The Emphasis on Ecological Design for High-rise Buildings

Feng Xu, Associate Professor
Guoqiang Zhang, Professor
Mingjing Xie, Ph.D Candidate
Hunan University
Changsha, China, 410082
xufeng@188.com

Abstract: Along with the rapid development of urbanization, there are more and more high-rise buildings in cities. Meanwhile, the negative impacts of high-rise buildings on the urban environment have become more and more serious. The ecological design of high-rise buildings should be paid more attention because high-rise buildings consume a large amount of natural resources and energy. An ecological design method of high-rise buildings was introduced based on four points: adaptation of climate, ecological accounting, passive design and energy saving and integrated design.

Key words: high-rise buildings; ecological design; climate; ecological accounting; passive design; integrated design.

1. INTRODUCTION

Along with the development of industry, commerce and finance and rapid increase of city population, land resources became scarce. High-rise buildings (HRBs) quickly developed because of its gigantic economic value. HRBs can decrease the waste of land resource and return more land to nature. Le Corbusier considered skyscraper as a “perfect means to solve the population concentration, avoid land scarcity and increase internal efficiency of the city.” In 1952, the Lever House, designed by Gordon Bunshaft who worked in SOM design business office, created a template of standard skyscraper with an authorized form and became the original form of thousands copies all over the world. The skyscrapers even acted as a symbol of economic ability and scientific ability of a country or a city.

But HRBs cause a series of problems during the development. For example, consume large amount of energy, affect the sunlight and air flow in the city environment and destroy the ecological environment. Along with the serious problems of energy resources, people paid more attention to the ecological impact cause by the HRBs [1]. In 1982, the National Commercial Bank Headquarters at Jeddah, which was also designed by Gordon Bunshaft, represented huge change of the HRBs towards ecological way [2]. Therefore, more efforts deserve to be paid in the ecological design of HRBs. So far as the reasonable urban planning and the environmental design in accordance with the design and construction of HRBs, we can reduce the energy consumption and the impact on environment, and achieve the ecological objective with the economic objective to realize the ecological and sustainable development of HRBs.

2. CLIMATIC ADAPTATION

2.1 Relationship between Climate and HRBs

Le Corbusier dissertated the purpose of building as: “A house: A shelter from the heat, the cold, the rain, thieves, indiscreet people. A light and sun receiver” [3]. In 1963, Victor Olgyay put forward a design theory of integration of architectural design, region and climate in his book — Design With Climate: Bio-climate Approach to Architectural Regionalism. It emphasized the concordance between artificial climate and natural climate; this symbolized the foundation of bio-climate theory.

In 1982，the National Commercial Bank HQ at Jeddah designed by Gordon Bunshaft represented the ecological turning of practice of HRBs. It emphasized the adaptation of desert zone: very deep hole on huge mass, all glasses dropped back, insulated stone used in exterior surface — consideration of the sun effect on building surface; pure form — smaller form coefficient; skycourt constituted by the vertically overlaying V shape planes — microclimate improvement and native air cooling for glass curtain.

Among all environmental factors that HRBs may face, climate is a dominant factor. All buildings must finish this objective — make accordance between human needs and specific climate and geography [4]. In nature, the relationship between climate and HRBs is to resist the disadvantage of climate and utilize the natural climatic resources. Thus the design solutions of HRBs should grow from climate. The design procedure of HRBs should follow: climate — biology (comfort) — technology — design. Designers should adapt the characters of different climate zones and achieve the purpose of energy saving and environmental protection by means of utilizing heat preservation, heat insulation, natural ventilation and sunlight shading actively and reasonably.

2.2 Architectural Composition

Architectural composition of HRBs is related to path of sunlight through the base and local wind direction. The decision of composition will affect every subsequent design strategy. The sunlight routeway decides the main orientation of HRBs that ensure the utilization of natural sunlight resources to process daylighting, passive solar energy heating and solar electric power generation. The local wind direction and air flow distribution are also prerequisites for composition that avoid intercepting cold and moist air in winter and preventing cool breeze in summer. Through carefully study on basic micro climatic condition, we can ensure the most suitable orientation and composition that furthest utilize the potential of natural climate in the site.

2.3 Plane and Form Coefficient

In HRBs, small form coefficient can reduce the exposure interface under external climate. This is of advantage to either heat loss in winter or heat gain in summer. It means that smaller form coefficient can decrease average cost of comfort space. But the relationship between form coefficient and heat performance in HRBs is very complicated, it is not a simple ratio. Thus we must consider it synthetically form three aspects, which are building height, plane form and function disposal.

