value and performance (Deshmukh, 1992).

concrete buildings are typically the materials of choice. The embodied energy of the materials used in the structural system of a tall building is far greater than that in low-rise buildings that generally employ wood, brick, stone, etc.

Façade Technology: Daylighting and shading are usually the key aspects to façade design for typical green buildings. The façade covers over 90 to 95 percent of the external building surface area in a tall building, that is, the roof area is almost insignificant compared to façade areas. Thus, the energy gain or loss for a tall building depends very much upon the materiality and technology employed in the façade treatment. Facades not only offer the aesthetic look and the building’s architectural expression, but it can also be advantageously used to control the internal conditions of the building, since it represents the building’s envelope or “skin.”

The latest trend is the use of double skin, and occasionally triple skin, façade with ventilation system (Behr, 2001). Double glazing with argon-filled cavities, triple-glazing and glass coatings can increase U-values (Pank *et al.*, 2002).

Table 1. Energy Output Distribution of CHP System

Electricity	25 percent
High grade heat	55 percent
Medium grade heat	10 percent
Low grade heat	10 percent

For the design of a sustainable high-rise building a few passive low-energy strategies and ecological design principles may also be considered. These are: natural ventilation of spaces; location of service cores; narrower floor area; sunshading; wind scoops; skycourts and atriums; and smart materials. The service cores in a tall building should be located in the building to allow natural daylight and ventilation to the elevator lobby and stair areas (Beedle *et al.*, 2007). Solid concrete cores can act as a second line of defense against deliberate attacks using airplanes or missiles (Ali, 2003). In general, the more time spent on the core design, the more efficient and sustainable the building can be.

Structure and Material Preferences: At first sight it is hard to relate sustainability to the structure of a tall building. However, there is a relationship that needs to be investigated in each building—particularly tall building in which the structural framework is enormous. For example, the core provides structural stability and its positioning is important for sustainability (Beedle *et al.*, 2007). To capture cold night air in desert-like climate and harvesting it as cooling energy during occupied hours, a massive concrete structure can be employed. Also, a steel framed structure can be made of recycled content. As buildings go taller, the structural frame gets heavier. Although residential masonry buildings can be built up to 60 stories (Khan, 1974; Ali, 2001), steel and reinforced

Harnessing Solar Energy: There are two categories of solar energy: passive and active. Passive solar energy is put into practice as a design strategy to accomplish direct or indirect space heating, daylighting, etc. Active solar energy is implemented through technical installations such as solar collectors and photovoltaic (PV) panels. The average annual growth rate of PV cells has been at 30 percent in recent years (IEA, 2003). The application of PV technology for tall buildings can be significant since they provide an opportunity for a clear path of direct sunlight by towering over other buildings. The Law Courts Building in Los Angeles designed by Perkins and Wills is a recent example of a sustainable tall building in which PV panels are integrated with aesthetics providing efficiency and a high-tech expression of the building.

Harvesting Wind Energy: Wind is a renewable energy source which can be advantageously tapped at higher altitudes of tall buildings where wind speed is considerably large. Tall buildings can be shaped to funnel wind into a zone containing wind turbines without having negative effects on the structure, its surroundings and the occupants. By such profiling of the structure, wind speed can be amplified that can produce more energy.

The Beddington Zero Energy Development in Sutton, London, for example, uses the concept of “eco-functional” design developed by Bill Dunster to

harness energy from the wind and the sun (Pank *et al.* 2002). His Flower Tower has a footprint of interlocking petals which meet in a space in which a vertical axis wind turbine is installed. While this design was originally intended for a housing development, it could be suited as well for a mixed development of an office block. It is a highly insulated building equipped with wind turbines and PV panels on the roof and the walls.

