REVIEW ARTICLE

# Energy-saving, green, and environmentally friendly construction techniques in civil engineering construction in China

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**Green and environmentally friendly construction, as an important stage in the entire life cycle of buildings, is a key link in achieving resource conservation, energy conservation, and emission reduction in the construction field. By comparing domestic green construction and American green building evaluation methods, this paper proposed an overall framework for green construction and analyzed in depth the management measures and specific practices of green construction to enhance people's awareness of green construction and promote the implementation of green construction. Through specific engineering cases, in-depth analysis was conducted on the application of energy-saving, green and environmentally friendly construction technology in civil engineering construction. Specific application strategies for energy-saving, green and environmentally friendly construction technology were proposed to achieve energy-saving, green and environmentally friendly goals in the construction process of civil engineering, which would help to reduce energy consumption and environmental pollution, and promote sustainable development of the civil engineering construction industry.**

**Keywords:** green construction; green buildings; new technologies in green construction.

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## Introduction

Sustainable development in the construction industry is inseparable from energy-saving, green, and environmentally friendly technologies. Integrating the concepts of energy conservation, greenness, and environmental protection into civil engineering construction will become a trend in the future field of civil engineering. Currently, the construction industry faces many problems with the most prominent ones being environmental issues and resource waste, which directly affect the balanced development of the ecological environment. Li *et al*. took building energy efficiency and environmental protection technology as the research object and deeply discussed the necessity of developing and utilizing building energy efficiency and environmental protection technology, aiming to promote positive progress in environmental protection issues in the construction industry [1].

Many studies have been done in this field. Bao analyzed the energy-saving and environmentally friendly construction technology in green buildings, focusing on its application significance and key points, aiming to alleviate resource waste and environmental pollution and promote the sustainable development of the construction industry [2]. Deng *et al*. mentioned the need to introduce corresponding equipment and technologies in civil engineering construction based on construction needs, emphasizing the importance of introducing energy-saving equipment and technologies to properly dispose of harmful substances such as wastewater and dust, in order to promote the achievement of sustainable and stable development goals in the construction industry [3]. Wu combined specific civil engineering projects to discuss in detail the application value and practice of energy-saving, green, and environmentally friendly technologies [4], while Lu emphasized the importance of applying energy-saving, green, and environmentally friendly technologies in civil engineering, proposed improvement measures to deepen their application, and meet modern needs [5]. Further, Feng introduced types and uses of green building technologies and proposed an evaluation system for their application in construction management [6]. Li analyzed the application of energy-saving and environmentally friendly technologies in the construction process and proposed effective strategies to promote green development in the construction industry [7]. In addition, Zhang *et al*. discussed the trend of green building technology becoming the future development trend of the construction industry based on the background of dual carbon targets [8], while Yu *et al*. used literature retrieval, comparative analysis, and empirical research to analyze the necessity of green building technology and charming rural housing and explored green technologies for charming rural areas in cold regions [9]. Opoko *et al*. used structured questionnaires to collect data from 296 registered architects, obtained application cases of green building technology, and increased people's understanding of green building technology and traditional building technology [10]. Patil *et al*. introduced various green building technologies including cooling, wastewater treatment systems, energy efficiency, photovoltaic power generation cooling systems, *etc.* [11]. In green buildings, Building Information Modeling (BIM) and ontology are used to manage multidisciplinary activities. The combination of SWRL and OWL models based on Jess rule-based reasoning improves the efficiency of green buildings. The application of green building construction technology and environmentally friendly construction helps to improve resource waste and environmental pollution, thereby promoting the sustainable development of the construction industry [12-15]. The concept of energy-saving, green, and environmentally friendly technologies is crucial for the harmonious coexistence of civil engineering construction and urban living environments, helping to reduce construction costs and energy consumption [16-19]. If the construction industry wants to develop in the long run, it must conform to the development trends of future society, adhere to the concept of green energy conservation and environmental protection, continuously innovate and enhance the application effect of green construction technology [20-23], and to ensure that energy-saving and environmentally friendly technologies play a greater role in practice [24-26].

This study reviewed the theoretical research and practical applications of energy-saving, green, and environmentally friendly construction technologies domestically and internationally, summarized the advantages, disadvantages, and scope of application of existing technologies, selected typical civil engineering construction projects for empirical research and case analysis. Through comparative analysis of changes in energy consumption, environmental pollution, and other indicators before and after adopting energy-saving, green, and environmentally friendly construction technologies, the practical application effects of the technologies were assessed, which would help to verify the feasibility and effectiveness of the technologies and provide empirical support for subsequent technology promotion and application.