(1) Building Height

HRBs (especially skyscraper) are much higher than ordinary buildings. The form coefficient of HRBs is much bigger than that of ordinary buildings with the same volume (or usable floor area). So, the height of HRBs is not the taller the better but need to be properly controlled. It should be as low as possible on condition that satisfy the prerequisites of architectural aesthetics and building density.

(2) Plane Form

In constant plane forms of HRBs, round plane has the smallest external surface area, and the square plane is in the next place. If possible, use flattening plane because unevenness plane results in bigger form coefficient [5]. But the purpose of using unevenness plane is to form courtyard or atrium for daylighting and natural ventilation. There are two kinds of methods to solve this problem. One method is to increase the chance of daylighting and natural ventilation by using minor depth of floor while avoids using courtyard. Another possible method is to use adjustable glass interface system outside the building and close courtyard or atrium while under extreme climate (Fig. 1).

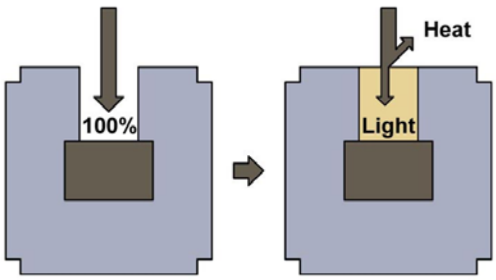

Fig. 1 Adjustable Glass Interface System Closes Courtyard or Atrium under Extreme Climate (e.g. Winter)

Climatic characteristics vary from different regions, so the best plane form of HRBs is not with the smallest external surface area. According to the investigation, the suitable plan ratio (X/Y) of HRBs in different climate zone is shown in Fig. 2.

(3) Function Disposal

No matter in what kind of climatic condition, people's request for heat comfort varies from different function and space. This demands better consideration for the relationship between internal function needs and external climatic conditions while designing function disposal of the HRBs. For example, in HRBs, those rooms with no specific environmental requirement (such as ordinary offices) should be arranged to proper orientation that can use daylighting and natural ventilation. Those rooms that emit large amount of heat (such as kitchen) should be arranged to the north orientation. Some rooms with specific requirement (such as cleaning rooms) could be arranged to central region of the building [6].

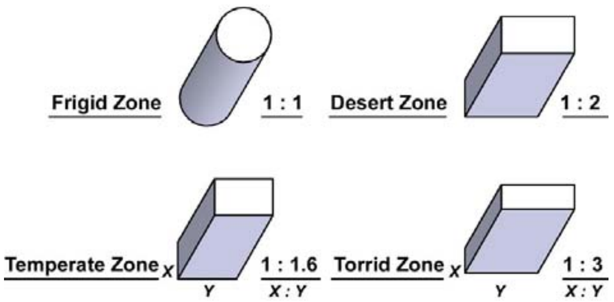

Fig. 2 Suitable Plane Ratio of HRBs in Different Climate Zone

3. ECOLOGICAL ACCOUNTING

The problems of energy utilization and energy supply in HRBs were put forward and considered in the 70's and 80's of 20 century after the energy crisis. After the 90's of 20 century, the ecological and environmental factors in HRBs became the focus of study and argument.

3.1 Concept of Ecological Accounting

On October 19th, 1994, the EDI institute，which was found by Sim Van der Ryn, published The BIG SUR declaration. This declaration advanced that the ecological design must "erect the whole concept of ecological accounting and evaluate design with environmental impact on the life cycle of the building" [7]. Ecological accounting is a kind of standard for assessing the design based on three kernel concepts, which are energy, environment and ecology, and for predicting the ecological efficiency of different design selection. So, it should be used at the beginning of the concept design but not after construction.

3.2 Factors of Ecological Accounting

HRBs consume and occupy much more energy and resources than ordinary buildings, so the ecological accounting must be considered as an important factor. We should think better of a serious impact on energy, environment and ecology during the HRBs design procedure. Meanwhile, we should do quantity analysis with multidisciplinary knowledge to ensure the beneficial cycle of ecology. Some issues about ecologic accounting factors that need to be considered are list as follow:

(1) Energy

- •Take full advantage of solar energy and light energy;
- •Heat regeneration / cycle utilization;
- •Renewable energy source / wind energy;
- •District heating / built-up heating and power supply;
- •Decrease energy demand and load;
- •Position, building lot selection and orientation;
- •High efficient composition;
- •Thermal insulation;
- •Use low energy consumption equipment as possible.

