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Research Paper

Analysis on green technology system and LCA CO_2 emission reduction of phase II construction project of JDXG

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ABSTRACT

With rapid socio-economic development and the fast progression of urbanization, at present, China has become the world's largest energy consumers and carbon dioxide emitters, whose environment and resource faces enormous threatens and challenges. It is imperative that effective measures be taken to solve this problem. Green building in China has surely got a favorable development momentum over recent years, *Assessment standard for green building (GB/T 50378-2014)* (China Academy of Building Research, 2014) has been widely used in the evaluation work of the green building. In this paper, the case phase Ⅱ construction project of JDXG (Lingping, Hangzhou, China) has been rated as two-star green building by the standard. This project used plenty of green technology in energy conservation, water conservation, raw material conservation, land conservation and environmental optimization of interior space, and optimized the architectural design, which is expected to achieve significant effects, moreover, the green technology such as solar water heating system, spray irrigation system in landscape and high-ratio of green space would make significant contributions to carbon dioxide emission reduction in its life-cycle.

1. Introduction

The term ‘green building’ was originated from ‘arcology’, which was proposed by American architects Paola Soleri. Since the world energy crisis broke out in 1970s, the trend of ‘Energy-efficient buildings’ ranged throughout the entire world, then combined with environmental design concept such as ‘vernacular architecture’, ‘Ecological architectural’, the concept of green building is continually updated and cleared. In 1992, the UNCED was hold in Brazil and put forwards a clear proposition of green building for the first time. In the present, this concept integrates with Environmental Impact Assessment (EIA) and Life Cycle Assessment (LCA) which has developed into a comprehensive scientific system. For promoting the rapid and healthy development of green building, many countries formulated the corresponding evaluation standard of green building, the most influential green building assessment systems among them is BREEAM (UK), LEED (USA), CASBEE (Japan) and so on.

Compared with the development history of green building in foreign countries, the green building starts rather late in China, however, it has a good momentum of development. The green building concept was introduced into China in the 1990s, since then authorities

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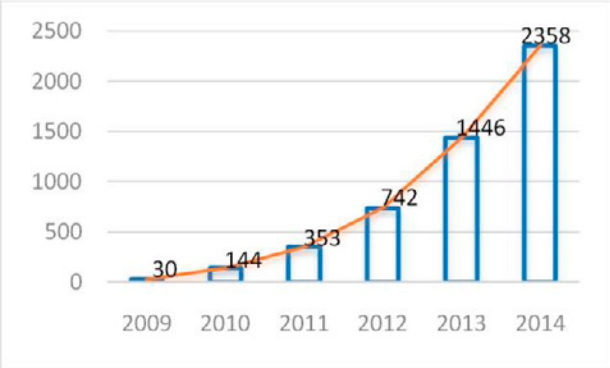

Fig. 1. Statistical chart on the number of green building in China since 2009.

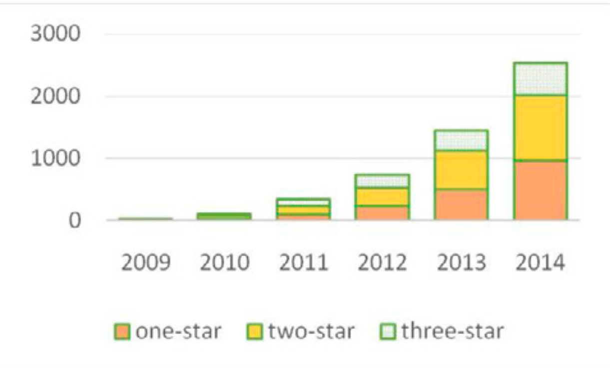

Fig. 2. Distribution of Green Building Appraisement Label in China.

