Title: **The Core Urban Design Strategies of Tall Building - Low Carbon Community**

Authors: Enfang Liu, Shanghai Institute of Architectural Design & Research
Wenli Fan, Shanghai Institute of Architectural Design & Research
Jianing Pan, Shanghai Institute of Architectural Design & Research
Jianqiang Li, Shanghai Institute of Architectural Design & Research

Subjects: Sustainability/Green/Energy
Urban Design

Keywords: Energy Efficiency
Integrated Design
Low Carbon
Urban Design

Publication Date: 2013

Original Publication: International Journal of High-Rise Buildings Volume 2 Number 2

Paper Type:
1. Book chapter/Part chapter
2. **Journal paper**
3. Conference proceeding
4. Unpublished conference paper
5. Magazine article
6. Unpublished

International Journal of High-Rise Buildings
June 2013, Vol 2, No 2, 85-91

International Journal of
High-Rise Buildings
www.ctbuh-korea.org/ijhrb/index.php

The Core Urban Design Strategies of Tall Building - Low Carbon Community

Enfang Liu, Wenli Fan, Jianing Pan, and Jianqiang Li†

Shanghai Institute of Architectural Design and Research (Co., Ltd.), 258 Shimen Er Road, Shanghai 200041, China

Abstract

Tall building has some controversial aspects with low carbon city, but it is still a sensible choice for the metropolitan city. This paper aims to develop holistic urban design strategies to minimize impacts on the environment, increase energy efficiency and improve the quality of living in tall building communities by utilizing tall building characteristics. It puts forward the concept of integrated tall building-low carbon community design from the perspective of urban design, and summarizes five core strategies: Temporal state based on energy use, Complementary energy use state based on functions, Spatial state based on regional environment features, Transportation state based on low-carbon lifestyle and Waste utilization state based on tall building characteristics. It also applies the strategies to a practical project. The results show that the proposed urban design strategies are available approaches to mitigate the side effects of tall building on low carbon city.

Keywords: Tall building - Low carbon community (TBLCC), Urban design, Integrated design strategies, Energy efficiency of tall buildings

1. Introduction

Developing low carbon city has been the mainstream of urban development in the world. The C40, a group of large cities tackling climate changes, is committed to promoting the development of low carbon cities (C40, 2012). More than 150 cities in China by 2008 have proposed plans and targets to build sustainable eco-cities (Niu et al., 2009). Meanwhile, tall buildings as the achievement of science and technology in the region and the icons of cities are continually being pursued by the world-wide cities. It can be seen from the first tall building - Chicago Insurance Company Building completed in 1883 to the 66 tall buildings over 200 meters high constructed across the world in 2010 (CTBUH, 2011). The track of tall building development shows the significant development on the extension of regions, the increase of the quantity, the continually break of height record, the innovation of building form and the widely application of sustainable building technology (Oldfield et al., 2008; Abel, 2010).

Tall buildings, as the important components of low carbon cities, are an inevitable topic in the urban design. The reasons to develop tall buildings are attributed to its advantages of intensive land use, efficient development, mixed-use variety, and promotion of technology innovation and so on (Wood, 2008). However, tall buildings have the disadvantages of high energy consumption and high material consumption as well as high electricity load and high accumulated carbon emission, compared with low-rise buildings (Roaf et al., 2005). As their surfaces absorb the sun's heat, causing surfaces temperature to rise, the group of tall buildings can heat overall ambient temperature and reduce the air flow velocity among them. As a consequence, their impacts on regional environment, such as heat island effect (Fig. 1) and recirculation wind, which can potentially influence the health and welfare of urban residents. The negative effects of tall buildings largely contradict the purpose of the low carbon city.

