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# *Analysis of the Application Potential of Green Materials in Campus Buildings*

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***Abstract.*** With the deepening of global climate change and the advancement of the "dual carbon" goals, campus buildings, as an important component of public buildings, urgently need to transform toward greening. Green building materials, due to their characteristics of energy saving, environmental protection, and recyclability, have become key support for reducing energy consumption and emissions in campus buildings. This paper studies the application potential of key green building materials such as prefabricated composite panels, thermal insulation materials, and Carbon Fiber Reinforced Plastic (CFRP) /Glass Fiber Reinforced Plastic (GFRP) in campus buildings by combining material performance comparison, case evaluation, and life cycle cost analysis. The study finds that green materials can shorten the construction period, improve the thermal resistance of the envelope structure, and significantly reduce operating energy consumption; low-volatile Organic Compounds (Low-VOC) and phase change energy storage materials effectively improve indoor environmental comfort; although the initial investment is slightly higher, the life cycle cost can be slightly saved, and the investment payback period is controlled at around 10 years. This study provides specific paths and decision-making references for the promotion and application of green building materials in campuses, which helps realize the low-carbon transformation of the construction industry and the goal of green education.

***Keywords:*** green materials, campus building, low-carbon

## 1. Introduction

Traditional building materials produce different levels of carbon emissions during production or application, further exacerbating the greenhouse effect. As the global climate change problem is becoming more and more serious, green and low-carbon is the development trend and direction of sustainable development of the construction industry. As an important source of energy consumption and carbon emissions, the green transformation of the construction industry is not only related to environmental protection but also to the achievement of the national “double carbon” goal [1]. Therefore, green building materials, as an important part of green buildings, are being incorporated more into the scope of architectural design and practice due to their energy-saving, environmentally friendly, recyclable and other characteristics.

The campus is an important part of public buildings, which has many building types, complex functions and low building density. Nationally and globally, campuses are large in number and

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widely distributed, and there is both a continuous demand for construction and renovation, as well as the potential to become an important scenario for the promotion and application of green building materials [2]. Chen pointed out that compared with high-rise buildings, campus buildings are mostly low-rise structures with lower strength requirements for building materials, making a variety of green materials more applicable [3]. In addition, campus buildings are not only a key place for teaching and research but also an important platform for the dissemination of green concepts and education. Song believes that widely applying green building materials in campus construction, can not only improve the functionality and sustainability of the building but also help to cultivate green and low-carbon lifestyles and values among students and teachers [4].

Although some current campus construction projects have begun to try to introduce green building materials, overall they are still in the preliminary exploration stage, facing problems such as limited material choices and immature construction techniques [5]. Therefore, it is of great significance to systematically study the green building materials applicable to campus buildings and compare their advantages over traditional materials in terms of energy saving and emission reduction, functionality and economic benefits, in order to promote the green construction and transformation of campuses.

Therefore, this paper will focus on the application and popularization of green materials in campus buildings, and provide a theoretical basis and practical reference for campus green construction through material analysis, case evaluation and promotion strategy research.

## 2. Overview of green materials

Common traditional building materials include cement, steel, common paints, man-made sheets, red bricks, concrete, single-pane doors and windows. These materials often bring about a series of environmental problems during building construction and use. On the one hand, conventional building materials, such as cement and steel, need to consume a large number of mineral resources and fossil energy in the production process, with huge carbon emissions, which has become the main source of greenhouse gas emissions in the whole life cycle of the building, and it is difficult to meet the requirements of carbon neutrality [1]; on the other hand, ordinary paints and man-made panels commonly contain formaldehyde, benzene, and VOCs, and these hazardous substances continue to evaporate in the process of use, which not only pollute the On the other hand, formaldehyde, benzene and VOCs are commonly found in common paints and artificial plates, and these harmful substances continue to evaporate during the use process, which not only pollutes the indoor air but also seriously threaten the health of teachers and students [6]. In addition, the relatively poor thermal and acoustic insulation performance of traditional materials such as red bricks, concrete, and single-glass doors and windows makes the energy consumption of building operation high, and the indoor thermal comfort and acoustic environment are difficult to guarantee, and cannot meet the modern energy-saving building standards [7]. Traditional building materials increase carbon emissions, generate energy consumption, and environmental health problems. Moreover, the wet-work-based construction method has a long construction period and serious dust and noise pollution, which is not conducive to the efficient organization of special construction periods concentrated in summer and winter vacations on campuses, while the frequent maintenance and renewal in the later stages further pushes up the total life cycle cost [8]. More importantly, traditional building materials have low recycling rates and long degradation cycle, and the pressure of large amount of construction waste disposal is increasing day by day, which is not conducive to resource recycling and sustainable development [9]. Therefore, the use of modular prefabricated, low-carbon and high-performance green building materials to replace traditional materials has