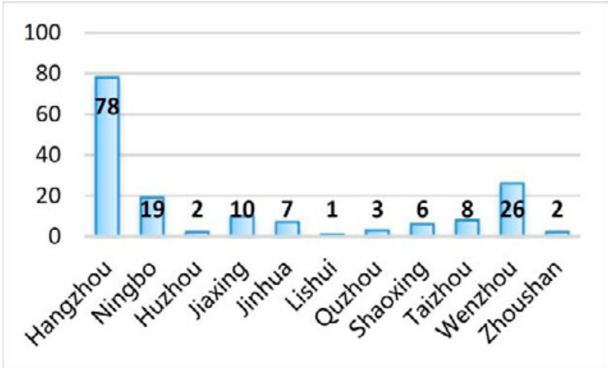

Fig. 3. Geographical distribution of green building appraisement label in Zhejiang province.

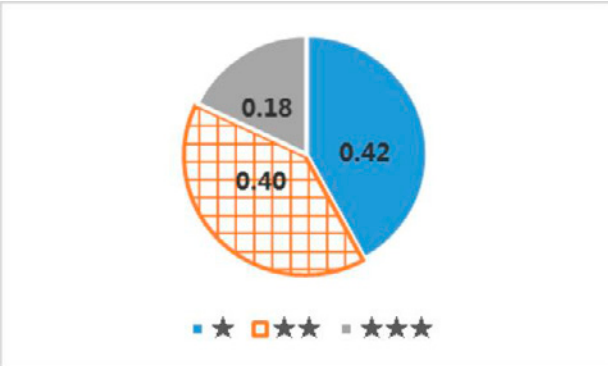

Fig. 4. Distribution of green building appraisement label in Zhejiang province.

concerned through series related methods and regulations to promote green building. *Assessment standard for green building (GB/T 50378-2006)*(China Academy of Building Research, 2006) issued in 2006 is China's first green building evaluation system written by the official, which provides a theoretical method and technical lines for promoting and practicing green building. The implementation of Green Building Appraisement Label System in April, 2008 filled the void of evaluation work of the green building in China, the history of using foreign evaluation standards to assess domestic building has moved away, turned over a new page in the history of green building in China (Tanjiaoyi, 2015). The new edition of *Assessment standard for green building (GB/T 50378-2014)* (China Academy of Building Research, 2014) issued in January, 2015, in this version, the evaluation method optimized from "counting items" to "points system", the evaluation content was refined, which made the evaluation system more scientific, objective and operational. The number of green buildings steadily increased over the years (see **Fig. 1**), as of January, 2015, the projects awarded green building appraisement label in China reached 2538, at the same time, the ratio of green building gained two-star and three-star is rising (see **Fig. 2**), these figures suggest that the career of green building in China not only focuses on increasing quantity but also pays attention to the quality construction.

Zhejiang province is located in Chinese eastern costal economy developed area, while its natural resources and energy resources are very scarce. With the continuous advance of the urbanization process recently, the short of factors of production such as resource, lands and so on has restricted the social and economic development increasingly (Xu and Zhang, 2006). 90% of the total energy consumption relied on transportation from other provinces or import in 2010 (Zhejiang Provincial Bureau of Statistics, 2011). In this context, Zhejiang government timely proposed the strategic policy to construct Eco-Zhejiang and promote the development of green building. In 2011 Zhejiang province raised development objectives which aimed to add the share of green building to 10% of new civil building at that time by 2015 (Zhejiang Provincial Government, 2011). The whole province is located in hot-summer and cold-winter area, which has the most complex and changeable meteorological condition and high energy consumption among China's Building

Thermal Design zoning map. It should take into consideration heat insulation in summer and heat preservation in winter in energy-saving design.

Fig. 5. The rendering of the project.

Fig. 6. Master plan of Phase II construction project of JDXG.

As of November, 2015, the number of building awarded green building appraisement label in Zhejiang province up to 162, the distribution of green building among cities and counties showed in **Fig. 4**. Most of labeling programs are concentrated in the three city: Hangzhou, Wenzhou and Ningbo, the labeling programs in Hangzhou account for almost half, moreover, the number of three-star is less while one-star and two-star labeling programs are the mainstream of current certifications of Green architecture (see **Fig. 3**).