Combined Heat and Power: A highly efficient technology for energy saving in densely built-up urban areas is the Combined Heat and Power (CHP) system. CHP is the simultaneous production of power, heat and, occasionally, chilled water for air-conditioning, and is also known as co- or tri-generation. CHP avoids transmission losses as electricity is generated close to the point of use. The simultaneous production of electricity and heat in a useable form enables overall thermal efficiencies, meaning significantly less fuel is used for a given amount of work. The result is a cost saving and reduction of CO₂ emissions of over 30 percent with respect to generation from coal-fired power stations and over 10 percent with respect to gas fired combined cycle gas turbines. The widespread use of CHP is common in many European cities. Stockholm, Helsinki and Copenhagen, for example, provide much of their electricity and heating from CHP systems. CHP technology can be applied as well to the considerable loads of individual tall buildings or groups of tall buildings where the electricity load and annual cooling requirements are similar. A typical distribution of total energy output from a CHP system is shown in Table 1 (Smith, 2001). CHP is thus an attractive option since most of the energy is useful and it can be adapted to low to zero carbon applications. It is a flexible system.

Fuel Cells: Fuel cells are electromagnetic devices that generate electricity like batteries and can be considered as electrochemical internal combustion engines. They take continuous supply of fuel, usually hydrogen. The most efficient way of extracting hydrogen is from natural gas or methanol by using a reformer unit, which is then fed directly into the fuel cell. A fuel cell is essentially a reactor that combines hydrogen and oxygen to produce electricity, heat, and water. Therefore, its environmental qualifications are immaculate. At this time its cost is high but with future mass production it is bound to go down. Fuel cells are used in spacecrafts and airplanes. Now they are being used in buildings such as in the Conde Nast Building in New York City. In the near future fuel cells will provide heat and electricity for many offices and residences.

Fuel cells are clean, quiet and efficient with few moving parts. They are classified by their type of electrolyte. One of the most common kinds of fuel cell is the proton exchange membrane fuel cell (PEMFC). Some other types are phosphoric acid fuel cell (PAFC), solid oxide fuel cell (SOFC), alkaline fuel cell (AFC), and molten carbonate fuel cell (MCFC). The U.S. Department of Energy plans to power two to four million households with hydrogen and fuel cells by 2010 and 10 million

households by 2030. A fuel cell depends on renewable energy and will warrant an efficient electricity storage system. This remains a challenge at present. It has great potential as a carbon neutral energy source of the future.

Other Strategies for Green Tall Buildings

There are other approaches to the design of sustainable tall buildings. For example, energy consumption by elevators is significantly high as the cost of operating and maintaining them is also high. Because of the construction of many supertall buildings, elevator technology has been a topic of continuous research and development. Significant improvements have been made in this technology to make the elevators safe and the mode of travel efficient and comfortable (Beedle *et al.*, 2007).

Rainwater harvesting collects the rain onto roofs, then stores it in a tank, intended for eventual use. When required, the water is pumped to the point of use, thus replacing what would normally be a demand for regular water. The size of the storage tank is determined considering the amount of water available as a function of roof area and local average rainfall. The recycled water is used for toilets, washing machine and outside tap use. Grey water recycling is another process in which water from bath, shower, and hand wash basin is reused. This “grey water” is more suited to residential tall buildings in which sufficient amounts are generated regularly for reuse in toilets, washing machines and outside tap. The proposed Freedom Tower in New York has included water recycling systems in its design.

Biomass Energy: In addition to solar and wind energy, another source is the bioenergy. Biomass is the sum total of all the Earth’s living matter within the biosphere. More specifically, it refers to the concept of growing plants as a source of energy. The energy reaching the planet is equivalent to about seven times its primary energy expenditure. When biomass is converted to a fuel as a store of chemical energy the process is carbon neutral, that is, the carbon emitted when it is burnt equals the carbon absorbed during growth.

Biomass fuel, such as waste paper can be used for generating electricity and steam for high-rise buildings. A 73-story multi-use high-rise project was investigated by Alfred Swenson and Pao-Chi Chang of the Illinois Institute of Technology, Chicago in this regard (Ali and Armstrong, 1995). Substantial amounts of biomass are ubiquitous in tall office buildings in the form of paper, most of which is used only briefly and trashed. The use of gas turbines with biomass fuels was investigated at the Princeton Center for Energy and Environmental Studies (Larson and Williams, 1990). Biomass energy generation does not contribute to global warming.

