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Challenges to achieve ecological domestic buildings in China

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ABSTRACT

Domestic buildings are one of the main consumers of energy, as well as the main sources of environmental pollution especially in China, where 32% of the total energy consumed is related to buildings. The construction of domestic buildings at present, in China, is still of the extensive-type production mode, which is high in resources consumption, has a low level of technology integration, is high in energy consumption and has a high pollution emission during the building construction and operation processes. Consequently, it has becomes a burning issue for us to change the development methods of domestic building, and develop ecological, abstemious and sustainable society. This article explores the approaches to achieve the ecological domestic building (EDB) by integrally considering the building's whole life cycle .

Keywords: Ecological Building, Energy Consumption, Resource Consumption

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INTRODUCTION

In China, buildings' energy consumption takes up to 30% on total energy consumption (Decreasing building energy-consumption, 2010) and furthermore it keeps growing at the speed of one percent per year. The statistics data from the Ministry of Housing and Urban-Rural Development of the People's Republic of China shows that: two billions square meters of new buildings are constructed every year in China and 80% of them are high energy consumption buildings; 95% of the existing 40 billions square meters of domestic buildings are high energy consumption buildings (Zhan T, 2010). In China, energy consumption per unit of domestic building is 3~4 times of those in the developed countries; steel consumption is 55 kg/m^2, which is 10%～15% higher than the developed countries; the usage of cement is 22115 kg/m^2, and that means that per one cubic metre concrete 80 kg more cement is required compared with the developed countries (Wang J, 2005). Meanwhile, the energy and resource consumption during the operation of buildings are 2~3 times of those in the developed countries. For instance, the average water consumption is 30% more than the developed countries (Wang J, 2005).

2.*Promoting the concepts of EDB domestic building consumption model*

For domestic building, a compact, efficient and comfortable indoor space will be enough to meet the human's natural needs and demands and will meanwhile greatly reduce the energy and resources consumption during the stages of construction, usage and maintenance. In Japan, it is a social norm and quite acceptable that a very good income family happily lives in an 80~90 m^2 house (Japan Statistical Yearbook, 2005). The average housing area per capita in China, which includes entire urban and rural population, is over 30 m^2, which is higher than in Japan and Korea. In Korea, the average housing area per capita is 19.8 m^2 and it is 19.6 m^2 in Japan (Average living area in the world, 2011). The average annual income per person in China is only $1100, which represents 3.2% of the Japanese average annual earnings. Japan would be a good reference for China to learn the concept of compact and comfortable domestic buildings and how to reduce consumption of the energy and natural resources, as well as how to decrease the environment pollution. In fact, with an appropriate structural design, 60 m^2 floor areas can be divided into three bedrooms, one sitting room, one kitchen and one bathroom. Or 40 m^2 floor areas can accommodate two bedrooms, one sitting room and kitchen, and one bathroom. These space layouts can be very cozy with fewer resources needed and with less energy consumption. If the same living functions can be accommodated with each house area decreased by 10 m^2, 10% more houses could be built up accommodating 10% more residents on the same land, (Zhouhui Z, 1986).

3.Consideration of energy saving during the planning and design phases

3.1Planning of residential areas

By scientifically planning and designing the residential areas it will be possible to save the earth resources and improve the efficiency of the earth usage. This can be achieved by taking into consideration of different factors such as: taking the full account of the elements of the area plan such as building layout, orientation, distances between buildings, vertical space, shape and body, space utilization and color, etc; considering the building physical characters such as temperature, humidity, air change rate, noise levels, daylight and indoor air quality; evaluating the possibility of using natural energy sources including the natural ventilation, natural heating/cooling and lighting, and expanding the underground/roof space application; reducing the building body mass, improving the internal space utilization rate; developing the vertical space direction rather than the horizontal ,etc.