## Green construction and the concept of green buildings in the United States

### 1. The concept of green construction

Green construction is a core stage in the full lifecycle of a building, and it is crucial for resource

**Table 1.** Green building standards in different countries (partial).

| SN | Countries | Green Building Standards | Abbreviation | Evaluation Method |
|---|---|---|---|---|
| 1 | China | Green building evaluation standard | GB/T50378-2006 | Graded system |
| 2 | USA | Leadership in energy and environmental design | LEEDTM | Scoring system |
| 3 | UK | Building research establishment environmental assessment method | BREEAM | Scoring system |
| 4 | Japan | Comprehensive assessment system for building environmental efficiency | CASBEE | 5-point system |
| 5 | France | Building environmental impact assessment software | ESCALE | Scoring system |
| 6 | Germany | Sustainable building certification system | DGNB | Scoring system |

conservation, energy conservation, and emission reduction in the construction industry. Green construction emphasizes maximizing resource conservation and minimizing negative environmental impacts through scientific management and technological innovation, while ensuring the quality and safety of the project. Its core objectives are to achieve the conservations of energy, land, water, materials, and environmental protection, known as "four conservations and one environmental protection." In the implementation of green construction, the principle of adapting to local conditions should be adhered to, and relevant national, industry, and local technical and economic policies should be strictly followed to ensure the smooth progress and effectiveness of green construction. The partial green building standard systems in different countries are shown in Table 1.

**2. Green building in the world**

Green building refers to a type of architecture that aims to maximize resource conservation, environmental protection, and pollution reduction throughout its entire lifecycle, providing people with healthy, suitable, and efficient usage spaces while harmoniously coexisting with nature. The Leadership in Energy and Environmental Design (LEED) certification for green buildings in the United States is a pioneering award specifically designed and managed by the US Green Building Council. The green building evaluation system serves as an assessment tool with the core objective of effectively reducing negative impacts on the environment and residents during the architectural design stage. Its primary task is to establish a complete and accurate definition of green building, preventing pseudo-greening phenomena in construction projects. In brief, this system categorizes buildings based on a "scoring" mechanism, focusing on the entire process from site selection, planning and design, construction implementation, to usage and maintenance, providing comprehensive regulations and guidance for green buildings. The significance of this system lies in establishing a common benchmark to promote the development of green buildings, providing an evaluation framework to measure building performance, emphasizing cutting-edge strategies to support sustainable development goals in architecture, recognizing and promoting green technologies, honoring green leaders in the construction industry, and stimulating competitive vitality in the field of green building. It also enhances consumer recognition of green buildings, providing guidance for green building design, thus driving the entire construction industry towards a more green and environmentally friendly direction.

**3. Green construction measures for LEED certification**

The green construction measures for LEED certification primarily focus on sediment and erosion control, including on-site temporary measures and water resource utilization, aiming to minimize the ecological impact during the construction process. This includes measures such as dust management at the construction site, control of noise impact, and prevention of light pollution. Additionally, attention is given to construction materials and resources, management of construction waste, as well as indoor air quality management (IAQ management) during construction and prior to occupancy.

Green construction is a practice focused on the construction process, aiming to reduce negative environmental impacts. In contrast, green buildings emphasize the implementation of green concepts and quality throughout the building's entire lifecycle. Even if green construction is achieved, it does not necessarily mean that the standard of a green building is met. The primary prerequisite for the formation of a green building is that the design phase must embody green concepts. The key to green construction lies in integrating green elements into the construction organization design and construction plan planning to ensure that the construction process meets the requirements of green construction. Green construction mainly focuses on the environmental impact during the construction period. Although the greening of the construction process does not necessarily increase costs, it provides important support and protection for society and the human living environment. Green buildings, on the other hand, pay more attention to the health, operating costs, and functional use of building users, having a far-reaching impact on the entire lifecycle. Therefore, green construction and green buildings are both interconnected and independent. It can be said that green construction is an indispensable part of building green buildings, and both are committed to promoting sustainable development in the construction industry.

## The connotation and necessity of green and environmentally friendly construction

### 1. The connotation of green and environmentally friendly construction

Green buildings involve issues closely related to sustainable development, including ecological and environmental protection, resource and energy utilization, and social and economic development. Green building refers to construction activities that maximize resource conservation and minimize negative impacts on the environment through scientific management and technological progress, while ensuring quality and safety. It aims to achieve environmental protection, energy efficiency and utilization, material and resource conservation, water resource conservation and utilization, and land resource protection. In a broader sense, green building refers not only to the greening of the building process, but also to the greening of the building structure. The system framework of green buildings is shown in Figure 1.