2. Project profile

JDXG residential project is located in Lingping economic development zone, Hangzhou, Zhejiang Province, China, phase Ⅱ construction project of JDXG (Lingping, Hangzhou, China) is located in eastern, northern and western side of the entire project.

The total land area: 120850.55 m^2, overall floorage (including stilt floor): 329297.97 m^2 including the ground floor area: 229035.29 m^2, underground floor area: 98605.09 m^2. Green area: 52780.0 m^2, ratio of green space: 43.67%, total numbers of households: 2118. The project is consist of 24 low-rise dwellings, 4 small high-rise dwellings, 4 high-rise dwellings and 3 super high-rise dwellings. The number of automobiles parking lots is 2059, including 184 ground parking lots and 1875 underground parking lots. The rendering and master plan of this program are showed in **Figs. 5** and **6.**

3. Analysis on green building technical system

According to the definition of green building in *Assessment standard for green building (GB/T 50378-2014)* (China Academy of Building Research, 2014), implement the concept of ‘four resource-conserving & one environmental protection’ in planning design phase of the project, and carry out throughout the operation management phase of the buildings. Establish scientific and feasible green building technical system to provide engineering method and conception with technical support. The green building conception was originally built in this project during the planning and architecture design stage, combined the technology with building function, site condition and surrounding environment to make a healthy, practical, efficient and harmonious living environment for resident, improving the quality of life.

3.1 Solar water heating systems

Using renewable energy is one of the efficient measures to encourage energy efficiency and reduce CO_2 emissions, which is widely utilized in green building technical system. Solar energy, as one of the most readily available renewable energy, at present, the solar water heating systems is the most technically matured and widely used applications among solar energy application which is a safe, energy efficient, environmentally friendly, no space occupation and highly profitable product. This technology is very highly considered in green buildings.

In the project, solar water heating system integrated with buildings design so it is necessarily to consider the geographical conditions of the site, local meteorological data, sunshine condition and other objective factors. Furthermore, using computer simulation to analyze the sunshine condition of the program and improve the layout, orientation, and building interval. Make sure the layout, architectural forms, building orientation and building interval can maximize the technical requirement of designing and installing solar water heating systems.

The installation position of solar water heating systems has direct influence on using benefit, to comprehensive consideration of external factors such as architectural image, roof forms, layout of pipeline, latter maintenance and snow, hail and other natural damage decided to install the solar water heating system in all low-rise dwellings and the inverse six floors of small high-rise dwellings, high-rise dwellings and super high-rise dwellings By calculating, there are 458 households installed solar water heating systems, the ratio of households who use solar water heating systems to provide domestic water is 21.6%.

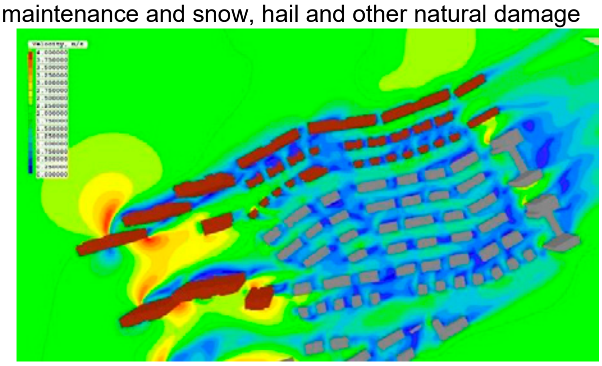

Fig. 7. Distribution of wind speed from the ground, 1.5 m of the footway around buildings.

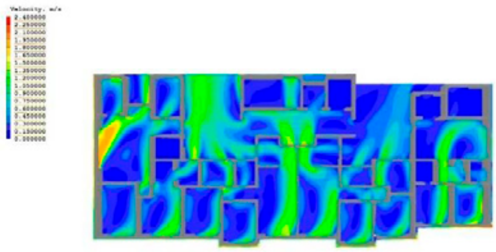

Fig. 8. Distribution of wind speed from the floor, 1.5 m of a certain house type.

