Proceedings of the 2023 International Conference on Functional Materials and Civil Engineering
DOI: 10.54254/2755-2721/25/20230744

Research on green building design methods in cold regions

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Abstract. In response to the growing severity of the energy crisis, buildings in cold regions are faced with many challenges due to their unique geographical limitations and characteristics. This paper focuses on the design method of Green Buildings in cold climate, aiming to solve the poor thermal insulation performance, high energy consumption and environmental pollution. Firstly, the definition and background of Green Building in cold areas are introduced. The practical application effect of Green Building design in cold regions is discussed from different angles, and the development trend and suggestions of Green Building design in cold regions are put forward. In addition, in order to ensure that these measures achieve the desired effect, there is also a need for a sound evaluation system to monitor and evaluate the sustainability and practical effects of Green Buildings. The paper concludes with a summary of the future trend of Green Building design development in cold areas and suggestions. The research findings in this paper are of great importance in promoting sustainable building development in cold regions.

Keywords: green building design, cold regions, sustainability, building envelope insulation materials, evaluation system.

1. Introduction

Resource scarcity and climate change are becoming increasingly severe on a global scale. According to China Association of Building Energy Efficiency, the total lifecycle energy use of buildings in China was 2.27 billion tce in 2020, representing 45.5% of China's total energy use [1]. The building energy consumption of China has increased at an average annual rate of over 10% in the past 20 years, leading to a gradual increase in carbon emissions resulting from energy use. On the one hand, Chinese buildings have a relatively low level of energy conservation, with building materials having low energy content and poor insulation properties. These all lead to the difficulty of maintaining a comfortable temperature indoor, which requires the strong support of air conditioning and heating equipment. On the other hand, China uses a lot of high-carbon-emission materials in the construction process, i.e., steel and concrete. These materials produce a lot of pollution such as carbon dioxide during their production and application, causing serious environmental impacts [2]. In general, improving the utilization rate of Green Building materials has a certain driving effect on China's transition to a resource-saving society from the perspective of civil engineering [3].

Buildings in cold regions face more severe challenges, as buildings require more energy to stay warm, requiring more energy to maintain warmth. About two-thirds of China's land is located in cold regions, where heating energy use accounts for about 40% of the total building energy consumption. There is

DOI: 10.54254/2755-2721/25/20230744

enormous potential for conserving energy and reducing emissions in these regions [4]. Therefore, it is particularly important to promote and ensure sustainable development in cold regions by improving building energy efficiency and reducing environmental impact through reasonable Green Building design. In this case, how to achieve Green Building design in cold regions has become an important research direction.

This paper aims to discuss the design methods of Green Buildings in cold climates from three perspectives. (1) The definition and background of Green Buildings in cool zones are introduced, and the importance of Green Buildings to people's quality of life and environmental protection is expounded. (2) The practical application of Green Building design to cold climates is discussed from different angles. (3) This paper summarizes and proposes the development trend and suggestions of Green Building design in cold regions in the future. Furthermore, in order to ensure that these measures achieve the desired effect, a comprehensive evaluation system is needed to monitor and evaluate the sustainability and practical effects of Green Buildings. This paper provides a unique application method and design concept for Green Building technology for architects in cold areas. It makes the implementation of Green Building solutions and energy-efficient technologies in China more regional, flexible and scientific. It also pushes Green Buildings toward being more sustainable and environmentally friendly.

2. Green building design methodology

2.1. Definition and background of green buildings

The concept of "Green Building" emerged and became widespread in Italy in the 1960s. Green Building refers to the practice of building environmentally responsible and resource-efficient structures and processes throughout the life cycle of a building, from site selection to design, construction, operation, maintenance, renovation and demolition [5]. Green Buildings typically employ technologies such as renewable energy, Internet-based system controls, natural materials, and water-saving techniques. These measures are aimed at reducing negative environmental impacts, achieving sustainable development, and creating more employment and profit opportunities for the construction industry.