Green construction, as an important stage in the entire lifecycle of a building, essentially aims to protect the ecological environment and conserve resources. It involves optimizing the technologies and management strategies employed in construction projects and implementing them rigorously. The goal is to ensure a safe and efficient construction process and strict control over the quality of the end product. Green construction is a crucial link in achieving resource conservation and energy efficiency in the field of construction, as well as reducing emissions. Green construction, as a critical stage of the full life cycle of buildings, aims to protect the ecological environment and conserve resources. To this end, it strives to optimize the technical and management plans for engineering project construction and strictly implement them to ensure the safety, efficiency, and strict quality control of the construction process. This process is an important link in achieving resource conservation, energy conservation, and emission reduction in the construction industry.

### 2. Necessity of green environmental protection construction

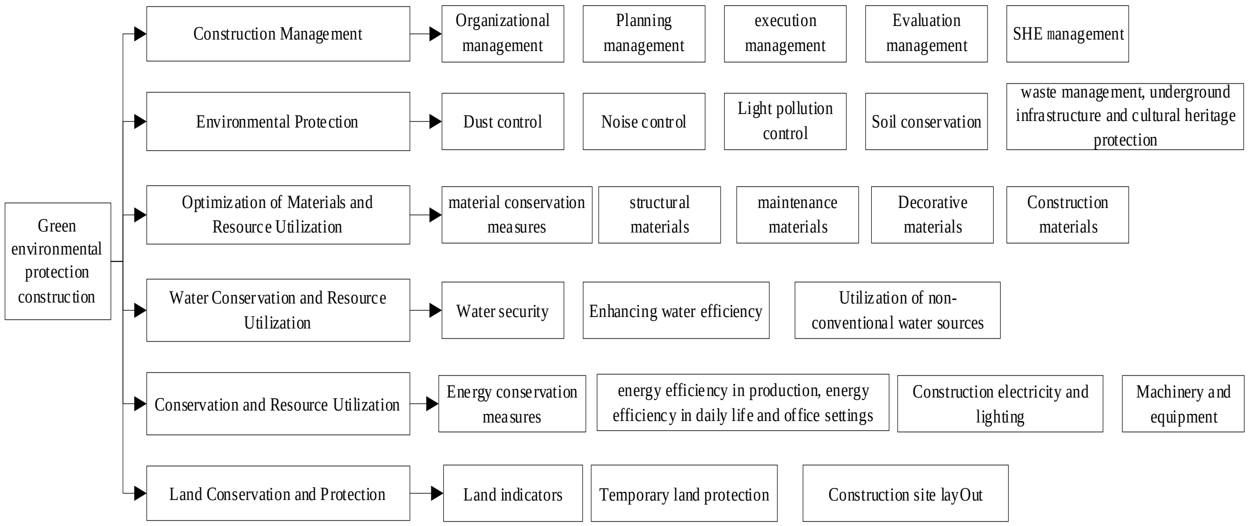


**Figure 1.** Overall framework of green environmental protection construction.

In the full life cycle of construction projects, energy consumption can be divided into the following four stages: The design energy consumption stage mainly involves energy expenses during the planning and design implementation process; the construction production energy consumption stage covers energy usage throughout the production, processing, handling, and construction of materials and equipment; the operational energy consumption stage includes energy expenditures for daily building operations such as heating, air conditioning, lighting, and maintenance management; the building dismantling and recycling energy consumption stage involves energy consumption during building demolition and the recycling of energy-saving materials. Although the construction production cycle is relatively short, its impact on the natural environment is often long-term and sudden, and resource and energy consumption are also quite concentrated. Research shows that energy consumption during the construction production stage can account for 23% of the building's full life cycle, and this proportion is even higher in low-energy buildings. According to statistics, the amount of cement used in construction accounts for 70% of the country's total, wood accounts for 40%, water accounts for 32%, and construction steel accounts for 25%. Compared with developed countries, these energy consumption data are 2 to 3 times higher, posing a heavy burden on China's ecological environment. The implementation of energy-saving and environmentally friendly construction is particularly necessary in the current social context. With the increasing scarcity of resources and the intensification of environmental pollution, traditional construction methods have been difficult to meet the needs of sustainable development. Energy-saving and environmentally friendly construction helps alleviate resource pressure and environmental issues by reducing energy consumption and pollution. It can also improve the quality and performance of building products, enhance the service life and reliability of buildings, and satisfy people's pursuit of a better life. Additionally, adopting energy-saving and environmentally friendly construction techniques can reduce engineering costs, improve construction efficiency, and create more economic benefits for enterprises.