3.2 Permeable pavement

Natural features have changed significantly since the rapid urbanization, the increasing frequency of waterlogging in cities, the depletion of groundwater resources, the deterioration of urban heat island effect and other eco-environmental problems have suggested that the changes in underlying surface had a number of negative impacts on urban thermal, hydrological environment and ecosystem. From the view of aesthetics, durability and other aspects, many urban settlements are still using traditional impermeable pavement, compared to permeable pavement, which is lower in ecological benefit and contrary to the conception of 'Coexistence with the Environment' of green building. Permeable pavement is constructed with large porosity structure layer or infiltration facilities, when precipitation occurring, the surface runoff can infiltrate through the void so as to decrease surficial runoff, delay the peak time and supply groundwater.

Using permeable pavement can reduce damage to near-surface soil, its ventilated surface can increase the moisture transfer and heat exchange between the site and atmosphere, which can improve the microclimate of the residential district and reduce the urban heat island effect. According to the structural feature, it can reduce standing water and improve the safety and comfort of driving during raining days. Not only can the application of permeable pavement in road surface provide inhabitant with favorable outdoor recreational, traffic space, it also shows a positive response to the construction of 'Sponge City' given by green building.

In the project, the total permeable pavement area is 23890 m^2, including the road, ground parking lots, outdoor playgrounds and so on, among them, the road uses permeable asphalt, the ground parking lots use permeable bricks. The total rigid pavement area is 34338m^2, the ratio of permeable pavement up to 70%. Utilizing permeable pavement to create an 'elasticized' surface for the residential community to enhance the adaptability to the environmental influences and decrease the impact of project-building activities to the environment.

3.3 The optimizing design of residential environment by CFD

Architectural design scheme will have a direct impact on the quality of building thermal environment. In the architectural layout and the selection of building orientation, considerate that Hangzhou is located in hot-summer and cold-winter area, the predominant wind in summer and transition season is southeast wind, the most building orientation is perpendicular to predominant wind in summer for the sake of guarantee the heat radiating effect in summer and airflow distribution in transitional seasons. The CFD was used to optimize the architecture design, the layout is north south high-low and the intervals among buildings are proper.

The PHOENICS computational fluid dynamics simulation software was used to simulate the outdoor wind environment of the project, the mainly family house indoor wind environment and the UHI intensity in the residential district, the analog data indicated that the wind speed from the ground, 1.5 m of the footway around buildings is lower than 5 m/s, the amplification coefficient of outdoor wind speed is less than 2 (see **Fig. 7**); the results of the simulation of indoor wind environment suggested that the natural ventilation of indoor environment is favorable, the house plans, the position, size of the windows is reasonable, the average gas velocity of indoor major function rooms is between 0 to 1.5 m/s, which contribute to make draft (see **Fig. 8**); The results of the simulation of UHI intensity is 1.23℃, lower than the 1.5℃ required by planning and codes. Generally speaking, with the help of PHOENICS to simulate different operating conditions and optimize, to build a good settlement thermal environment, reduce the air-conditioner use to drop the energy consumption, which will get considerable benefit for dwellers.

3.4 Green lighting systems

The conception of green lighting systems was proposed by USEPA at the beginning of 1990s (CIES, 2008). A complete connotation of green lighting systems includes 4 indexes: high-effect saving energy, environmental protection, safety and comfort, each index is indispensable. In the public space such as elevators, stairs, public corridors, underground garage and so on selects efficient light source such as compact fluorescent lamps and T5 fluorescent, public corridors lighting use infrared induction controlled switches. The whole lighting engineering is appropriate parted and well-designed which achieves the target of conserving energy and protecting environment, also provide households with a no glare, no light pollution lighting space.