With the increasing awareness of environmental protection, proactive measures are needed to deal with the energy crisis and reduce environmental pollution. The construction industry needs to strengthen energy conservation and reduction and adoption of renewable energy technologies to minimize energy use and carbon emissions. At the same time, the concept of Green Building should be actively promoted in building design, material selection, and construction processes. Traditional building methods have a significantly negatively impact on the environment, such as using large quantities of energy and water, resulting in large quantities of waste and carbon dioxide emissions. Green Buildings have emerged to mitigate these negative impacts and to provide a healthier and more sustainable living environment for people.

2.2. Analysis of green building design methods

Since 1990, various countries have developed their own Green Building assessment systems that are tailored to their national conditions. BREEAM, developed in the United Kingdom, was the first global standard for the assessment of Green Buildings worldwide. Subsequently, many Green Buildings assessment systems have emerged, such as LEED in the United States, CASBEE in Japan, and DGNB in Germany [6]. These assessment systems have devised carbon calculation methods that enable carbon performance indicators and carbon calculations to be evaluated over the building's life cycle and then presented to the building designer in the form of a score.

Compared with the mature system of Green Building in advanced Western countries, the introduction of Green Building in China was relatively late and did not attract widespread attention until the 1980s. Based on the reference of foreign evaluation systems, China has gradually improved a Green Building evaluation system that is suitable for the national conditions [7]. The current Green Building assessment systems adopted in China are the LEED China version and GB/T 50378-2019 "Green Building Evaluation Standard". In China, single buildings or building clusters are usually evaluated as the object

DOI: 10.54254/2755-2721/25/20230744

of assessment, requiring a full life cycle technical and economic analysis of the participating buildings. This requires the selection of appropriate technologies, equipment, and materials, and a full process control evaluation of the planning, design, construction, and operation stages. Green Building evaluation is divided into two stages, with a pre-evaluation possible after the completion of the construction drawings, and a formal Green Building star rating evaluation possible only after the project is completed [8].

As shown in Table 1, this paper comparisons between the Chinese LEED Green Building rating system and the American LEED-OM Green Building rating system. In terms of specific assessment metrics, the Chinese LEED Green Building evaluation system and the US LEED-OM Green Building evaluation system have the following differences.

(1) Water resources: The Chinese LEED Green Building rating system only allocates15 points for water resources, while the American LEED-OM Green Building rating system gives 22 points. This is because the United States places greater emphasis on water resource management, and therefore assigns a higher point value in the evaluation system.

(2) Indoor environmental quality: The Chinese LEED Green Building rating system awards 21 points for indoor environmental quality, while the American LEED-OM Green Building rating system only awards 15 points. This is because China has stricter indoor environmental quality standards, and thus assigns a higher point value in the assessment system.

(3) Land and ecology: The Chinese LEED Green Building rating system awards 15 points for land and ecology, while the American LEED-OM Green Building rating system only awards 14 points. This is because China has stricter standards for land and ecology, and therefore assigns a higher point value in the evaluation system.

Table 1. Comparisons between the Chinese LEED green building rating system and the American LEED-OM green building rating system.

Evaluation Indicators	Chinese LEED Green Building Rating System (points)	American LEED-OM Green Building Rating System (points)
Energy and Atmosphere	35	35
Water resources	15	22
Materials and Resources	14	14
Indoor environmental quality	21	15
Land and ecology	15	14

3. Green building design in cold regions

3.1. The necessity of green building design in cold regions

In China, the cold zone covers a vast area with a total area of about 1.5 million square kilometers, mainly in the northeast (including Heilongjiang, Jilin and Liaoning provinces), as well as Inner Mongolia, Xinjiang and Tibet. The impact of climate on building energy consumption and performance cannot be ignored. As shown in Table 2, the environmental characteristics of cold and warm regions have different impacts on building design. The harsh climate in cold regions makes it a relatively fragile natural environment. The winters are long and cold, requiring a large amount of energy for heating, while also protecting the local ecological environment. Most of the total energy consumption is consumed by heating and cooling systems, and therefore, the design should take into consideration both winter and summer conditions [9]. The high energy consumption poses significant challenges to building design.