In order to mitigate the conflicts between tall buildings and low carbon cities, this paper analyses the relationship between tall buildings and low carbon community, proposes the concept of tall building low carbon community, puts forward the tall building low carbon community

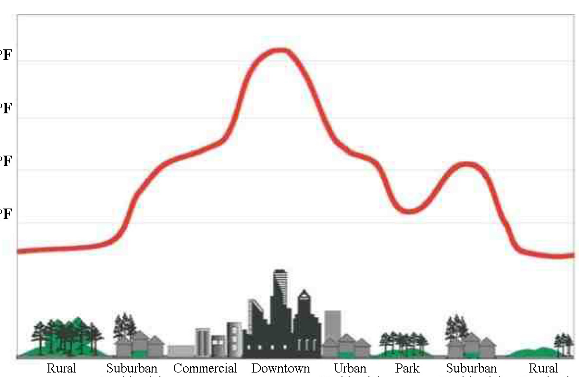

Figure 1. The schematic of heat island effect. (Source: EPA, 2011)

†Corresponding author: Jianqiang Li
Tel: +86-21-5252-4567; Fax: +86-21-6246-4209
E-mail: lijq@siadr.com.cn

design based on the tall building characteristics, and conducts a case study to verify the concept.

2. Tall Building-Low Carbon Communities

2.1. Definition of Tall Building-Low Carbon Community

Tall Building-Low Carbon Community (hereafter, TBLCC) refers to the tall building community in a neighbourhood region that greatly improves the energy efficiency and the quality of community environment, whilst greatly reduces its comprehensive energy consumption and the level of carbon emission during the whole building lifecycle by the integrated urban design.

2.2. The scope of urban design in TBLCC

The urban design in TBLCC is a design process to efficiently configure the urban spatial resources by taking passive design as the primary approach. The configurations of urban spatial resources can be classified into three levels: macro level for low carbon city, middle level for low carbon community and micro level for green building. Low carbon community as the middle level of low carbon city consists of several blocks. It is the key linkage between green buildings at the micro level and the whole low carbon city at the macro level.

It is essential to consider the buildings but beyond the individual buildings when doing TBLCC design. Based on the individual sustainability of tall buildings (Pank et al., 2002), it focuses on the energy and resources of the whole region. It pays much attention to the factors of TBLCC, such as the energy configuration in the region (Long et al., 2011), energy efficiency of mixed use, transportation system with low carbon lifestyle, regional layout and healthy environment, waste reuse and so on.

2.3. Design strategies of TBLCC

SIADR (Shanghai Institute of Architectural Design and Research) puts forward the design system of TBLCC according its years of practical experiences and research, and summarizes the 5+ core technique strategies, taking passive design as primary. They are Temporal state based on energy use, Complementary energy use state based on functions, Transportation state based on low-carbon lifestyle, Spatial state based on regional environment features and Waste utilization state based on tall building characteristics and so on (see Fig. 2). Its emphasis is the integrated design process by passive strategies as primary, associating with active technologies.

2.3.1. Temporal state based on energy use

TBLCC has a temporal state based on energy use. One reason is that the building has its individual energy use intensity during a day. For example, hotel buildings usually have larger energy use intensity at night time than day time. The other reason is that different building types have various energy uses every hour. For example, office

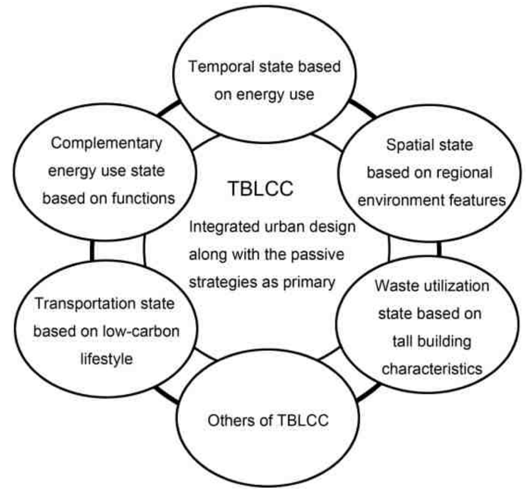

Figure 2. Components of TBLCC.

buildings usually use energy from 7 am to 20 pm and residential buildings from 17 pm to 8 am, and commercial buildings from 10 am to 22 pm (see Fig. 3). It implies that there are differences in energy use among different building functions, which result in the fluctuation of energy use of the community. The larger peak to valley difference in electricity load of the whole region can cause the lower energy efficiency.