Geothermal Energy: Geothermal energy is one of our most plentiful resources. The “geothermal gradient” i.e., the rate of increase of temperature according to depth in the ground, averages 36.5 to 37.5 degrees F (2.5 to 3 degrees C) per 330 ft. (100m) of depth. Modern drilling techniques can penetrate up to about 6 miles (9.5 km). The most common surface manifestation of geothermal

energy is simply hot water from springs. Natural hot water has been used since the nineteenth century for industrial applications. The first geothermal power station was built in 1913 which produced 250 kW (Smith, 2001). Another source is the high-temperature dry rock. The geothermal heat has to be brought to the surface. Water is pumped through boreholes and returned to surface to provide space heating — a process known as borehole heat exchange (BHE) system

A significant area of innovation is the pairing of geothermal energy with heat pump technology. This technology has incrementally been improved, especially in the U.S. During the last five years the number of geothermal ground-source heat pumps has grown by 59 percent with most of the development in the U.S. and Europe (Smith, 2007). Development and refinement of this technology and its application to tall building design could prove to be more relevant than any other building type.

Building Management Systems

Innovative building technologies such as computer-based smart or intelligent building systems can play a major role in managing the energy usage. The increasing reliance on computer technology and automated systems can be directed toward achieving a sustainable functioning of skyscrapers. The Building Management System (BMS) is a centralized control system to manage the operations of the various building systems such as fire protection, security, communication networks, elevators, HVAC systems, etc. The environmental data collection and control system is usually incorporated within the BMS which can also be used to control more passive features like opening windows and shading devices. The component of the BMS that deals with energy-related services is controlled by the Building Energy Management System (BEMS), also known as the Energy Management and Control System (EMCS), which may in some circumstances function autonomously. The control system need not be located on-site and the supervision of the system can be centrally for multiple building complexes or for a number of similar buildings in outlying areas.

Energy Performance

Although a tall building may be designed to be sustainable and energy efficient, its actual performance in this regard needs to be assessed and verified. Computer software packages for assessment methods are developed and constantly upgraded to offer designers a tool for determining the energy performance and lifecycle costs for the buildings they design. Extensive research is needed to measure the performance of sustainable tall buildings that were recently built. While this seems to be a straightforward task that may merely involve collection of data on year-round energy usage on a global scale for a building, the challenge lies in finding out the relative energy consumption for different systems, such as mechanical and HVAC, lighting, computing, elevators, etc.

The utility companies keep track of the total energy consumed and not the energy consumed by each system in a building. Being aware of the breakdown of energy demand of a building in terms of its systems will enable designers to design the building in a more efficient manner. Another area of research will be the development of strategies for making recently built tall buildings sustainable. This obviously is a much bigger challenge since it involves remodeling and reconstruction.

Europe has pioneered building sustainable high-rises. As of this writing, plans for Brighton Marina have been approved by Brighton & Hove City Council, UK. This 40-story multi-use tower, when built, will be a good example of sustainable tall buildings. The architect for the project adopted renewable energy harnessed from solar, wind, wave and CHP and other green technologies to reach a 25 percent reduction in domestic water use and a 40 percent reduction in carbon dioxide emissions. It will be one of the most sustainable developments in the country, achieving 100 percent EcoHomes “Excellent” rating (World Architecture News, 2006).

A principal reason of why European architects are leading the way in terms of sustainable design is the fact that legislation in some European countries requires the building owners to take on a more responsible attitude to energy consumption. Energy costs are higher in Europe than in the USA making the reduction in life cycle cost of a building and making expensive initial cost systems viable investments. Germany has also made an enormous contribution to sustainability by building a few remarkable towers based on sustainable principles, such as the Commerzbank Tower in Frankfurt and RWE Headquarters in Essen. In Asia, Malaysia has led the way by applying the bioclimatic design principles suitable for tropical climate (Yeang, 1996). Thorough analysis of site and its environment is fundamental to the design of a climate-sensitive skyscraper. The analysis should range from the general macro-climatic characteristics of the region, including solar radiation, wind, air temperature and humidity data to the more site-specific conditions at the micro-climatic level. Such analysis should also include the effects of shadows, the topography, vegetation, adjacent buildings and the availability of daylight.

Case Studies

A new generation of sustainable tall buildings is challenging conventional high-rise building practices and setting trends for future projects incorporating innovations in materials and intelligent building systems.

Menara Mesiniaga: Ken Yeang and T. R. Hamzah were among the first architects to apply ecological principles to their “bioclimatic skyscrapers.” The Menara Mesiniaga in Subang, Malaysia (see Figure 2), designed in 1992, presents an early model building for the physical translation of ecological principles into high-rise architecture (Abel, 2003).