As shown in Table 3, when designing buildings in cold regions, there are many challenges due to the climate. However, Green Building design methods can provide solutions. Green Buildings can use clean energy, reduce energy consumption, and alleviate ecological environmental pressure. The comfort level inside a residence is an important factor affecting living quality. Optimization of construction materials, design, heating, and other aspects of a building can directly or indirectly affect indoor temperature, humidity, and other factors, thereby improving indoor comfort. Green Building is one of the main

DOI: 10.54254/2755-2721/25/20230744

development directions of future architecture. In the long term, the promotion of Green Buildings in colder regions can foster the development of a green economy and foster the process of sustainable resource use and conservation.

Table 2. Comparison of the impact of climate characteristics in warm and cold regions on the difficulty of building construction.

Features	Warm Regions	Cold Regions
Temperature	High temperature and rainy, Hot and humid in summer, Warm and dry in winter	Extremely cold in winter, Short summer, Large temperature difference
Humidity	High humidity, Easy to cause mold and rot	Low humidity, Easy to cause dryness and static electricity
Wind	Strong wind, Easy to cause building damage	Strong wind, Easy to cause building damage
Rainfall	Heavy rainfall, Easy to cause water logging and leakage	Rain and snow, Easy to cause icing and slipping
Sunlight	Adequate sunlight, Easy to cause overheating of buildings	Inadequate sunlight, Easy to cause indoor darkness
Soil	Soil is moist, Easy to cause foundation settlement	Soil freezes, Easy to cause foundation deformation

Table 3. Issues in cold regions and solutions provided by green building design.

Aspect	Problem	Solution Provided by Green Building Design
Energy Efficiency	Require more energy to maintain warmth	Using efficient insulation materials, Adopting renewable energy sources
Indoor Air Quality	Require sealing to prevent cold air, Causing air quality deterioration	Using low VOCs building materials, Increasing ventilation, Installing air filters
Water Resource Management	Affected by freezing and drought	Low-flow faucets, Rainwater harvesting
Building Durability	Affected by ice and snow, Damage the aging of the buildings	Using more durable building materials, Using waterproofing and anti-freezing measures

In summary, the promotion of Green Buildings in cold regions has multiple benefits, including maintaining the environment, conserving energy, enhancing residential comfort, and contributing to the development of a green economy. Therefore, the necessity of Green Buildings in cold areas cannot be ignored.

3.2. Development status of green buildings in cold regions of China

The popularization of the concepts of environmental protection and sustainable development has led to the widespread promotion and application of Green Buildings in China. In cold regions, the evolution of Green Buildings faces certain challenges and opportunities. Currently, a range of policies and standards have been implemented in China to promote the development of Green Buildings in colder regions. For instance, national standards such as "Building Energy Efficiency Design Standard" and "Building Energy Efficiency Design Standard" are essential in the field of civil engineering. These regulations provide specific requirements for designing and constructing Green Buildings in cold regions from the perspective of civil engineering.

DOI: 10.54254/2755-2721/25/20230744

China vigorously promotes passive Green Building technology that does not require active energy to regulate indoor temperature. Passive Green Building technology is achieved through the selection of appropriate building materials, electrical equipment, natural ventilation, and solar energy utilization to achieve environmental control. Passive Green Buildings are particularly suitable for cold regions because they can maintain warmth indoors while reducing energy consumption and carbon emissions. Moreover, China is increasing the use of new building materials during construction. The higher insulation performance of these materials can significantly reduce energy consumption for winter heating, while also reducing environmental pollution and conserving resources. In addition, intelligent technologies such as using BIM software to manage Green Buildings have also been widely applied. It is possible to achieve information and model management of the whole process of construction work [10].

In practical applications, Green Buildings still face some challenges in cold regions. For example, due to the need for more insulation materials and equipment for energy-saving in cold climates, the cost of building construction is increased. Simultaneously, winter lighting and indoor temperature control are also difficult points for Green Buildings in cold regions. Therefore, there is a constant need to introduce more efficient, economical and practical Green Building designs and technologies.