It is possible to reduce the peak to valley difference in electricity load for energy efficiency in the region. The approaches include the reasonable mixed use, and the utilization of the characteristics of their intensity and complementary energy use. To study the annual energy consumption as well as the peak to valley difference in electricity load of the region are the research areas in this paper.

2.3.2. Complementary energy use state based on functions

There are some complementary energy use features among

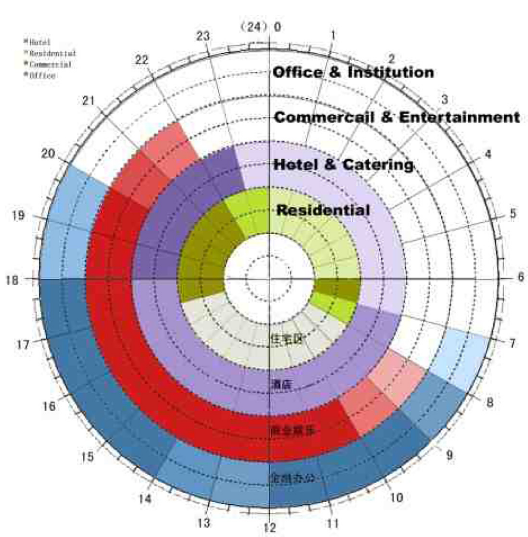

Figure 3. The occupied periods of buildings in a day.

the different building functions. These unique modes of energy use and waste exhaust for some special functions can be mutually exchanged and benefit the community. For instance, the data centers of financial office buildings produce large waste energy because of its requirement of cooling in a whole year. If the waste energy is collected, it can be used as the heat resource of domestic hot water for the nearby hospital, hotel and sanatorium. As a consequence, it reduces the large amount of carbon emission. It could be an innovative viewpoint to analyze the proportion of every function in the whole area.

The complementary energy use state based on functions is the basic factor of TBLCC. It can be used to study the proportion of TBLCC from the angles of the carbon emission rate and amount, condensation water for make-up cooling tower water and so on.

2.3.3. Spatial state based on regional environment features

Spatial state based on regional environment features means that the building form and layout are dependent upon the local environment and reflect the adaptability to the local environment. It emphasises the tight connection between TBLCC and its environment. With the help of effective technical analysis, the building form and layout are adjusted to adapt to the local climate features and maximise the external thermal comfort level. For instance, the analysis of wind and daylight environment of tall building clusters develops the link between buildings and the local environment at the initial stage. This relationship plays an important role in the realisation of low carbon environment with responding to local climate and cultural characteristics.

2.3.4. Transportation state based on low-carbon lifestyle

TBLCC transportation state pays much more attentions on the public transportation. As public transportation has close relationship with community, it contains a lot of factors which affect people's life. The sensible transportation state can guide and promote the safe and healthy lifestyle.

TBLCC transportation state cares about people's lifestyle and the welfare of community. For example, it advocates the slow speed transportation system, so that a holistic and safe pedestrian system can be built. This walkable deign in the mixed-use neighborhood can encourage the development of social capital (Leyden, 2003); it also advocates the connection between the stops of track transportation and activity centre in order to realize the win-win situation of convenient and fast commutes and urban activities.

2.3.5. Waste utilization state based on tall building characteristics

TBLCC emphasizes the waste reuse based on the features of tall buildings. Tall buildings have their special characteristics in energy use and waste exhaust. Air conditioning can produce a large amount of condensing heat and condensate when it consumes energy for cooling. This condensing heat can be used as heating resource for hot domestic water and the condensate can be used for making up the cooling tower water.

Compared with the low and multi-storey building, tall building can accumulate large amount of heat emission, condensate and other wastes. Tall buildings have large vertical facade, which can be collected amount of rainwater as the roof. In fact, these wastes can be reused in the whole community. The rainwater could be applied to irrigate the plants or clean the road and square on the site. It implies the wastes of the community can become its resource.

3. Case Study of TBLCC in the Practice

This case is a practical project, a high density and tall building district. Its land area is about 26 ha, and the gross building area is 865,000 m^2. It consists of office, hotel, commercial and residential buildings, including 21 buildings with building height over 100 m (see Fig. 4). This case study analyses from the three main aspects of the above design strategies: temporal state based on energy use, complementary energy use state based functions and waste utilization state based on tall building characteristics.