Sustainable development emphasizes meeting the needs of the current generation without compromising the ability of future generations to meet their own needs. Energy-saving and environmentally friendly construction is one of the important means to achieve this goal. By implementing energy-saving and environmentally friendly construction, we can effectively conserve resources, reduce energy consumption, and reduce pollution, laying a solid foundation for future sustainable development. At the same time, it also helps promote technological progress and industrial upgrading in the construction industry, promoting sustained and healthy economic development. Therefore, strengthening the application of energy-saving and environmentally friendly construction in civil engineering is one of the important ways to promote sustainable development.

## Application example of green and environmentally friendly construction technologies

### 1. Project overview

The project was located in Plot C6-05 of Zhongguancun Innovation Park, Haidian District, Beijing City, China with the northern side of the plot adjacent to Weiyi Road, the eastern side next to Chunyang Road (Daxianghu East Road), the southern side connected to the Central Ring Road of the Innovation Base, and the western side adjacent to Jing'er Road of the Innovation Park. According to the architectural planning layout, the project was divided into sections A and B. Section A was designated for data server rooms, while Section B was designated as a research and development office area. The total construction area of this project was 157,067.4 $m^2$, of which the above-ground area was 90,817.2 $m^2$ and the underground area was 66,250.2 $m^2$. In Section A, the underground second floor primarily consisted of chilled water storage rooms, high-voltage distribution rooms, cooling source rooms, spare parts storage, fire water pump rooms, and electrical rooms. The underground first floor was composed of battery rooms, spare parts storage, security control rooms, high-voltage distribution rooms, substations, and electrical rooms. The above-ground portion consisted of three buildings, A-1, A-2, and A-3. A-1 was the equipment room building with the ground floor housing the entrance lobby, testing operation area, testing area, and data server rooms. The 2$^{nd}$ and 3$^{rd}$ floors accommodated the monitoring hall, corresponding management facilities, and data server rooms. A-2 and A-3 buildings comprised the power supply building for the server rooms, spanning the 1$^{st}$ to 3$^{rd}$ floors. In Section B, the underground first floor included a kitchen, staff cafeteria, activity room, accounting archives storage, equipment room, bicycle parking, and part of the underground car parking lot. The underground second floor consisted of a boiler room and a level 6 civil air defense material storage along with an underground car parking lot. The above-ground portion comprised four buildings, B-1, B-2, B-3, and B-4. B-1 was the R&D archives building with the ground floor housing the archives storage and reading area, and the 2$^{nd}$ to 4$^{th}$ floors accommodating archives storage and corresponding management offices. B-2 served as the Beijing Branch Technology Building including an outdoor exit for civil air defense, B-3 was the clearing center including an outdoor exit for civil air defense, and B-4 housed the Application Research Department. All floors from 1$^{st}$ to 4$^{th}$ were open office areas with corresponding supporting auxiliary function zones.

### 2. Four new green construction technologies

The project adopted 15 advanced construction techniques from the 10 major categories of the "Ten New Technologies", which included new construction techniques such as concrete crack control technology, plastic formwork technology, and rainwater recycling and utilization technology during the construction process.

#### (1) The rebar tying machine

The new equipment introduced in this project mainly consisted of a rebar tying machine, tower crane anti-collision system, reusable tension rods, standardized formwork equipment, and laser line markers. The advantages of the rebar tying machine included its simple operation, fast average tying speed, and high efficiency of 40-50 ties per minute. The machine reduced the number of workers required for rebar tying while meeting construction requirements. It significantly shortened the time needed for rebar tying, thus accelerating the construction progress. However, it had the drawback of requiring battery charging, and in some cases, it might be unable to tie rebar in tight steel structure corners or with narrow spacing between rebar. The rebar tying machine is an advanced binding device that enhances construction efficiency by reducing rebar tying time and accelerating the construction progress. It also reduces the number of personnel required for rebar tying, thereby lowering construction costs and overall project expenses.

**(2) Application of plastic formwork**

The advantages of plastic formwork were as follows: (i) minimal material wastage: plastic formwork experienced minimal material loss during usage with a high turnover rate of over 30 times, resulting in cost reduction; (ii) reduced consumption of steel and wood: plastic formwork reduced the need for steel and wood, promoting their reuse and contributing to energy conservation and environmental protection; (iii) smooth surface and easy demolding: plastic formwork offered a smooth surface, facilitating easy removal of the formwork. Additionally, it was lightweight and exhibited excellent corrosion resistance; (iv) recycling capabilities: plastic formwork could be 100% recycled at specialized processing facilities to create new plastic formwork, promoting sustainability. However, the disadvantages of plastic formwork included lower strength and stiffness compared to conventional materials, limited load-bearing capacity, and higher technical requirements due to being a relatively new construction method. When used as horizontal formwork, plastic formwork might result in more significant material wastage. The cost of using conventional wooden formwork was approximately ¥18/m$^2$ when calculated based on the construction area. In contrast, the cost of using plastic formwork was approximately ¥5/m$^2$ based on the construction area. Adopting new formwork materials could significantly improve cost-effectiveness. Additionally, using new materials allowed for the conservation of wood resources, contributing to ecological preservation.