(2) Environment

- •Site selection / orientation / composition can utilize sunlight / fresh air / scene;
- •Reduce garbage and offer space for garbage classification / collection;
- •Pollution restriction;
- •Do not use poisonous / environmental disruption chemicals;
- •Plant trees for carbon dioxide absorption;
- •Provide convenience public traffic and reduce private car using;
- •Provide field for bicycle riding / depositing.

(3) Ecology (Nature Protection / Biology Diversity)

- •Preserve / improve current environment of vegetation and animal;
- •Choose indigenous species;
- •Utilize natural site and micro-climate condition;
- •Choose plants that need less water;
- •Provide opportunity for feeding / nidification;
- •Build / reserve autarkic green belt.

4. PASSIVE DESIGN

4.1 Significance of Passive Design in HRBs

Maximum utilization of natural resources such as solar energy, wind and daylighting is the most efficient way for energy saving. The so-called passive design is directly generate power through utilization of climatic characteristics but not in virtue of mechanical system. Properly designed and constructed passive buildings offer many benefits: [8]

(1) Energy Performance: Low energy bills year-round;

(2) Investment: High economic return on the incremental investment on a life cycle cost basis and greater financial independence from future rises in energy costs;

(3) Comfort: Greater thermal comfort, less reliance on noisy mechanical systems;

(4) Productivity: Increased daylighting / higher quality lighting systems can increase worker productivity;

(5) Low Maintenance: Reduced building maintenance costs resulting from less reliance on mechanical systems;

(6) Environmental: Reduced energy usage and reliance on fossil fuels.

The significance of passive design is very important for HRBs as it consumes more energy. This means that architects should comprehend situation of environment, geography and climate during the design procedure. So, the design could adapt climatic characteristics by means of thermal insulation, natural ventilation and sunlight shading.

4.2 Building Envelope

Compared with ordinary buildings, the building envelope of HRBs has its particularity. On the one hand, wind speed and wind pressure grows quickly with the escalation of height that leads to quick heat exchange between building envelope and outside. This situation is not of benefit to energy conservation. On the other hand, HRBs receives more sunshine than ordinary buildings (including direct radiation, diffused radiation and radiation reflected from roof of the nearby multistory buildings). So, materials with high thermal mass and enough thickness should be chosen for the building envelope of HRBs to reduce and delay the impact on internal space cause by external wall temperature fluctuation.

4.3 Natural Ventilation

Reasonable organization of natural ventilation leads to energy saving and cost cutting. The energy consumption of the natural ventilation is only half of using air-conditioning. Meanwhile, it decreases dependency of those equipments used by mechanical ventilation and air-conditioning to ensure healthy building environment (reduce occur of the Synthetic Building Syndrome). Furthermore, it reduces the emission of carbon dioxide. But HRBs has much longer vertical distance and much bigger volume than that of the ordinary buildings, thus the organization of natural ventilation in HRBs is more difficult.

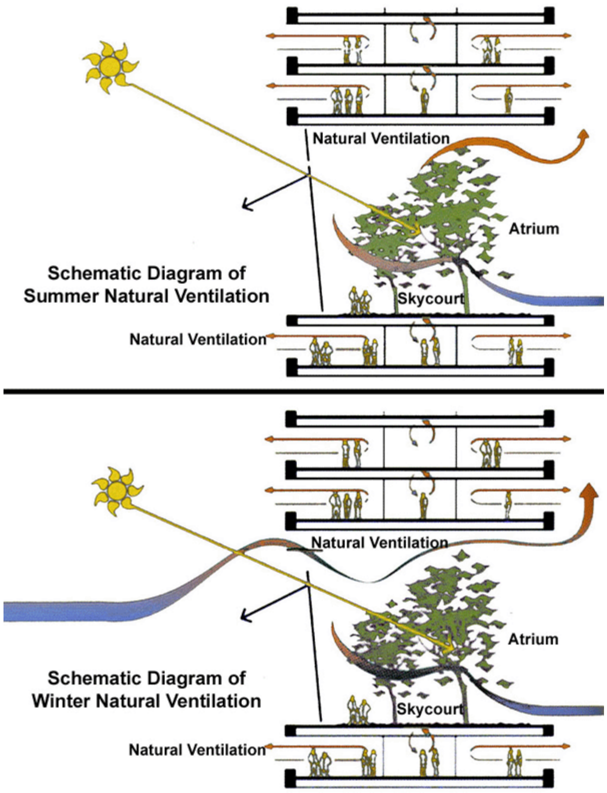

Fig. 3 Natural Ventilation Strategy in Summer and Winter in Commerz Bank Headquarters

Conventional types of natural ventilation include wind pressure ventilation and thermal pressure ventilation. But simply using these two types in HRBs are not suitable because of the instability of natural wind and heat loss in upper air. Mixed ventilation combined with atrium is a better way —

establish ventilation strategies in different seasons and use mechanical ventilation under extreme climate. Fig. 3 describes natural ventilation strategies in different seasons used in Commerz Bank Headquarters, Frankfurt, Germany that designed by Norman Foster [9].