According to SIADR's experience, 22 samples with different building function and mixed-use proportions are set up (see Fig. 5). The percentages of office building areas is from 20% to 40%, the commercial building from 13% to 25%, the residential building from 30% to 50% and the hotel building from 5% to 15%. Every sample is evaluated from the aspects of annual energy consumption, daily peak to valley difference in electricity load, condensing heat recovery, condensate reuse and other aspects based on the high-rise building characteristics. After the comprehensive evaluation, an appropriate proportion of building area of each building type is acquired.

3.1. Comparison of annual energy consumption

An appropriate mixing proportion of TBLCC needs to consider their annual energy consumption. The annual energy consumption includes the energy for air conditioning, lighting, equipments and heating. The calculation of

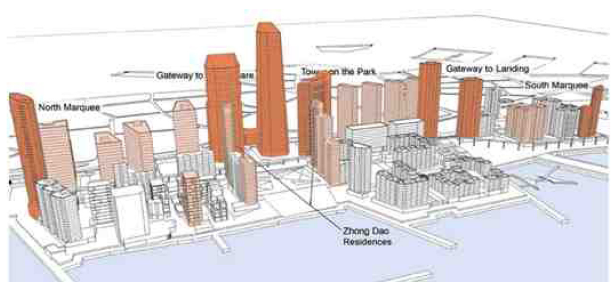

Figure 4. The schematic view of the case.

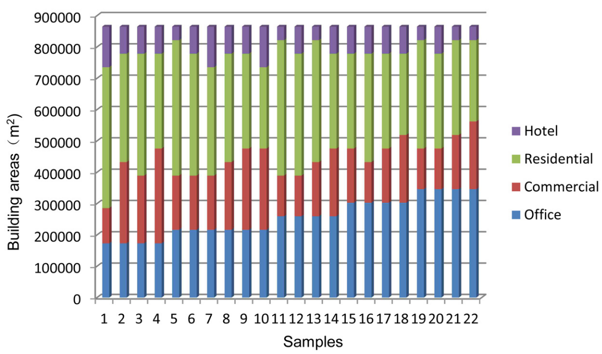

Figure 5. Samples of various building area proportions.

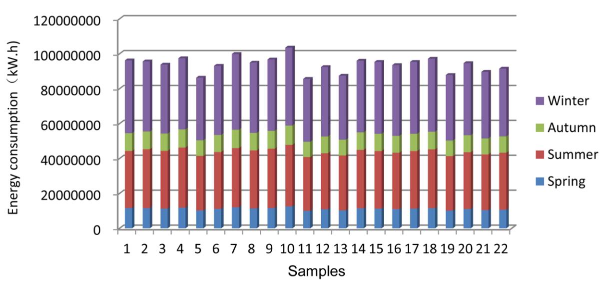

Figure 6. Annual energy consumption of the samples.

annual energy consumption is based on the typical building energy consumption of national building standards in China. It can be seen from Fig. 6 that there are large difference of the annual energy consumption among the 22 samples with different proportions. The results show that Sample 5, 11, 13, 19 and 21 consume the amount of energy less than the average of all the samples and have better performance in energy consumption. Sample 4, 7, 9, 10 and 18 have worse performance in annual energy consumption.

3.2. Comparison of daily peak to valley difference in electricity load

The intensity of energy usage is depended upon the characteristics of functions during the period of occupied time. In order to balance the 24 hourly electricity loads in the region and reduce the peak to valley difference in electricity load, it is necessary to study the daily feature of electricity load of per square meter, the mixed use modes in the single tall building and the typical daily difference of peak and valley electricity load in summer. It can help to find an appropriate mixed use and proportion.