**(3) Water recycling technology**

During the construction process, water recycling technology referred to the collection, treatment, and reuse of wastewater in the construction process to achieve water conservation and environmental protection, which included (i) rainwater recycling: through collection, infiltration, sedimentation, and other treatment methods, the rainwater on the construction site was rationally utilized. The treated rainwater could be used for landscaping, car washing, dust suppression, and other construction activities. It could also meet the water demand for masonry plastering, structural maintenance, and other aspects; (ii) recycling of groundwater extracted during foundation pit construction: by setting up water storage tanks and drainage pipes, the groundwater extracted from the construction site was collected and treated. These water resources could be used to wash construction equipment. After sedimentation treatment, they could be recycled for other aspects of the construction site; (iii) utilization of wastewater produced on the construction site: wastewater generated during concrete pouring, building material cleaning, mechanical equipment cleaning, and other processes was recycled and treated. After purification, this wastewater could be reused for non-critical water use in the construction process, such as flushing, wetting, etc., thus achieving the recycling of water resources.

**(4) Concrete crack control technology**

The material selection and mix design were done by choosing medium-heat or low-heat cement varieties and minimizing the amount of cement used, controlling it within the range of 220 -240 kg/m$^3$, prioritizing the use of cement with good water retention, low bleeding, and low drying shrinkage such as slag Portland cement, selecting hard, continuously graded, and non-alkali reactive gravel with suitable particle sizes such as 5 - 31.5 mm gravel for beams and plates, avoiding excessive or insufficient water-cement ratio to ensure the compressive, tensile, and flexural strength of the concrete. The construction process control was performed by strengthening the early maintenance of commercial concrete through covering the concrete with grass mats, grass bags, or plastic film in time after pouring and watering them for wetting and maintenance; in weather conditions with low temperature, low humidity, and high wind speed, covering and spraying water mist early and appropriately extending the curing time; controlling the pouring temperature of the concrete, using low-temperature water to mix the concrete, cooling the sand and stone with cold water mist or setting up a simple shading device; meanwhile, adopting thin-layer pouring with a thickness of no more than 30 cm to accelerate heat dissipation; avoiding pouring concrete in hot weather and at night to reduce the impact of temperature on the quality of the concrete; using polypropylene fibers, polymer emulsions, or carbon fibers as crack control agents, which could effectively increase the ductility of the concrete, reduce the drying shrinkage effect, and suppress the expansion of cracks.

**3. Water conservation and water resource technologies**

**(1) Drainage scheme for the project**

The project management team was responsible for developing a wastewater discharge plan for the construction site, which should be integrated into the construction organization design. This plan included the layout diagram of drainage ditches or drainage pipelines, the selection of drainage pipe diameter, and specifications for sedimentation tanks and vehicle wash stations.

**(2) Water recycling and utilization technologies in the construction process**

In this project, rainwater harvesting and utilization technologies were adopted to collect rainwater during the construction process. After undergoing treatments such as infiltration and sedimentation, the collected rainwater was stored centrally and used for dust suppression, landscaping, vehicle washing, as well as for structural maintenance water, excavation support water, curing water for concrete test samples, and site masonry and plastering construction water. By harnessing rainfall during the construction season, large-scale water storage reservoirs were constructed to store rainwater for use in the construction process. This approach reduced the reliance on groundwater, saved energy consumption associated with pumping water, and minimized manual labor. More than 20% of water used on the construction site was currently sourced from recycled rainwater and production wastewater. Currently, rainwater utilization in construction processes is limited in China. However, maximizing the utilization of rainwater can significantly reduce the consumption of groundwater, enhance process control, lower costs, protect the environment, foster water conservation awareness, and contribute to the establishment of a water-saving society. The project department had procured a complete set of water purification equipment to purify the collected rainwater. The purified water was used for spraying on roads and flushing toilets. After the backfilling of the basement septic tank was completed, the garage roof formed a basin shape, and during the rainy season construction period, rainwater could not drain away and accumulated on the garage roof. To address this, the project department installed a rainwater collection system inside the basement. A waterproof steel plate was reserved at the joint between the roof of the underground garage and the poured concrete strip. Rainwater flew through steel pipes to the basement collection pit and elevator pit. The water in the collection pit and elevator pit needed to be manually extracted and settled through a three-stage sedimentation tank. The settled water would be directed to the formal fire water tank below the office building. The basement was equipped with a fire pump room to collect rainwater for fire protection and concrete curing during construction. The utilization of non-traditional water sources was a crucial aspect of the three-star technical requirements for green building design. Considering its unique characteristics,