The average occupied built-up area of each house for multi-storey and high-rise building will be reduced by increasing the number of levels in the building. Statistics show that with an increase of one level, the built-up area will increase by 800～1000 m^2 per hectare of residential area (Li G, 2009). However with increasing number of levels, the distances between two buildings need to be increased to enable sufficient exposure to sunlight. Thus, the building height is a directly related to the area-use rate, natural resources such as light, wind, temperature, etc. Table 1 shows a calculation of land use and the rate of saving with the increasing number of layers, which indicates that the effect of land saving is not obvious above fifth or sixth layer (Zhang H, 2010).

Table 1 Layer and land-use

layer	Land-use of every house m^2/house	Land-saving m^2/house	Land-saving by increasing one layer m^2/house	Saving rate to one layer %	Saving rate to five layer %	Difference between one and five layer buildings %
First	74.1	0	0	0	219.2	120
Second	48.91	25.19	25.19	66.01	144.6	44.6
Third	40.52	33.58	8.39	54.68	119.8	19.8
Fourth	36.33	37.77	4.19	49	107.45	7.45
Fifth	33.81	40.29	2.52	45.6	100	0
Sixth	32.13	41.97	1.68	43.3	95	－5
Seventh	30.93	43.17	1.20	41.7	91.48	－8.52
Eighth	30.03	44.07	0.80	40.5	88.82	－1.18

Note: *the analysis above is taken in the flat surface condition of unchanged, arranged by determinant.*

If the storey height is decreased, sunlight space between buildings will be decreased too. In some cases, the effect of saving land by reducing the height of each layer is more effective than increasing the number of layers on the same land. According to the statistical analysis, increasing the number of building layers from five to seven, 7.5%～9.5% of land will be saved. But, if storey height is decreased from 3.2 to 2.8 metres, 8.3%～10.5% of land will be saved. For every 10 cm of layer's height reduction, 2% of land will be saved. In accordance to this principle, about 500 m^2 of built-up area per hectare will be saved by 10 cm decrease in each layer's height. If the number of building layers increased from 5 to 9, building density in a residential sub-district would rise to 35%, while, if the number of building layers increased from 6 to 17, more than 50% land would be saved whilst maintaining the same residential density (Zhang H, 2010).

3.2Building design

China is still in early stage of Zero/Low carbon building design. Although heating/cooling represents the main proportion of the building's energy consumption, the building designers have only just started realizing the correlation between the energy consumption and the design of the building's external/internal walls and structure, this development is far behind the countries such as Japan, EU and UK.

The essential considerations for the ecological building design include building facade treatment, shape coefficient, window to wall area ratio, window to ground area ratio, south to north window area ratio, levels height, construction depth, low carbon technologies and sustainable energy application etc. The relationships between the energy saving and the new design, building's function and the project capital cost should be carefully considered to ensure the building meet the required function whilst using less energy and with less capital cost. Optimal calculation should be carried out to identify the best energy and ground saving design by comprehensive consideration of the building layout, orientation, as well as shape, height, and insulation technologies of the building envelope. In order to achieve this a relevant building design software have been developed and applied to optimize the design, for example, the architecture shade simulation of Tianzheng Architecture (Zhang H, 2010) can help designing with the building orientation, district roads, greenery and grass area and outdoor recreational area; Computational Fluid Dynamics (CFD) software, such as PHOENICS and Fluent, are used to simulate the indoor and outdoor air movement; Integrated Environmental Solutions (IES) and Passivhaus Planning Package (PHPP) evaluate the building thermal and energy performance and yearly energy consumption. There is a huge gap of the building energy efficiency standards between China and the developed countries. At present, the external wall thermal performance of the domestic building in the majority of China's heating regions is much worse than that in developed countries. In China, the heat transfer coefficients of the external walls are 3.0～4.0 times higher of that in developed countries, the exterior windows are 4.0 times higher , the roofs are 3.5～6.0 times higher, and the air infiltration through the doors and windows are about 5.0 times higher (Li G, 2009). Practical heating energy consumption per year in the developed country, is about 7.57 kg standard coal (1kwh=0.404 kg standard coal) per square meter, while, in China, it is 1.5 times more than that (China Machine Press, 2005). The investigation of a six floors brick and concrete structure building with four apartments at each floor was carried out, and it was found that the heat loss through the building envelope accounted for 77% of the total energy consumption, and infiltration heat loss through doors and windows was 23% (Reusing of Construction Waste View in Foreign Countries, 2010). In total envelop heat loss breakdown is as follows: 25% is lost through the external wall, 24% is through the windows, and 11% is via the internal wall to stairs, 9% is through the roof, 3% is via the door to the balcony, 3% is via the door to the corridor, and 2% is through the floor. Most of domestic buildings in China are like this and in urgent need of energy efficiency transformation.