The daily electricity load per square meter of building types is the basic of proportion for mixed use. Fig 7 shows the daily electricity loads per square meter of the office, commercial, residential and hotel buildings. It can be seen that the different building types have their individual electricity loads. The electricity loads of office and commercial buildings have dense use during daily time, and the

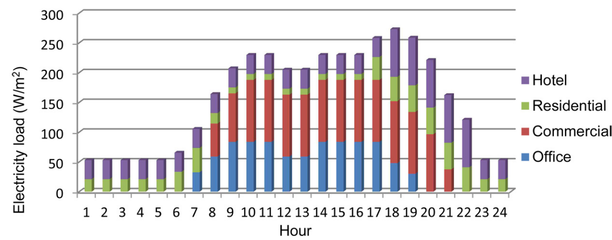

Figure 7. Electricity loads of building types based on hours.

commercial building have the largest electricity load per hour and square meter, while residential buildings have the lowest electricity load. It is possible to utilize their characteristics to complement each other. As a consequence, the peak to valley difference in electricity load can be dropped, which can improve efficient energy use in the whole region.

The individual tall building has the same characteristic of mixed use as the above study, so that it can reduce the daily peak to valley difference in electricity load by mixing its vertical functions. Fig. 8 shows the suitable mixed-use types of tall buildings based on their daily difference of peak and valley electricity load. Type 1 and 2 are the mixes of residential with office and residential with commercial function in a tall building. As the residential buildings have low electricity load, so they usually can have larger integration of the whole tall building. The result of calculation shows that the proportion of residential and office could be 2:1 and the residential on the top and the office at the bottom are sensible, because it follows the rule that smaller weight load and energy consumption should put on the top. Type 3 and 4 are the mixes of the three functions. This study result supports to deeply study the proportion of mixed use in order to balance the peak to valley difference in electricity load.

We continually investigate the 22 samples from the angle of whole region based on the above study. As summer is peak time for electricity loads in the whole year, we choose the daily electricity load in summer as the object. Fig. 9 shows the peak to valley difference of the 22 samples on the typical summer day. Their peak electricity load

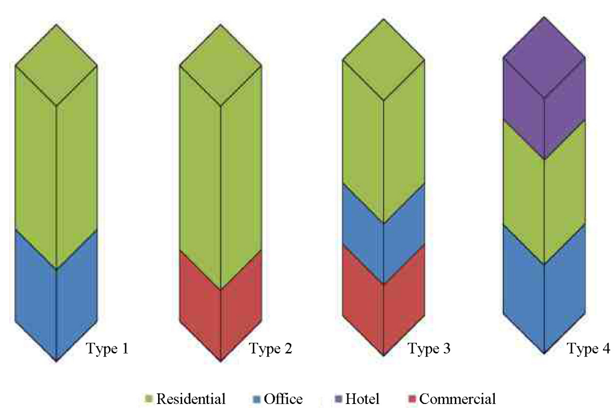

Figure 8. Mixed use types of tall buildings.

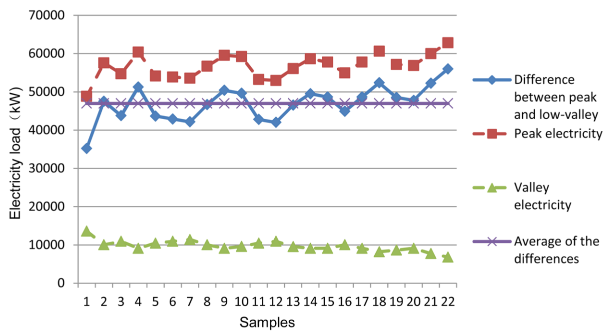

Figure 9. Peak to valley difference in electricity load on the typical summer day.

has large differences, while their valley electricity loads tend to stability. Their peak to valley differences in the Sample 1, 6, 7, 11 and 12 are less than the average difference. It could help to improve the energy efficiency of the whole TBLCC. While the Sample 4, 10, 18, 21 and 22 with the larger difference could cause the imbalance of electricity use and cause electricity loss during the electricity transmission.

3.3. Comparison of condensing heat recovery

Air conditioning system provides the cooling for the users in summer along with amount of heat produced. The condensing heat usually is exhausted in atmosphere and could increase the cooling loads of the surrounding buildings. In fact, it can be collected for domestic hot water, which can also lessen the heat island effect.