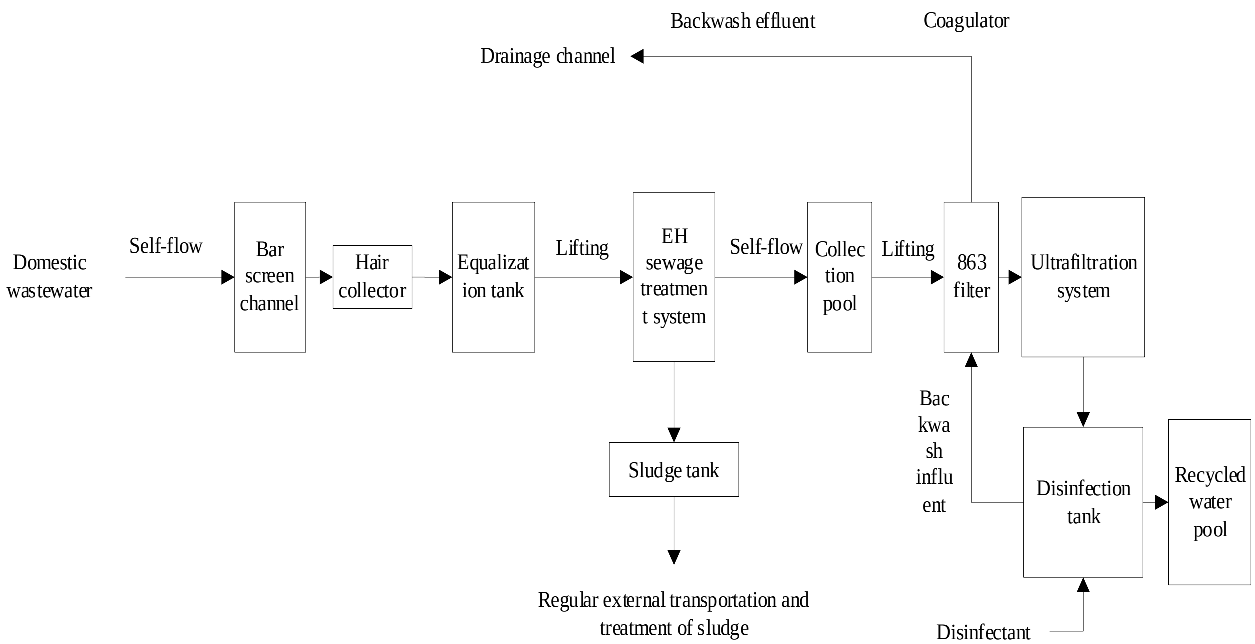


**Figure 2.** Process of water system in green construction.

regional water resources, and the water utilization requirements of green buildings, the reclamation and reuse of treated wastewater system was selected (Figure 2). With a focus on technical and economic feasibility, the aim was to maximize the utilization of non-traditional water sources. By implementing the recycling of wastewater, the system helped to reduce the volume of sewage discharge and alleviate the pressure on municipal sewage networks. This approach rationalized water system investments and operations while optimizing emission reduction effects, thereby promoting sustainable development of green buildings.

**4. Land and site management**

The overall construction site layout was meticulously planned in a phased, scientific, and rational manner, making full use of existing buildings, structures, roads, and pipelines to support the construction process. For temporary offices and living quarters, an economical, aesthetically pleasing, space-efficient solution was adopted. This solution minimized the impact on the surrounding topography and environment while allowing for dynamic adjustments in the construction site layout. The standardized assembly structure of three-story light steel movable panel houses was chosen, ensuring the maximum utilization of temporary land resources.

**5. Energy efficiency and energy utilization**

**(1) Construction technology for external wall thermal insulation system**

In this project, except for some reinforced concrete shear walls, the exterior walls were entirely constructed using autoclaved aerated concrete blocks that were lightweight, porous, provide excellent thermal insulation, good fire resistance, and nailable, sawable, planable, and possessing certain seismic resistance capabilities to make them a superior and environmentally friendly building material. Serving as both infill and insulation material, they met the design standard of achieving 50% energy savings for regions with hot summers and cold winters, as well as regions with hot summers and mild winters.