4. Optimization scheme for green buildings in cold regions

4.1. Optimizing building structures

The energy efficiency of building structures is a crucial aspect in creating Green Buildings. Building structures refer to the load-bearing structures of buildings, typically consisting of columns, beams, slabs, walls, etc. The energy consumption of buildings due to thermal losses from the building envelope can represent over 50% of the total energy consumption during building operation. During the design process, measures such as optimizing structural design, selecting materials, adopting new technologies, designing reasonable ventilation systems and reducing energy waste can be used. This can effectively enhance the energy efficiency of the building structure and the heat collection efficiency of the building, thus realizing the original intention of Green Building design [11].

Figure 1 presents a case study of reducing energy consumption through optimized structural design. The architect determined the composition of the facade louvers and cantilevered balconies through local annual sunshine analysis. After digital optimization, the external building structure can form a special angle with the sunlight. This can reduce direct sunlight exposure in summer while optimizing solar heat gain in cold seasons, achieving the goal of energy consumption reduction.

(a) Architectural elevation (b) Architectural detail drawing

Figure 1. Example of green building through optimizing building structure (Taking Zaha Hadid's business stadium central as an example) [12].

In cold climates, the Heating, Ventilating, and Air Conditioning of buildings is an essential piece of equipment, and equipment selection and operation management directly influence the buildings' energy performance. The use of new energy-saving equipment such as ground source heat exchangers and solar

DOI: 10.54254/2755-2721/25/20230744

panels can effectively enhance the energy efficiency of the system, reduce cost expenditures, and reduce environmental pollution.

4.2. Reasonable selection of building insulation materials

In the mid-20th century, a variety of new materials with light weight, loose structure, and numerous small pores inside emerged. Due to their excellent thermal insulation properties, they can reduce the temperature differential between the interior and exterior of buildings, improving insulation performance. These features slow down changes in indoor temperature, guarantee stability and comfort and reduce the load on indoor air conditioning equipment, thus reducing energy consumption [13]. The exterior walls and roofs of buildings are critical parts for heat transfer and waterproofing. In the design, thermal insulation and insulation materials such as rock wool, glass fiber, and polyurethane should be used to reduce the energy waste of the building and improve thermal comfort. In addition, building insulation materials also have multiple functions such as fire resistance, corrosion resistance, and weather resistance, which can improve the safety and durability of buildings. In recent years, building insulation materials can also be used for decoration on the exterior surface, making buildings more beautiful and increasing their value [14].

In summary, the impact of building structural insulation materials on buildings is multifaceted. They can enhance the energy efficiency, the comfort and the structural performance of buildings, reduce environmental pollution and resource waste, and contribute to the sustainability of buildings and the protection of the environment.

4.3. Rational utilization of natural resources

Green Building design can effectively utilize natural resources, especially in cold regions. The utilization of natural resources can reduce energy consumption, such as using ground source heat pumps and utilizing shallow geothermal energy as building heating and cooling sources to reduce energy consumption [15]. The utilization of natural resources can also lower the cost of building design and operation and improve indoor environmental quality. By scientifically designing natural lighting and lighting systems, energy-saving effects can be achieved by fully utilizing natural resources and reducing energy consumption. Figure 2 provides a visualization of an excellent example of a building that utilizes solar energy and geothermal groundwater for radiant heating and cooling, achieving reduced operational costs. The design should fully consider humanistic space requirements, such as comfort and sustainability, and comprehensively consider the design scheme. Furthermore, by using renewable energy sources such as solar and wind power, building risk management can be improved, and maintenance and repair costs can be reduced.