We set two indexes to evaluate condensing heat recovery in this study. One is the ratio of amount of energy for domestic hot water to amount of condensing heat recovery. The larger ratio means the larger amount of condensing heat recovery, which benefits the regional environment; the other is the amount difference between condensing heat recovery and heat consumption for domestic hot water. The smaller value means fewer effects on the regional environment.

Fig. 10 shows the amount of condensing heating and the energy for domestic hot water of all the buildings in the 22 samples. It can be seen that the amount of condensing heat is much more than the requirement of domestic hot water. The results of the first index indicate Sample 1, 3,

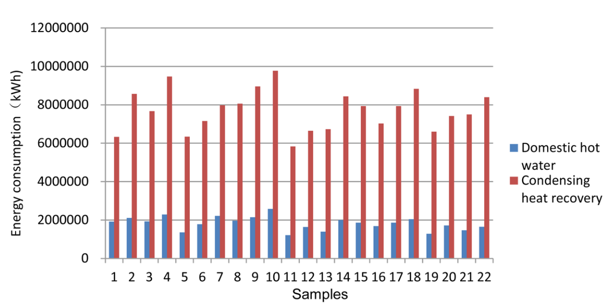

Figure 10. Condensing heat recovery for domestic hot water.

6, 7 and 10 have larger ratios. On the other side, Samples 10, 13, 19, 21 and 22 have smaller ratios. The results of the second index are that Sample 1, 5, 11, 12 and 19 have smaller amount of heat emission, while 4, 9, 10, 18 and 22 have larger amount of heat emission.

By the analysis of the two indexes, it indicates that Sample 1, 3, 5, 6 and 7 have better performance in condensing heat recovery, and Sample 4, 9, 10, 18 and 22 have worse performance in condensing heat recovery.

3.4. Comparison of the condensate for cooling tower

Air conditioning in the tall buildings is an essential system for the comfortable indoor environment in the tall building in summer. However, it requires a large amount of water to make up the cooling towers. Meanwhile, air conditioning produces large amount of condensate. The condensate has low ion content, which specially benefits to the cooling tower. How to reuse this waste water definitely adds the value to the tall buildings.

The ratio of amount of condensate to that of make-up water requirement in cooling tower indicates to what extend the condensate can be reused. Fig. 11 shows how much the condensate is recycled in the 22 samples. In general, the condensate can make up about 18.5% of water for the cooling tower, saving about 25000 m^3 water. Sample 2, 4, 5, 9 and 22 have larger ratios, which mean their water systems work more efficient than others, while the rank of Sample1, 7, 12, 16 and 20 is at the bottom.

3.5. Waste energy utilization

Some special functions in the TBLCC can produce amount of waste heat, such as data center, ice storage of supermarket and so on. It can produce a large amount of heat in the whole year due to their interior environment. This kind of heat can be reused for heating in winter or dome-

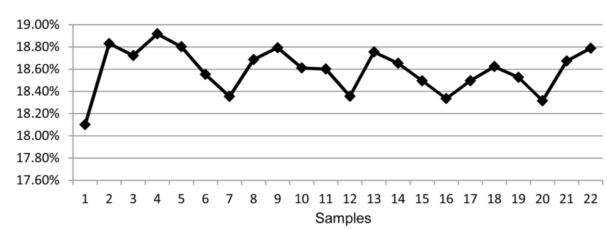

Figure 11. Condensate for cooling tower make-up water.

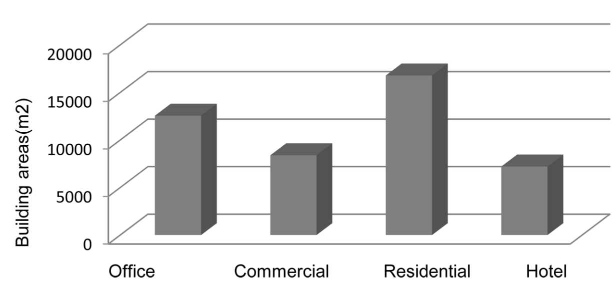

Figure 12. Waste heat from data centre for heating.

stic hot water in the whole year for the surrounding buildings; in turn it can save energy and reduce carbon emission.