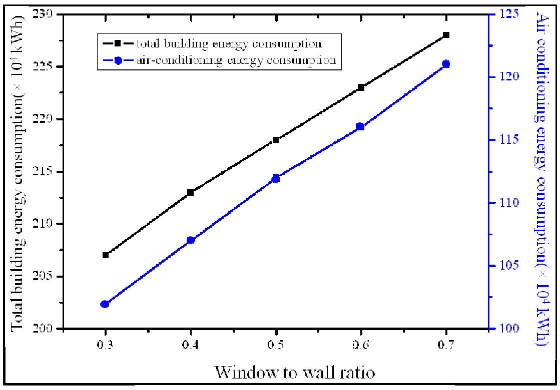

Fig.1. Total building energy consumption and air conditioning energy consumption

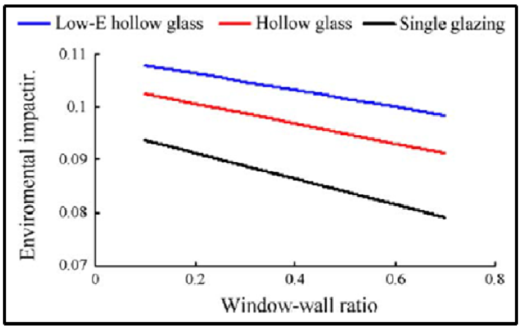

Fig.2. Environmental impact of external envelope[2]

In order to save energy in domestic buildings, the following can be done in the design stage:

i) Building layout design

1)Optimizing the building layout by maximum usage of the natural resources around site in order to reduce the heat gain/loss in summer/winter, and improve indoor air quality. For example, utilizing the existing plants including trees, grass and liana plants to decrease the buildings' cooling load in the summer.

2)Manipulating the horizontal and vertical building layout with building orientation to increase the rate of indoor natural light in winter and reduce radiation gain in summer. For examples, the sitting room set in the south of the building shaded by a blind or a thick curtain can gain less solar energy in summer and store plenty of solar energy in

the winter to create a comfortable leisure space for a family with less energy consumption.
3) Using lighter colours on building's external and internal walls would create cooler feeling environment for the residents in summer, and would be more aesthetically pleasing than a darker colour. In China, even at present, a lot of building still uses dark color on the external wall to make the effect of the heavy air pollution less visible. Light color façade should be encouraged for domestic buildings in the future.

ii) Building shape design
The key to decreasing the energy loss and conserving energy is by rigorously controlling the surface area of building façade. By reducing the external wall area and the window to wall ratio whilst keeping the same construction area, it is possible to significantly reduce the energy loss.

iii) Building shape coefficient
Building shape coefficient is defined as the ratio of the external skin surfaces to the inner volume of the building (Reusing of Construction Waste View in Foreign Countries, 2010). The building shape coefficient is mainly determined by the shape of the building plan. For the same building area, the longer perimeter of external wall directly contacting the outdoor air results in the higher external wall area and the higher building shape coefficient. As a result, consumption of the energy and resources and the capital costs are increased, and the building running energy costs after the construction will be high as well.