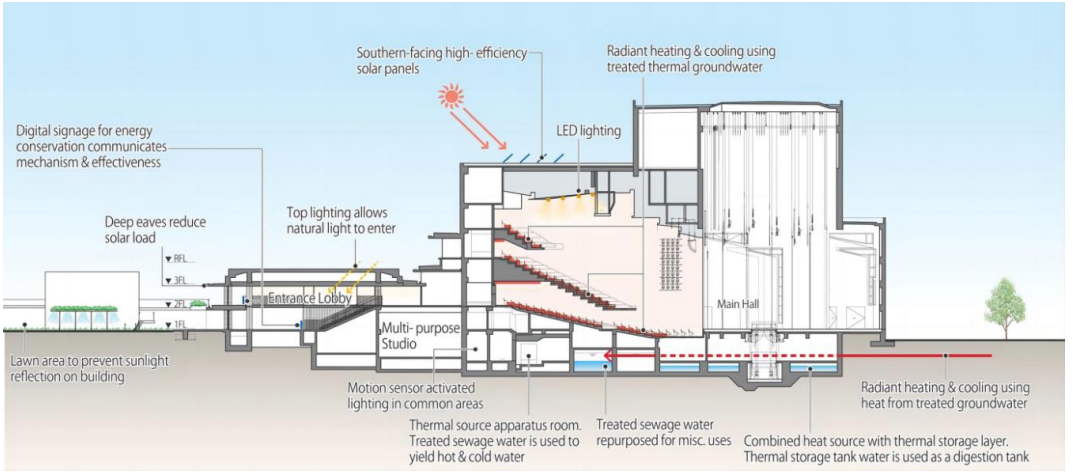

Figure 2. Schematic diagram of building design utilizing natural resources (taking the Hirakata Performing & Visual Arts Center as an example) [16].

DOI: 10.54254/2755-2721/25/20230744

4.4. Rational utilization of green building evaluation system

The Green Building Rating System is important because it helps engineers and designers to design and construct buildings with a greater focus on environmentally friendly, sustainable and energy-efficient principles. The Green Building Evaluation System is a comprehensive evaluation system that assesses and compares building design options to ensure that the building is environmentally friendly, sustainable and energy efficient. When carrying out scheme design, the various parameters can be brought into the Green Building evaluation system for different design schemes. Points are awarded based on checkpoints, safety and sustainability, health and comfort, amenity, resource efficiency, environmental friendliness and enhancement and innovation. Calculated scores are used to compare the focus and overall situation of the building design options. The most suitable building design is then selected in relation to the actual situation, thus reducing the impact on the environment and resources and increasing the sustainability and longevity of the building.

5. Conclusion

In the background of global climate change and the recognition of environmental protection, Green Building design has become a hot topic in the construction industry. However, due to the unique climatic conditions of cold regions, the design methods of Green Buildings need to be continuously innovated and improved according to the local climate, culture and resource availability. This paper provides an overview of Green Building design methods in cold areas, with emphasis on sustainability, building envelope insulation materials, and evaluation systems. The main conclusions are as follows:

(1) Sustainability is one of the most important considerations in Green Building design. With the aim of achieving sustainable development in cold regions, a number of measures can be taken, such as utilizing local renewable energy sources, optimizing building orientation and layout, and regulating indoor temperature through green plants.

(2) In terms of building insulation materials, green materials are considered one of the best choices because they can provide more sustainable solutions and are more friendly to human health and the environment. green materials are considered to be one of the best options because they can provide more sustainable solutions that are more friendly to human health and the environment.

(3) The evaluation system is another key factor in Green Building design methods. In cold areas, the evaluation method of buildings should comprehensively consider the local climate conditions, including temperature, humidity, snowfall, wind speed, etc. For example, factors such as indoor temperature stability and cold bridge elimination rate should be used to evaluate a building's thermal insulation performance and overall energy efficiency. In addition, the evaluation system should also consider technical, economic, environmental and other factors to maximize the comprehensive benefits.

In conclusion, in order to achieve the sustainability of Green Building design in cold regions, innovative and improved design methods are required. Incorporating factors such as sustainability, building structural insulation and evaluation systems into the design process will both enhance the energy efficiency and sustainability of buildings and provide a more comfortable and healthy indoor environment for users.

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