4.4 Daylighting

Daylighting provides more desirable and better quality illumination than artificial light sources. This reduces the need for electrical light sources, thus cutting down on electricity use and its associated costs and pollution. Because of the characteristics of height, HRBs prefer to use sidelighting rather than to use toplighting. So, it is important to avoid direct sunlight and control thermal gain near the window. Some usable principles are list as follow:

(1) Establish the location, shape, and orientation of the building on the site based on daylighting performance objectives;

(2) Avoid excessive thermal gains and excessive brightness resulting from direct sunlight, which can impair vision and cause discomfort. Use indirect lighting through reflecting ceiling and equip with additional elements such as shades, blinds, and light shelves.

(3) Integrate daylighting systems with the artificial lighting system to maintain required task or ambient illumination while maximizing the amount of lighting energy saved.

4.5 Passive Heating, Cooling and Thermal Storage

Integration of passive heating, cooling, and thermal storage features into HRBs can yield considerable energy benefits and added occupant comfort. Incorporation of these items into the HRBs design can lead to substantial reduction in the load requirements for building heating and cooling mechanical systems.

(1) Passive heating works particularly well in climates where many sunny days occur during the cold season. One thing should be attention is to match the time when the sun can provide daylighting and heat to a building with those when the building needs heat. Meanwhile, design the building's floor plan to optimize passive solar heating (e.g. appropriate glazings in windows within 15 degrees of true south);

(2) Passive cooling strategies include cooling load avoidance, shading, natural ventilation, radiative cooling, evaporative cooling, dehumidification, and ground coupling. Passive design strategies can minimize the need for cooling through proper selection of glazings, window placement, shading techniques.

(3) Thermal mass storage can handle excess warmth, therefore reduce the cooling load, while storing heat that can be slowly released back to the building when needed. The thermal mass can also be cooled during the evening hours by venting the building, reducing the need for cooling in the morning.

5. INTEGRATED DESIGN

5.1 Concept of Integrated Design

Integrated Design Process (IDP) is a kind of method with multidisciplinary cooperation. The final purpose of IDP is to gain high performance and extensive benefits with lower cost. Generally, this method tightly combines ecological design strategies with conventional design standards from the aspects of form, function, performance and cost.

The IDP has been developed on the basis of experience gained from a Canadian demonstration program for high-performance buildings, the C2000 program. The goal of the program is to construct ecological buildings with high level by visualized design measures and current building technologies. The development of IDP depends on the Task 23 — Optimization of Solar Energy Use in Large Buildings, which supported by the International Energy Agency (IEA). The subtask B of Task 23 studied the characteristics of IDP and involved 12 countries in 5 years. After arranging the opinions from specialist including architects, researchers and consultants, a set of practical method of the IDP was introduced.

5.2 Necessity of Using the IDP in HRBs

The design procedure and technical problems of HRBs is more complicated than that of the ordinary buildings, thus multidisciplinary cooperation must be emphasized in order to realize the ecological design of HRBs. The cost and energy performance of HRBs is related to the cooperation of design team; only the earliest intervention of the design team composed of different specialty can achieve the optimization of the efficiency of energy and cost (Fig. 4) [10]. The necessity of using the IDP in HRBs demands architects, engineers, urban planners, economists, socialists, technical specialists and other consultants to plunge together. In this multilateral cooperation, all people must make an effect to act with the background of new technologies, scientific researches and revolution thoughts of HRBs.