**(2) Mechanical and energy conservation in daily life**

(i) Using construction machinery and equipment that matched the required power and load, avoiding prolonged operation of high-power machinery with low loads. Optimizing work schedules to improve the utilization and load capacity of various machinery, reducing the energy consumption per unit of equipment.

(ii) Making the best use of the site's natural conditions by designing temporary facilities for production, living, and office spaces with appropriate size, orientation, spacing, and window-to-wall area ratio, which ensured adequate sunlight, ventilation, and natural lighting.

(iii) Employing materials with excellent insulation properties for the walls and roofs of temporary structures, reducing the need for air conditioning in summer and heating equipment in winter, thereby decreasing energy consumption and usage time.

(iv) Strengthening the promotion of energy conservation by adopting a combination of automatic timing and manual control for electrical usage in the construction area. Conducting regular inspections on-site and prohibiting the unnecessary use of lighting in non-operational areas.

(v) Setting air conditioning temperatures at a moderate level, avoiding excessively high or low settings.

(vi) Turning off computers, printers, lighting, and air conditioning when the office area was unoccupied. Minimizing paper waste in the office by utilizing double-sided printing whenever possible.

**6. Technological advancement - economic and social benefits**

**(1) Benefits of plastic formwork technology**

In this project, plastic formwork was proposed for the construction of the four main buildings, reducing the loss of wood formwork. When considering the use of wood formwork, conservatively estimating, the on-site formwork loss per floor was approximately 2,016 $m^2$. If ordinary wooden boards were used with an average price of around $11 (USD) per sheet, a new set of wood formwork needed to be replaced every 8 floors to ensure the exterior finish of the concrete walls and columns. Therefore, the on-site consumption would be calculated as follows (intended for buildings 16 to 19, based on an average of 32 floors):

$$32 \div 8 \times 2{,}016 \div (0.915 \times 183) \times 4 \times \$11 = \$161{,}100$$

By using plastic formwork, only one set of formworks for walls and columns was required with a unit price of $11.9 per sheet, resulting in the following expenditure:

$$2{,}016 \div (0.915 \times 1.83) \times 4 \times \$11.9 = \$57{,}200$$

The direct profit from using plastic formwork was then calculated as:

$$\$161{,}100 - \$57{,}200 = \$103{,}900$$

Social benefits included ensuring construction quality, accelerating construction progress, and saving wood consumption.

**(2) Benefits of early stripping formwork technology**

By adopting the early stripping formwork technology in this project, the concrete formwork, which originally required 7 to 8 days of curing before removal, could now be partially removed as early as 2 to 4 days, which allowed for a 30% reduction in formwork input. Taking Building 16 as an example, with traditional formwork technology, the initial input would require 3 sets of formworks and was calculated as follows with 2,016 $m^2$ of formwork used per floor:

$$2{,}016 \times 3 = 6{,}048 \text{ m}^2$$

The total cost would be:

6,048 ÷ (0.915 × 183) × $11 = $39,700

However, with the implementation of early stripping formwork technology, only 2 sets of formworks would be required with a total quantity of:

2,016 × 2 = 4,032 $m^2$

The total cost would then be:

4,032 ÷ (0.915 × 1.83) × $11 = $26,500

The economic benefit for one building would be:

$39,700 – $26,500 = $13,200

With the technology applied to 3 buildings, the total economic benefit would be:

$13,200 × 3 = $39,600

Social benefits included reducing the initial amount of formwork required, which could shorten the construction period.

**(3) Benefits of green construction technology**

The water recycling technology employed during the construction process took advantage of the abundant rainfall in the area. According to meteorological data, the average annual precipitation was 1,129.5 mm, and with a site area of approximately 130,000 $m^2$, collecting 10% of the rainfall would amount to:

130,000 $m^2$ × 1.1295 m × 10% = 14,683.5 $m^3$

or approximately 14,683.5 metric tons of rainwater. In the local area, the unit price for industrial water was $0.56/hour, resulting in a cost-saving of:

14,683.5 tons × $0.56 = $8,222.76

For the construction site, two water storage tanks with dimensions of 3 × 6 × 4 $m^3$ were built. The cost for one water storage tank was calculated as follows:

The required quantity of standard bricks:

0.24 m × (3.24 m + 6.24 m) × 2 × 4 = 18.2 $m^3$

The cost of bricks:

18.2 $m^2$ × 512 bricks/$m^2$ × $0.0392/brick × 1.1 = $40,145

The cost of cement, sand, and other materials was $35.