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become a necessary way to enhance building energy efficiency, improve the indoor environment, optimize construction management and achieve resource recycling.

Green building materials are a key component of the construction industry's response to the sustainable development strategy, referring to building materials that minimize resource consumption and environmental impacts throughout the building's lifecycle, as well as having both health and safety properties [10-11]. Currently, with the aggravation of environmental pollution and energy crisis, green building materials not only reflect the practical application of the concept of environmental protection but also become an important guarantee to improve the performance of buildings and the quality of people's living. According to the material performance and source, green building materials can be divided into three categories: energy-saving, environmentally friendly and recycled. Energy-saving materials, such as rock wool and polyurethane foam, effectively reduce the energy consumption of air conditioning and heating under their excellent thermal insulation properties [12]. Environmentally friendly materials emphasize the reduction of harmful substance emissions during production and use, such as low VOCs paints and formaldehyde-free panels, which not only improve indoor air quality but also reduce environmental pollution during the construction phase [10]. Recycled materials utilize waste materials such as recycled concrete and recycled metals to achieve resource recycling while safeguarding functionality [11].

## 3. Potential for green materials in buildings on campus

### 3.1. Commonly used green materials on campus

In campus buildings, the application of green materials is gradually replacing traditional high-energy and high-pollution building materials to achieve the goal of energy saving and emission reduction. Cross-laminated timber (CLT), as a structural material, has the advantages of low carbon and renewable and is suitable for light buildings such as teaching buildings and dormitories. It has good thermal insulation performance, and it can even be used to reduce on-site pollution by assembled construction methods, and although the initial cost is high, the life-cycle cost is low, which reduces a lot of maintenance and repair costs. Lightweight insulation blocks are commonly used in internal partition walls or non-load-bearing walls, which are made of industrial waste residue, both good thermal insulation performance and ease of construction, compared with red bricks, more environmentally friendly and more conducive to improving the energy efficiency of buildings. In the application of thermal insulation, natural fibers replace traditional polystyrene foam, which has better air permeability and biodegradability, does not release harmful substances, and is suitable for classrooms, libraries, and other spaces that require a high level of comfort. Low-VOC water-based paints, which are widely used in interior decoration, can effectively reduce the concentration of harmful substances in the air and improve indoor air quality, as well as having good durability and environmental performance. In terms of window and door systems, broken-bridge aluminum with Low-E glass is widely used in campus buildings, which can effectively insulate heat, reduce noise, block ultraviolet rays, and reduce air-conditioning energy consumption, and is suitable for libraries, laboratories, and other areas with high requirements for temperature and light. In addition, fly ash or slag concrete is widely used as a structural material in foundations, beams and columns, and floor slabs, which reduces carbon emissions and is more environmentally friendly while maintaining durability.

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### 3.2. Potential for green materials in buildings on campus

Campus buildings have stringent requirements for construction lead time, environmental impact, structural performance, cost of ownership, and indoor and outdoor thermal performance. Green building materials, with their prefabrication and low emissions, can be quickly installed during the short summer and winter breaks and significantly reduce post-construction environmental pollution. High-performance composites and smart functional materials ensure structural safety and comfort. Life Cycle Cost Analysis (LCCA) shows that green building materials reduce maintenance and repair costs over the long term. Ultra-thin and efficient thermal insulation materials can reduce energy consumption and enhance environmental comfort. The following section combines typical case studies with experimental studies to systematically evaluate the potential of green materials in campus buildings.