3.5 Water-saving irrigation & highly effective water devices

China is globally recognized as one of the 13 most short of per capita water resources countries around the world (Zhao et al., 2011). The rational utilization of water resources has been elevated to strategic level in China. According to the prediction showed in Hangzhou mid-long term planning of water resource (Chen, 2015), by 2010, the water deficit of the city would up to 480 million m^3, water deficient ratio would up to 5.2%, water resource has become one of the key factors which will restrict the sustainable development of economy and society. Based on the date given by Hangzhou water resource committee (Pao, 2009), Lingping economic development zone is located in the northern side of Hangzhou, which is a serious water shortages area. Save water and Improve water use efficiency is practice and measures of green building. It takes a lot of water to maintain the greening for settlement in later time. Irrigation for greening adopts pipeline sprinkler and thus it could save irrigation water cost, the scattering sprinklers are arranged on demand, at the same time, install a certain number of water collectors in greenbelt to water requirement of different plants such as shrub, grass and tree, using less irrigation water to make a good benefit of economic and ecological. Meanwhile, the development organization and resident families sign the undertaking on the use of water-saving implement to guarantee the application of innovative water-saving implements in resident families and to reduce the water quantity used by unit product. In this way to build a water-saving mechanism which is led by development organization and supplemented by corporation of households, to increase water-saving consciousness, carry out water saving behavior by themselves and raise the utilization ratio of resources

3.6 Intelligent system

Intelligent system uses modern communication technology, computer network technology and so on to realize real-time detection and optimal control for buildings and construction equipment, which can provide people a safe, healthy and efficient architectural environment. There are 89 monitoring devices of CO concentration in underground parking lots and link to underground exhaust fans to real-time monitor the CO concentration in underground, to provide dwellers with a safe, comfortable parking environment.

3.7 Energy-saving design in buildings

Energy-saving design of building is a crucial part of the way to realize the sustainable development viewpoint of energy, environment and society, and is the only way to realize the sustainable development of green building. In view of the building climate features of hot-summer and cold-winter zone, in this project, ensured the normal functional of buildings, from distribution in architectural planning, building orientation and interval, bodily form coefficient, energy-saving design for the envelope structure and other aspects to optimize architectural structures, promote the energy-saving and emission-reduction and enhance the comfort level of dwelling.

In order to meet the internal requests for energy-saving and emission-reduction of green building, in the planning and design stage, it learned practical experiences of green building at home and abroad to introduce the conception of ‘Integrated Design (IDP)’, the professionals used PKPM software to evaluate and analyze the energy consumption of architectural design scheme, Simulation Calculation of energy balance and indoor/ outdoor thermal environment to provide basis for other professional to do further optimizations.

Optimization Design of architectural plane: ratio of glazing to floor area of every bedroom and living room in each house type is up 1/5, the ratio of ventilated opening area to floor area of major used rooms is larger than 8%, and each house type has a bathroom with window at least, and the results of the simulation of indoor wind environment suggested that the natural ventilation of indoor environment is favorable.

Optimization Design of envelope structure: external wall system used exterior wall insulation system, based on different architectural form to adjust the thickness of thermal insulation mortars insulation; the roof insulation system uses XPS plate or polyurethane rigid foam as heat insulating material, the thickness has 3 different sizes: 40 mm, 55 mm and 60 mm; window frames use heat insulation break bridge aluminum-alloy hollow, glass is low-e glass, the opening area of window is larger than 30%; the gap between external walls and window applies efficient and fireproofing heat insulating material to seal to enhance the sealing property of building, all the technical measures of energy conservation for building insulations are to reduce heat exchange between buildings and external environment.

In this program, by calculation, the total building energy consumption is 3.80×10^7 MJ/a, unit area energy consumption is 32.01 kWh/m^2·a, the standard value for energy efficiency is 4.01×10^7 MJ/a, it reduces 2.11×10^6 MJ/a in theory. The data indicates that the energy-saving design can reduce the building energy consumption and get a considerable economic benefit.