Considering the project is a large scale, it has 2000 m^2 data center. Fig. 12 shows how many building areas the heat recovery from data center could be reused for heating. The amount of heat can serve as heating resource for residential buildings area over eight times as large as that of data center. Even for the hotel building, the waste energy can provide its area with heating for twice larger than that of data center.

3.6. Gray water utilization

Gray water can be used for flushing, irrigation, cleaning road and even for make-up cooling tower. Fig. 13 shows the amounts of flushing water and the gray water in the 22 samples. It can be seen that the gray water from the residential buildings can provide the flushing water for almost all of the buildings in the district. Although the gray water from office buildings does not have significant economic value, it is still positive considering of preservation of water for the ecosystem. To develop a gray water pipeline network in a city can collect the gray water from residential district for flushing water, irrigation, cleaning road and waterscape in other building areas.

3.7. Rainwater utilization

Rainwater utilization in the tall building has a positive effect. Compared to the low-rise building, the tall building has a larger façade area, which is usually more than the roof area. From the analysis the rainwater utilization of this project, the amount of rainwater collection from the facades is larger than that from the roofs. Fig. 14 shows the amount of rainwater utilization and those of irrigation and cleaning roads in the project in seasons. The amount of rainwater collection can definitely meet the requirements of irrigation and cleaning roads. As rainwater in

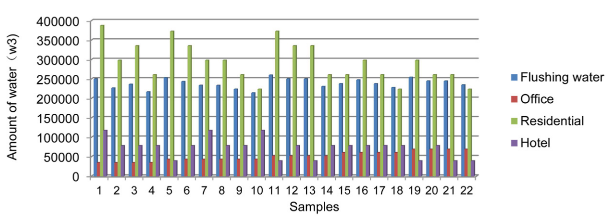

Figure 13. Flushing water and gray water.

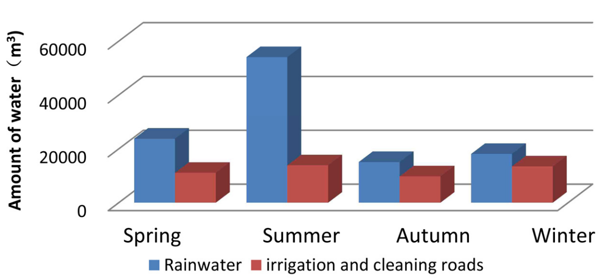

Figure 14. Rainwater utilization in the seasons.

summer has larger amount than that for irrigation and cleaning roads, the left rainwater can also be used for fire water supply or other purposes.

3.8. Comprehensive evaluation

After the above study on the seven aspects, Table 1 shows the result of comprehensive evaluation. It can be seen that Sample 2, 3, 5, 6, 11 and 19) have the better performance in the seven aspects, because they do not have the worse one in the seven aspects. The worse samples are Sample 4, 7, 9, 18 and 22. They all have at least two worse ones in the seven aspects. It implies that the study of annual energy consumption, peak to valley difference in electricity load, condensing heat recovery and condensate can be helpful to search an appropriate mixing proportion of TBLCC. The further study could be the investigation of their weighting coefficient in the aspects and develop a holistic evaluation system.

From the viewpoint of low carbon community, it can be summarized that there is a reasonable mixing proportion when a tall building community consists of office, residential, commercial and hotel buildings. The method based on the seven aspects can be taken as an efficient approach to evaluate a tall building - low carbon community at the stage of urban planning and design.

4. Conclusions

After the study of the urban design strategies of TBLCC and case study in the energy consumption, it can be concluded as the following:

Developing TBLCC can mitigate the conflicts of tall building and low carbon city.

TBLCC advocates the integrated urban design by the association of passive design and active technologies, while taking the passive design as the primary.

TBLCC includes 5+ design strategies: Temporal state based on energy use, Complementary energy use state based on functions, Transportation state based on low-carbon lifestyle, Spatial state based on regional environment features, Waste utilization state based on tall building characteristics.