Firstly, in order to meet the schedule and environmental requirements, campus buildings are more suitable for green materials. The construction of campus buildings is mostly concentrated in the summer and winter vacation periods, which has a short construction period and a greater impact on the teaching order.

Modular prefabricated components can be finished in a controlled factory environment for more than 80% of the components, and then quickly assembled on site, saving an average of 45%-50% of construction time compared to traditional cast-in-place methods, and reducing on-site waste and construction noise and dust emissions [8,13].

Low-VOC biobased insulation has an emission rate of less than 0.1 mg-m-$^{2}$-h-$^{1}$ in long-term indoor VOC monitoring, with no significant impact on microbial concentrations, thus safeguarding the air quality of the campus construction and early-use environments [6,14].

Secondly, in order to meet the quality requirements, it is more important to choose green materials for campus buildings. Campus buildings need to meet a service life of more than 50 years and stringent seismic, fire and environmental standards.

CFRP (Carbon Fiber Reinforced Polymer) composites have a residual tensile strength decay of no more than 33% after accelerated water immersion aging for 224 d. The life prediction based on the Arrhenius model is in high agreement with the measured data in the field, which indicates its reliable durability in long-term structural reinforcement and composite systems [15].

GFRP (Glass Fiber Reinforced Polymer) exhibits excellent corrosion resistance in salt spray and moisture-heat cycling environments, and its design attrition factor can be revised from 0.75 recommended by ACI 440.2R-17 to 0.85 to account for actual aging effects [15].

Low-E insulating glass (Low-E IGU) combined with phase change energy storage panels can reduce the building heat load by 20-30% and achieve dynamic adjustment of indoor temperature and humidity with the help of an intelligent monitoring system, thus enhancing the environmental comfort and learning efficiency of teachers and students [7].

In addition, in order to meet the cost of Utah requirements, campus buildings should choose green materials. The initial investment in green building is about 10-15% higher than the traditional program, but the life cycle perspective has a significant economy.

Compared to traditional industrial buildings, green buildings realize a total cost savings of 17% through energy savings and maintenance cost reductions over a 25-year lifespan, with a payback period of 10-12 years [9].

In the case of Harvard University's Center for Energy and Facilities Management, the application of the LCC methodology to evaluate rainwater recycling, photovoltaic roofing, and PCM systems resulted in a 15% reduction in the overall operating costs, which was further offset by carbon trading and government subsidies for the initial investment [16].

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The University of Arizona's “Rainwater Harvesting” demonstration project demonstrated the ability to recycle 60 $m^3$/100 $m^2$ of water per year during the rainy season and reduce municipal water demand by 30% [17].

Finally, green materials should be applied to campus buildings in order to fulfill thermal insulation requirements. Campus buildings are multi-functional and need to meet different thermal demands of classrooms, dormitories, laboratories, etc. at the same time.

Vacuum insulation panel (VIP) core material has a low thermal conductivity of 0.011 $W\text{-}m^{-1}\text{-}K^{-1}$, and the thermal resistance retention rate is higher than 98% after many years of testing, which is suitable for the exterior wall and roof renovation of existing school buildings [18].

Silica aerogel composite thermal insulation rendering layer can reduce heat loss by more than 40% in practical wall applications, and the thickness is only 1/3 of traditional rock wool, which significantly saves the net height of the interior [19].

Phase change energy storage material (PCM) embedded in walls and roofs increased the smoothness of day/night temperature difference by 50%, reduced the start/stop frequency of HVAC equipment by 25%, and had a significant effect on the pressure relief of centralized campus heating and air conditioning system [14].

### 3.3. Comparative analysis of commonly used green materials and traditional materials on campus

Table 1 compares the differences between the application of green building materials and traditional building materials in campus academic buildings, libraries, laboratory buildings, etc., and analyzes them in terms of environmental impact, cost, material performance, construction and maintenance, indoor air and health, and educational demonstration significance.