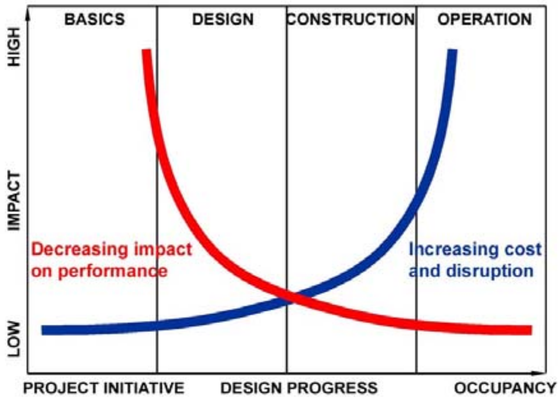

Fig. 4 Effectiveness of Decisions Made in Different Stages of a Building's Lifetime

5.3 Basic Procedure Used in HRBs

Successful IDP of HRBs comes from tight cooperation of designers from different specialty: the architect becomes a team leader rather than the sole form-giver; and the structural, mechanical and electrical engineers take on active roles at early design stages. The team always includes an energy specialist and, in some cases, an independent Design Facilitator. The IDP of HRBs should follow those steps list below [11].

(1) Establish performance targets for a broad range of parameters, and develop preliminary strategies to achieve these targets;

(2) Minimize heating and cooling loads and maximize daylighting potential through orientation, building configuration, efficient building envelope and careful consideration of the amount, type and location of fenestration;

(3) Meet heating and cooling loads through the maximum use of solar and other renewable technologies and the use of efficient HVAC systems, while maintaining performance targets for indoor air quality, thermal comfort, illumination levels and quality, and noise control;

(4) Iterate the process to produce two or three concept design alternatives, using energy simulations as a test of progress, and then select the most promising one for further development.

The IDP process contains no elements that are radically new, but integrates well-proven approaches into a systematic total process. The skills and experience of mechanical and electrical engineers, and those of more specialized consultants, can be integrated at the concept design level from the very beginning of the design process. When carried out in a spirit of cooperation among key actors, this results in a design that is highly efficient with minimal, and sometimes zero incremental capital costs, along with reduced long-term operating and maintenance costs. Furthermore, open inter-disciplinary discussion and synergistic approach will often improve the function and performance of HRBs.

6. CONCLUSION

The design, construction and operation management of HRBs cause huge impact on environment and resources. But it has huge potential on land resources saving, material saving and energy saving. HRBs are not an anti-ecological building form though it may cause unconvertible destruction to civil environment. Through reasonable design, it may bring enormous contribution. Thus the ecological design of HRBs is significant.

Indeed, few HRBs can comprehensively response to all ecological aspects. The design of most HRBs emphasizes on different aspects according to the economic conditions, climatic characteristics and cultural traditions. Four points must be considered during the design process: adaptation of climate, ecological accounting, passive design and integrated design. We should ascertain corresponding design objects and design principles, adjust and apply them to the design practice. This will ensure the HRBs integrate organically with the civil environment and develop towards ecological and sustainable way.

ACKNOWLEDEMENTS

This paper is financially supported by the European Union Asia-Link Programme: “A Multidisciplinary Approach to Curriculum Development in Sustainable Built Environment”.

REFERENCE

[1]America Council on Tall Buildings and Urban Habitat. Architecture of Tall Buildings[M] . Beijing: China Architecture & Building Press. 1997, Preface.(In Chinese)

[2]Chris Abel. Architecture and Identity[M]. Beijing: China Architecture & Building Press. 2003, 201.(In Chinese)

[3]Wang Shouzhi. World Modern Architectural History[M]. Beijing: China Architecture & Building Press. 1999, 95.(In Chinese)

[4]Geoffrey Broadbent. Architectural Design and Literae Humaniores[M]. Beijing: China Architecture & Building Press. 1990, 28.(In Chinese)

[5]Lv Aimin. Climate-responsive Building[M]. Shanghai: Tongji University Press, 2003, 117.(In Chinese)

[6]Brian Edwards. Sustainable Architecture, 2nd Edition[M]. Beijing: China Architecture & Building Press. 2003, 82.(In Chinese)

[7]Research Center of Green Architecture of Xi’an University of Architecture and Technology. Green Architecture[M]. Beijing: China Planning Press. 1999, 147. (In Chinese)

[8]Public Technology Inc. US Green Building Council. Sustainable Building Technical Manual Green Building Design, construction, and operations[M]. Beijing: China Architecture & Building Press. 1999, 71-92.(In Chinese)

[9]Li Huadong. Hi-tech Ecological Building[M]. Tianjin: Tianjin University Press, 2002, 128.(In Chinese)

[10]IEA Task 23. Integrated Design Process - a Guideline for Sustainable and Solar-optimised Building Design. http://www.iea-shc.org/task23/outcomes.htm

[11]Hanne Tine Ring Hansen. The Integrated Design Process (IDP) - A More Holistic Approach to Sustainable Architecture. Proceedings of the SB05 Tokyo[C]. Tokyo, 2005