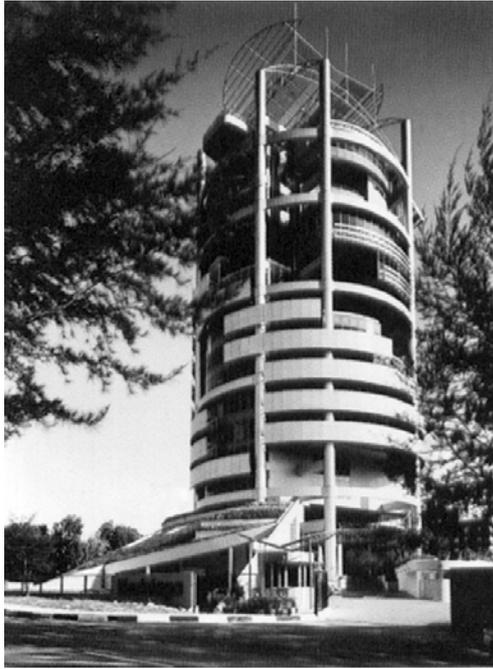


Figure 2: Menara Mesiniaga, Kuala Lumpur, 1992, T. R. Hamzah & Yeang (Beedle *et al.*, 2007, Plate 28).

The fifteen-story tower expresses its technological innovations on its exterior and uses as little energy as possible in the production and running of the building. Instead of a continuous facade, the building opens and closes in sections arranged in stages around the tower. It has an exterior load-bearing structure of steel with aluminum and glass, and a crowning superstructure for the roof, planned as a future support for solar cells. The interior and exterior structure of the tower is planned around climatic considerations and its orientation toward the daily path of the sun. The massive core of the building, with elevator shafts and staircases, faces east and screens off the penetrating heat up to midday. Deep incisions and suspended aluminum sunscreens on the south facade ward off the direct rays of the noon and afternoon sun into the interior. Most of the office space faces west and north. Around the base of the tower lies a semicircular, steeply sloping garden, which continues into the building itself in the form of spiral terraces planted with grass. This visibly brings the natural environment into the architecture.

Swiss Reinsurance Headquarters: Foster and Partners developed new technological, urban planning, and ecological design concepts in the Swiss Reinsurance Headquarters building (see Figure 3) constructed in 2004 in London. The steel spiral “diagrid” structure creates an aerodynamic form that provides the lowest resistance to wind and diminishes demands on the load-bearing structure, as well as the danger of strong downward winds in the area around the building. The office spaces are arranged around a central core with elevators, side rooms, and fire escapes. The net-like steel construction of the load-bearing structure lies directly behind the glass facade and allows support-free spaces right up to the core.



Figure 3: Swiss Reinsurance Headquarters, London, U.K., 2004, Foster and Partners, (Courtesy Katrina Haagensen).

The most innovative element in the inner structure is the inclusion of triangular light shafts behind the facade, which spiral upwards over the whole height of the building. These light and air shafts are interrupted every six stories by an intermediate floor, to minimize the development of drafts and noise.

The Swiss Re Tower has a circular plan that widens as it rises from the ground and then tapers toward its apex. This form responds to the specific demands of the small site and reduces its apparent bulk as compared to a conventional rectangular mass of equivalent floor area. The slimming of the building’s profile at its base reduces reflections, improves transparency, and increases daylight penetration at ground level. The aerodynamic form of the tower encourages wind to flow around its face, minimizing wind loads on the structure and cladding, and enables the use of a more efficient structure. Natural air movement around the building generates substantial pressure differences across its face, which can be used to facilitate natural ventilation within the building (Foster, 2005).

Conde Nast Building: The Conde Nast Building (see Figure 4) at 4 Times Square of 1999 in New York City is a 48-story office tower, is the centerpiece of the 42nd Street Master Plan prepared by the 42nd Street Development Corporation, a public/private consortium created to promote the redevelopment of this traditional heart of Manhattan (Wired New York, 2007). Designed by Fox & Fowle Partners, many of its innovations are considered standard for office buildings today.



Figure 4: Conde Nast Building, 4 Times Square, New York, 1999, Fox & Fowle Partners, (Wired New York, 2007).