The labor cost was:

10 workers × $28 = $280

The estimated cost for piping and fittings was $182.

The total cost for two water storage tanks was:

$899 × 2 = $1,798

The generated benefit was:

$8,221 - $1,798 = $6,423

The social benefit was the conservation of water resources and energy efficiency.

Another green construction technology employed was the external wall self-insulation system. The site used aerated concrete blocks for the external walls, which were lightweight, porous, good thermal insulation and fire resistance, and a new type of building material that could be nailed, sawed, planed, and had certain seismic resistance capabilities. They also offer environmental advantages.

## Specific application strategies of green and environmentally friendly construction technology

To achieve the goal of green and environmentally friendly construction in civil engineering, specific application strategies include selecting high-efficiency and energy-saving construction equipment and building materials, optimizing construction processes, promoting the utilization of renewable energy, strengthening water conservation, and reducing construction waste should be adopted, which will help to reduce energy consumption, mitigate environmental pollution, and promote sustainable development in the civil engineering industry.

**1. Selection of high-efficiency and energy-saving construction equipment and building materials**

It is preferential to select construction machinery and equipment with low energy consumption and high efficiency such as energy-saving generators and electric construction machinery. Simultaneously, it is important to strengthen equipment maintenance and ensure their good working condition to reduce energy consumption. The use of energy-saving building materials such as thermal insulation materials and energy-efficient doors and windows should be actively promoted. Additionally, renewable materials to replace traditional non-renewable materials such as bamboo and wood products and biomass materials, should be adopted to reduce resource consumption.

**2. Optimization of construction processes**

It is critical to reasonably arrange the construction sequence, reduce repeated and ineffective operations, and improve construction efficiency. The use of prefabricated construction technology to reduce on-site wet operations, thereby reducing energy consumption and environmental pollution needs to be promoted. Green construction techniques such as green fences and green construction roads should be adopted to minimize dust and noise pollution during construction.

**3. Promotion of renewable energy utilization**

Solar energy technologies such as installing solar water heaters and photovoltaic power generation systems can be utilized to provide clean energy for construction sites. Fully utilizing wind energy such as using wind turbines to supply power to construction sites is also considerable. Reasonably utilizing geothermal energy such as adopting ground source heat pump technology to provide heating and cooling services for construction sites is also a choice.

**4. Strengthening water conservation management**

The water-saving construction equipment and appliances such as water-saving flushing equipment and faucets should be adopted. A rainwater collection system and using the collected rainwater for flushing and landscaping at the construction site may be established. The water management on the construction site to avoid waste and pollution should be strengthened.

**5. Implementation of construction waste reduction and treatment**

A construction waste classification and treatment plan to separate recyclable and non-recyclable waste should be developed. The utilization of construction waste resource recovery technologies such as processing construction waste into recycled aggregates, bricks, and other building materials should be promoted. The cleaning and organization work on the construction site to reduce the generation and accumulation of waste should be strengthened.

## Conclusion

This research reviewed the actively practice of the green construction concept in management, which has played a pivotal role in facilitating the establishment of "Zhengzhou Safe and Civilized Construction Site" as well as serving as the observation site for "Zhengzhou City Quality, Safety, and Civilized Construction," thereby contributing significantly to the advancement of these initiatives. The principles of "saving materials, water, energy, and land" advocated by green construction not only effectively reduce project costs and bring considerable economic benefits to construction companies, but also closely integrate with the company's dual optimization strategy, enhancing the company's image and reputation. Meanwhile, green construction also helps maintain urban environmental order and promotes the sustainable development of cities. Green construction is closely related to the dual optimization strategy of enterprises. Through the implementation of green construction, companies not only enhance their image and reputation, but also optimize resource allocation and construction management processes, improving overall operational efficiency, which shows that green construction is not only an environmental protection concept, but also a management strategy with practical benefits. Green construction plays an important role in maintaining urban environmental order and promoting sustainable urban development. Through the implementation of green construction, the environmental quality of the project site has been significantly improved, creating a more livable living environment for urban residents. Green construction also aligns with the long-term interests of urban development and contributes to promoting green transformation and sustainable development. The application of energy-saving, green, and environmentally friendly construction techniques in civil engineering construction has important practical significance and far-reaching impact. It is not only a concrete manifestation of responding to the national energy conservation, emission reduction, and green environmental protection policies, but also an important way to promote enterprise transformation and upgrading and achieve sustainable development. In the future, with the continuous advancement of technology and the increasing awareness of environmental protection, energy-saving, green, and environmentally friendly construction techniques will be more widely used and promoted in civil engineering construction, making greater contributions to building an ecological environment and achieving green development.

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