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Table 1. Comparison between traditional and green materials

| Green Materials (Examples) | Traditional Materials (Examples) | Application Scenarios | Environmental Impact | Cost (Initial / Lifecycle) | Material Performance (Insulation / Fire Resistance / Durability) | Construction & Maintenance | Indoor Air Quality & Health |
|---|---|---|---|---|---|---|---|
| CLT / Sustainable Wood | Reinforced Concrete | Building structures, timber construction | Low carbon emissions, renewable | High initial, low long-term | Good insulation, requires fire protection | Fast assembly, low pollution | Eco-friendly, non-toxic |
| Lightweight Insulation Blocks | Red Bricks | Interior partitions, non-load-bearing walls | Contains waste residue, low energy consumption | High initial, low later | Good insulation, non-load-bearing | Quick construction, lightweight | Non-irritating |
| Natural Fibers / Wool | Polystyrene Foam | Building insulation layers, wall filling | Low carbon, biodegradable | High but durable | Good insulation and breathability | Easy to cut | Formaldehyde-free |
| Low-VOC Water-based Paint | Traditional Paint | Interior decoration | Low VOC emissions | High but healthy | Durable and eco-friendly | Quick drying | Non-toxic fumes |
| Broken Bridge Aluminum + Low-E Glass | Single-pane Glass Window | Doors and windows, curtain walls | Reduces energy consumption | High initial, saves energy later | Excellent insulation | Requires professional installation | Dust and noise reduction |
| Fly Ash / Slag Concrete | Ordinary Cement Concrete | Foundations, structural beams, slabs | 30% $CO_2$ emission reduction | Comparable cost | Durable and corrosion-resistant | Conventional construction | More environmentally friendly |

Overall, green building materials have greater advantages in terms of long-term operating costs and environmental friendliness. With the development of technology and the development of the concept of protecting the environment and green ecology, the application of green materials will become more and more extensive. The development of green building materials is not only due to the continuous innovation of related technology, but also due to the improvement of social environmental awareness and the strong support of the state. Therefore, the promotion of green materials in campus construction has multiple values of environment, economy and society.

## 4. Case study

### 4.1. Primary and Secondary Schools in Bo Long Lake Science and Technology Park

As a model of a green and low-carbon campus, the Primary and Secondary Schools of Bo Longhu Science and Technology Park fully meet the general trend of sustainable development in the construction industry. The project is located in the core area of Bo Long Lake Science Park in Binhai New Area, Tianjin City, with a total land area of about 58,000 square meters and a building area of about 44,600 square meters, with a total of 54 classes in elementary school, junior high school and senior high school. The whole project adopts a low-rise frame and prefabricated

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component structure to shorten the construction cycle and reduce on-site carbon emissions. To achieve the goal of near-zero energy consumption, lightweight energy-saving composite panels and high-performance thermal insulation materials are used for the exterior envelope, with the thermal resistance of the exterior walls increased by more than 50% compared with the traditional scheme; the heat transfer coefficient of the broken-bridge aluminum + LowE hollow glass doors and windows have been reduced to 1.4 W/(m²-K), which significantly reduces the hot and cold loads. The roof is covered with a highly reflective energy-saving coating (daily reflectivity of 0.75) and integrates 14.36 kWp photovoltaic modules and solar collector panels, providing the campus with about 12% of its electricity and hot water needs; indoors, low VOC water-based paints and formaldehyde-free solid wood composite panels are used across the board to safeguard the respiratory health of teachers and students. The rainwater recycling system recycles an average of 1,500 m³ per year for greening and flushing, reducing municipal water consumption by 30%, while green roofs and slope vegetation further regulate the microclimate; the online energy consumption monitoring platform tracks the energy consumption of air conditioning, lighting and water supply and drainage in real time, with an annual energy saving rate of 20%. The project has been awarded the Ministry of Housing and Construction's Green Campus Demonstration and Green Building 3-star certification and has won domestic and international sustainable building awards. It has also been incorporated into the environmental education practice of “Campus as a Classroom”, and has become an important model for spreading the concept of green and low-carbon, and leading the building materials revolution on campus.

### 4.2. Nanjing Lixian Elementary School

Nanjing Lixian Primary School is located in the Education New City of Gulou District, Nanjing, Jiangsu Province, covering an area of about 42,000 square meters, with a building area of about 31,000 square meters, planning 24 teaching classes to meet the teaching and living needs of more than 1,200 teachers and students. The project was initiated in 2020 with the goal of being a “zero-carbon campus demonstration project”. The overall low-rise frame structure and prefabricated components were adopted, with a construction period of only 18 months to ensure minimal disruption to the teaching order.