The case study shows that the three aspects of Temporal state based on energy use, Complementary energy use state based on functions and Waste utilization state based on tall building characteristics can be taken as the key low-carbon main attributes of TBLCC mixed use. Reasonable mixed use can achieve the lower annual energy consumption, the smaller daily peak to valley difference in electricity load, larger condensing heat recovery and increase the amount of condensate for make-up cooling tower water, efficient waste reuse, etc.

The proposed mixed use based on the characteristics of energy use is a state-of-the-art method for urban design and research. It advocates taking the reasonable mixing proportion as the vital point when doing the energy plan

Table 1. Summary of the comprehensive evaluation

	Annual energy consumption	Peak to valley difference	Condensing heat recovery	Condensate	Waste energy utilization	Gray water utilization	Rainwater utilization
Sample 1	Good	Better	Better	Worse	Good	Good	Good
Sample 2	Good	Good	Good	Better	Good	Good	Good
Sample 3	Good	Good	Better	Good	Good	Good	Good
Sample 4	Worse	Worse	Worse	Better	Good	Good	Good
Sample 5	Better	Good	Better	Better	Good	Good	Good
Sample 6	Good	Better	Better	Good	Good	Good	Good
Sample 7	Worse	Better	Better	Worse	Good	Good	Good
Sample 8	Good	Good	Good	Good	Good	Good	Good
Sample 9	Worse	Worse	Worse	Better	Good	Good	Good
Sample 10	Worse	Good	Good	Good	Good	Good	Good
Sample 11	Better	Better	Good	Good	Good	Good	Good
Sample 12	Good	Better	Good	Worse	Good	Good	Good
Sample 13	Better	Good	Worse	Good	Good	Good	Good
Sample 14	Good	Good	Good	Good	Good	Good	Good
Sample 15	Good	Good	Good	Good	Good	Good	Good
Sample 16	Good	Good	Good	Worse	Good	Good	Good
Sample 17	Good	Good	Good	Good	Good	Good	Good
Sample 18	Worse	Worse	Worse	Good	Good	Good	Good
Sample 19	Better	Good	Good	Good	Good	Good	Good
Sample 20	Good	Good	Good	Worse	Good	Good	Good
Sample 21	Good	Worse	Good	Good	Good	Good	Good
Sample 22	Worse	Worse	Worse	Better	Good	Good	Good

Legend: (dark green) Better; (red) Worse; (light green) Good

of a region. The further study will develop the scientific rules for TBLCC, and set up the foundation of tall building - low carbon community evaluation.

References

Abel, C. (2010). The vertical garden city: Towards a new urban topology. *CTBUH Journal*, (II) pp. 20~30.

C40. (2011). C40 Cities climate leadership group. Retrieved 18 May, 2012, from http://www.c40cities.org

CTBUH. (2011). 2010 The most successful year of skyscraper completion in history; China in the ascendancy. Retrived 10th November, 2012, from http://www.ctbuh.org

EPA. (2011). 'Basic information' EPA. Retrieved 16th April, 2012, from http://www.epa.gov

Leyden, K. M. (2003). Social capital and the built environment: The importance of walkable neighbourhoods. *American Journal of Public Health*, 93(9), pp. 1546~1551.

Long, W., Bai, W. and Fan, R. (2011). Community energy planning for built environment in low carbon cities. China Architecture & Building Press, Beijing. (In Chinese)

Niu, F., Pan, J. & Liu, Z. (2009). Urban development in China: 30 years (1978-2008). Social Science Academic Press. Beijing. (in Chinese)

Oldfield, P. et al. (2008) "Five energy generations of tall buildings: A historical analysis of energy consumption in high rise buildings." *The Journal of Architecture*, 14(5), pp. 591~613.

Pank, W., Girardet, H. and Cox, G. (2002). Tall buildings and sustainability. Eoconomic Development Office. London.

Roaf, S., Crichton, D. and Nicol, F. (2002). *Adapting buildings and cities for climate change, A 21st century survival guide*. Architectural Press. Oxford.

Wood, A. (2008). Green or Gray: The aesthetic of tall building sustainability. Proceedings of the CTBUH 8th World Congress, 'Tall and Green: Typology for a sustainable urban future'. Dubai, UAE. pp. 194~202.