The facades of the building address Times Square entertainment district to the west and the corporate Midtown area of Manhattan to the east. The building sets new standards in energy conservation, indoor environment quality, recycling systems, and use of sustainable materials. The large areas of glass curtain wall maximize daylight penetration into the office floors and incorporate low-E glass coating to filter out unwanted ultraviolet light while minimizing heat gain and loss. PV panels have been integrated in spandrel areas on upper floors of the east and south facades, generating a meager but symbolic amount of electricity by day. Sophisticated mechanical systems ensure high indoor air quality by introducing filtered fresh air into the office environment. Tenant guidelines produced by the architects established environmental standards for living, power usage, furniture systems, carpets, fabrics, finishes, and maintenance materials to ensure indoor air quality and also as a comprehensive strategy to maintain environmental sustainability for the life of the building.

The Solaire: Located at Battery Park in New York City, the Solaire (see Figure 5) is the first residential high-rise building in the U.S. to integrate green features in a comprehensive way (Carey, 2006). It is a 27-story, 293-unit luxury apartment building located on the Hudson River developed by the Albanese Organization and designed by Cesar Pelli & Associates. Its sustainable features include PV panels incorporated into the building's facade, a planted roof garden, and fully operational blackwater treatment system. It is based on guidelines developed by the Battery Park City Authority, which address five areas of concern: 1) Enhanced indoor air quality; 2) Water conservation and purification; 3) Energy efficiency; 4) Recycling construction waste and

the use of recycled building materials; and 5) Commissioning to ensure building performance (Carey, 2006).



Figure 5: The Solaire, Battery Park, New York City, 2003, Cesar Pelli and Associates, (Carey, 2006, p.70).

The Pearl River Tower: The Pearl River Tower (see Figure 6) is a 990-foot (300-meter) tall "net-zero energy" mixed-use building, which will be completed in 2010 in Guangzhou, China. Designed by Adrian Smith and Skidmore, Owings & Merrill, it has a curved glass facade that directs air flow through narrow openings in the facade that will drive large, stainless steel wind turbines to generate electrical energy. The building's aerodynamic shape, which resembles airplane wings turned vertically, was developed in collaboration with Rowan Williams Davis & Irwin, Inc. of Ontario, Canada using the RWDI-Skin suite of proprietary analysis tools, including its Virtualwind simulation modeling (RWDI Group, 2007).

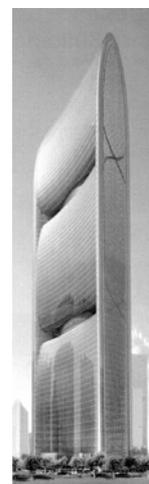


Figure 6: Pearl River Tower, Guangzhou, China, 2010, Adrian Smith and Skidmore, Owings & Merrill, Ltd., (RWDI, 2007).

Conclusions

Despite evidence of global warming, emissions from the most industrialized countries are showing little sign of abating. Experts estimate that as high as 60 percent global cut is necessary to halt global warming, which seems to be a far cry at present (Smith, 2001). The best chance for the survival of the developed countries seems to lie with the built environment because buildings in use or under construction are the greatest single indirect source of carbon emissions.

The paper shows that high performance tall buildings are achievable by adopting the appropriate strategies. The future of the built environment depends on the methods and techniques used by engineers and architects to design sustainable, intelligent buildings. Although application of new technologies to tall buildings will improve our living conditions incrementally, humanism will define our future. The initial cost of integrated green tall buildings may be 5 to 10 percent higher than that of a conventional building, but the long-term lower operational cost makes it justifiable.

By reducing both embodied and operational energy demands of tall buildings and the infrastructure, the life-cycle energy consumption can be reduced. Sustainability of tall buildings must therefore be viewed as an integral part of the city's sustainable growth. Responsible attitudes are also needed to conserve water and reduce waste and recycle materials during the building construction and demolition processes. A zero energy building may be achieved through high performance design, integrated physical systems, a symbiotic building within its context, and an interactive power grid with the building's energy generation system.

Market forces have begun to propel the governments and the private sector towards renewable energy in most industrialized countries with a few exceptions. Whatever the future holds for the environment, tall buildings must become sustainable considering the environment, long-term economic growth, and human needs.

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