In terms of external enclosure and thermal insulation, the school's external wall is made of a combination of polyphenylene sulfide (PPS) composite panels and rock wool insulation, with a thickness of 120 mm, and a thermal resistance value of about 3.5 m²-K/W, which is twice as high as that of the traditional 240-mm red-brick wall, and reduces energy consumption for winter heating by nearly 45%. The window and door system uses aluminum alloy broken bridge profiles with 6 mm+12 mm Air+6 mm LowE insulating glass, the overall heat transfer coefficient (U-value) is reduced to 1.3 W/(m²-K), which reduces the heat loss by more than 75% compared with the single-layer glass, and at the same time, the acoustic insulation performance is improved by 5 dB, which effectively protects the thermal comfort and quiet environment of the classroom.

The roofing system integrates a highly reflective nano-ceramic coating with photovoltaic and solar-thermal integration devices: the coating has a solar reflectivity of up to 0.80, making the roof surface temperature 15-18 ℃ lower than that of an asphalt roof, and reducing the air-conditioning cooling load by about 10%; the photovoltaic module with 15 kWp and the solar collector panels of 200 m² provide the campus with 12% of the electricity and 50% of the hot water demand respectively, reducing carbon emissions by about 18 tons per year. The annual carbon reduction is about 18 tons, which significantly reduces the dependence on municipal energy.

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For interior decoration, low-VOC water-based paint (VOC content ≤50 g/L, formaldehyde ≤0.3 mg/m³) and graphene-enhanced gypsum board are used, which is formaldehyde-free and odorless, with formaldehyde emission far below E0 level. The flexural strength of graphene gypsum board is 30% higher than that of ordinary boards, and it has the function of moisture absorption and temperature regulation, which provides a healthy and comfortable indoor environment for teachers and students.

The water recycling system consists of permeable paving, sunken rain gardens and intelligent rainwater recycling facilities, with an annual average of about 1,200 m³ of recycled rainwater, which is used for landscape irrigation and toilet flushing, replacing 25% of tap water. The campus is equipped with modular green roofs, which not only further reduces the heat load, but also fixes about 2.4 kg/m² of $CO_2$ annually through vegetation photosynthesis, thus enhancing the effect of eco-education.

The project won the Jiangsu Province Green Building Excellence Award and the Nanjing Municipal Bureau of Housing and Construction “Green Campus Demonstration Project”, and the design unit was awarded the honor of “Provincial Green Building Innovative Enterprise”, which reflects its leadership in the field of green campuses [20-21]. Neighboring communities and schools have organized many visits for teachers and students, and Lixian Elementary School has been used as a green campus on-site teaching site, with more than 20 media reports, which has greatly promoted the social promotion effect of the application of green building materials in the region [22].

## 5. Conclusion

This study employs a combined approach of material performance analysis, case study evaluation, and life cycle cost analysis to systematically explore the application pathways of green building materials in campus buildings. First, by comparing the performance of key technologies and incorporating actual operational data from the Tianjin Bohai Lake Science and Technology Park School and the Nanjing Lixian Primary School, the feasibility of green building materials in shortening construction cycles, enhancing the thermal performance of building envelopes, improving indoor air quality, and enhancing structural durability was validated. The study found that green building materials can reduce on-site construction time by nearly half, increase the thermal resistance of building envelopes, and significantly improve indoor environmental comfort. From a lifecycle perspective, although initial investment costs are higher than traditional solutions, energy savings and reduced maintenance costs keep the payback period within a decade. Additionally, the integrated application of rainwater harvesting and photovoltaic systems can respectively meet part of the campus's water and electricity needs, demonstrating the comprehensive benefits of the overall solution. Future efforts should focus on optimizing the production processes and cost control of bio-based composite materials, developing real-time energy consumption and environmental monitoring systems based on the Internet of Things, and establishing standardized guidelines for the selection and application of green building materials tailored to different climatic zones. Through continuous innovation and multi-stakeholder collaboration, this study not only provides theoretical and data-driven support for campus green building practices but also lays a solid foundation for advancing the transformation of the construction industry under the “dual carbon” goals.

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