4. Analysis of energy saving and carbon reduction in the whole life cycle

The greenhouse gases mainly having influence on global warming are CO_2, NO_2 and CH_4. Due to the largest proportion and longest remaining time of CO_2, which is accounting for more than 90% of all greenhouse gas emissions, the research would focus on the carbon emission of whole life cycle.

In the paper, the whole life cycle of building is divided into five stages including building material production, building material transportation, construction, building operation and destruction. However, the process of update and maintenance, whose frequency and quantity is difficult to determine as well as the corresponding research is limited, is out of consideration in the paper. Building's whole life cycle carbon emission per unit area can be calculated by equation [1].

$$\mathrm{E} = \mathrm{E_m} + \mathrm{E_t} + \mathrm{E_c} + \mathrm{E_u} + \mathrm{E_d} \qquad [1]$$

Where E_m, E_t, E_c, E_u, and E_d is the carbon emission per unit area of building material production, building material transportation, construction, building operation and destruction separately.

4.1 The process of building material production

The carbon emission in the process of building material production can be carried out based on the building materials foundation database and building materials consumption in the practical engineering. Because of the imperfection of database at present, only the carbon emission of the widely used materials can be calculated out by the Equation [2].

$$\mathrm{E_m} = \sum_{i=1}^{n} \mathrm{EM_i} \times \mathrm{m_i} \ /\mathrm{A} \qquad [2]$$

Where EM_i is carbon emission of material per-unit in the stage of production, mi is the usage amount of material i and A is the building area.

According to the carbon emission coefficient of per-unit building material that summarized by Yan Yan in master thesis (Yan, 2011), E_m=317.380 kg/m^2.

4.2 The process of building material transportation

Carbon emission in the stage of transportation, which is related to the weight of materials, means of transportation and distance, can be calculated out by Equation [3].

$$\mathrm{E_t} = \sum_{i=1}^{n} \mathrm{ET_i} \times \mathrm{m_i} \ /\mathrm{A} \qquad [3]$$

Where ET_i is carbon emission of material i per-unit in the stage of transportation, m_i is the usage amount of material I and A is the building area.

Because of the lack of the average transportation distance summary in China's mainland, instead of which database of Taiwan is put into use due to the principle of convenience in transportation (Yan, 2011; Chang, 2002). In the context of the assuming that transportation radius is same, it comes to a conclusion that E_t= 54.43 kg/m².

4.3 The process of construction

With detailed energy consumption information of construction, measurement method can be used for accurate calculation. With construction cost but not the energy consumption data, input-output method can be applied on calculation. In the situation that neither energy consumption data nor construction cost is acquired, carbon emission in the stage of construction can be estimated according to the building story with Taiwan method (Yan, 2011; Chang, 2002). As information in the research was limited in the paper, Equation [4] is available in calculation.

$$\mathrm{E_c} = \mathrm{X} + 1.99 \qquad [4]$$

Where X is the building story. Based on the stories and areas of each residential building, it can be calculated out that carbon emission of construction is 32.14 kg/m².

4.4 The process of building operation

Building operation refers to the process from constructed to the end of it, including heating, cooling, lighting, cooking, washing, household appliances and other indoor personal energy consume behavior. Generally speaking, there is two ways for calculation according to the accuracy of data, one is measurement method for accurate calculation and the other is rough estimation based on the energy consumption level of comparable buildings. Under the circumstances of the chosen case in the paper, the result can be carried out by Equation [5] (Yan, 2011).

$$E_u = 0.954\text{kg/kWh} \times \bar{e} \times L \quad [5]$$

Where is the annual average electricity consumption (kWh/m²•a) and L is the fixed number of year of building. On the basis of annual average carbon emission of comparable buildings in the stage of construction (Yan, 2011), taking the fixed number of year of different residential buildings of the case as 50, it was calculated that carbon emission per-unit area in building operation is 1217.5 kg/m^2.