In certain built up area, the round building has the most economical coefficient of all building shapes, the second one is square, the third one is rectangular, and the last one is L-shape or T-shape. Although, from the theoretical analysis, the round building should have the best shape coefficient with economical and lesser energy and resources consumption, but round external structure increases the construction cost by 20%～30%. It is generally acknowledged that square and rectangular shaped buildings are cheaper and easier to construct. The best rectangular shape is the one with 2:1 ratio of the length to width is due to the smaller exterior wall surface (Zhouhui Z, 1986). When the floor plan outline is concave and/or convex with many twists and turns, the construction cost, energy and resource consumption will be increased. This is because the construction cost per square meter for the corner unit is 5%～6% higher than the flat unit (Zhouhui Z, 1986). But in some cases, in order to satisfy the requirement for daylight and natural ventilation, a narrow deep gap between two residential units will be designed to solve the problem of opening windows for toilet and kitchen. This will increase the shape coefficient, the construction cost, the energy and recourse consumption, but is unavoidable. Generally, this design is acceptable for big deep houses, but only if the rate of width to depth of gap is less than 0.5. Whereas, if the depth is less than 12 meters, it is not reasonable for the residential buildings to use any gap. Some other design techniques such as lifting up roof and eaves, lengthening veranda, over-hanging balcony will provide more residential space within the limited construction area. The spaces created by the lifted roof and eaves, lengthened veranda and over-hanged balcony will also provide the shade and help cooling the spaces below.

iv) Window to wall ratio
Decreasing the area of windows is an important method to simplify the construction, and reduce the energy and resources consumption. Windows to wall area ratio is severely restricted in design standard for saving energy purposes, for example, the limitation for the public building is 0.7, for residential building facing north is 0.45, for residential building facing east without shading is 0.3 (Depecker P et al., 2001). The area of windows should be designed and standardized according to different orientation of each room. Domestic buildings with well adjusted windows to wall ratio, controlled building shape coefficient, and with a sufficient natural lighting and ventilation can save energy each day during the long building life cycle. Therefore, synthesized consideration of windows to wall ratio and building shape coefficient has as significant effect on energy saving especially for the operating energy consumption. Studies of the impacts of external windows area to the building energy consumptions have been carried out by researchers in Zhejiang University in China. It has been found that for the same room orientation, the thermal resistance, thermal capacity and shading coefficient, the room with a window to wall area ratio of 50 % consumed 17 % more cooling energy and 8 % more total energy per day compared to a room with a windows to wall area ratio of 30% (Maihua L, 2011). The building annual and HVAC energy consumption has the linear relationship with the ratio of windows to wall area as shown in Fig.1 Different ratio of windows to wall area has different effect on building energy consumption when buildings have different orientations as shown in Fig.2 (Xing S and Xu Z , 2010).

v) Environmental design in architecture
Integration of the multi-level stereoscopic green concept into the architectural design achieves ecological domestic building. A few techniques are used to realize this design purpose:

1) Enlarging the green area in the residential district. It has been found by researchers that green areas can have a

cooling effect on the surrounding areas. A rectangular garden in size of 96 m×61 m located in a residential centre of Lisbon where the building density is 2479 buildings/km^2 and a population is circa 17,500 residents was tested, and it was found that the air temperature can be reduced by 6.9°C (Sandra O, et al., 2011).

2) Developing green roof for the domestic buildings. The green roof will absorb CO_2, produce O_2 for the residents, has higher thermal resistance and beautify the residential living space. T. Susca, S.R. Gaffin, and G.R. Dell'Osso have proved that the roof temperature with green vegetation is 2°C lower than those without green plant, as well as having less heating/cooling load (Susca T, et al., 2011).

3) Using green external walls rather than concrete, stone or brick materials to improve the buildings' thermal performance. Eleftheria Alexandria and Phil Jones have indicated in their researches that the cooling energy can be saved by 32%~100% in the hot climates if the green wall and roof techniques are applied on a city scale (Eleftheria A and Phil J, 2008).

4) Using natural water bodies to collect rain water, encourage the water flow through the grass and then into the nearby river and lakes. Sufficiently using natural resources including the water, topography, earth and energy to establish a natural living environment.

CONCLUSION

This paper analysis the domestic buildings' whole lifecycle including the concept of EDB, plan of the residential areas, building design, construction plan, new management skills and new construction technologies, operation and maintenance of building. It comprehensively analyzes the energy and resources consumption as well as the environmental influences during the whole life cycle of the residential buildings. The ecological domestic building can only be accomplished by overall consideration of each stage and by saving the energy and resources at every step.

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