4.5 The process of destruction

Destruction includes the site operation, transportation of building waste and the waste disposal. Mechanical equipment in building destruction, waste transportation and landfill accounts for the main part of energy consume.

Because of the difficulty of gaining data of energy consumption in the stage of destruction and the limit of corresponding research in China mainland, Taiwan method was chosen to estimate the carbon emission of building destruction based on the building area and stories. According to the achievement of Chang (2002), the carbon emission of reinforced concrete construction in demolition stage and abandoned stage can be calculated separately by Equations [6] and [7]. (Chang, 2002).

$$E_{d1} = 0.06X+2.01 \quad [6]$$

$$E_{d2} = 0.54X+38.89 \quad [7]$$

Where X is the building story. Based on the stories and areas of each residential building, it can be calculated out that carbon emission of construction is 59.66 kg/m².

4.6 Carbon emission of full life cycle

With the calculation result of each component, full life cycle carbon emission of the case was calculated by Equation [1] (**Table 1**).

Table 1. Carbon emission of life cycle of Phase Ⅱ construction project of JDXG.

Stage	Full life cycle carbon emission of per-unit area (kg/m²)	Percentages (%)
Building materials production	317.38	18.88
Building materials transportation	54.43	3.24
Building construction	32.14	1.91
Building operation	1217.5	72.42
Building destruction	59.66	3.55
Total	1681.11	100

Through building life cycle assessment, full life cycle carbon emission of the case per-unit area is 1763.15 kg/m², and annual carbon emission per-unit area is 35.26 kg/m²a when the fixed number of year of buildings is 50.

4.7 Carbon reduction measures and effects

The project adopts the following green technologies, which have made outstanding contributions to the whole life cycle carbon reduction:

1) Solar water heating system

458 of the households are designed to adopt the solar water heating system, which will lead to a power saving of 606005.9Kwh every year. The carbon emission coefficient per kilowatt hour of coal power in East China Power System is 0.954 kg/kWh. Consequently, the full life cycle carbon reduction achievement is 87.33 kg/m^2.

2) Green sprinkler irrigation

Annual water consumption in the case is 14778.4 m^3/a. Compared to flood irrigation, the use of sprinkler irrigation leads to water saving of 30%. As the carbon emission coefficient in waterworks production is 0.3 kg/m^3, green sprinkler irrigation can bring about a carbon reduction of 0.2 kg/m^2 in full life cycle.

3) High green rate

The green rate of the case achieves 43.67%. As the green space's carbon absorption factor per unit area is 39 kg/m^{2}a, compared to the green rate of 30% which is demanded in standard, the case will have 213.61kg/m^2 more carbon reduction during full life cycle.

To sum up, after the adoption of the green technologies above, it comes to a full life cycle carbon reduction of 301.13 kg/m², in other word, total amount of carbon reduction will be 99161.5t. It is conceivable that significant carbon reduction effect comes after using green technologies.

5. Conclusion

As two-stars green buildings which is committed by 'Green Building Evaluation Standard', Phase II construction project of JDXG has established a complete system of green building technologies including solar water heating system, permeable ground design, CDF environment optimization design, green illumination system, water-saving irrigation and appliance, intelligent system and building energy efficiency design, which would lead to a remarkable energy saving effect and benefit both economically and ecologically. In addition, green technologies like solar water heating system, green sprinkler irrigation and high green rate make an outstanding contribution to full life cycle carbon reduction.

However, green building evaluation of the project currently only aims at the design stage, the actual effect of operation still needs investigation and verification. Furthermore, full life cycle carbon emission, which lacks the specific criteria, is still settled as an additional item in 'Green Building Evaluation Standard', waiting for further research and practice in the future. The study is aimed to be a reference in carbon reduction of technologies and a popularization suggestion in the establishment of the database for whole life cycle building carbon emission, the calculation method and calculation model.

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