Research on Integrated Art Design of Building Exterior Finishing with Photovoltaic Application Technology

Maoqing Cao*, Riqiang Li, Zijun Wang

Hei Long Jiang Institute Of Construction Technology Architectural Department, Harbin 150025, China

Abstract. This study is based on the cold regions of China, namely severe and cold regions. By fully utilizing photovoltaic technology, local green energy can be reasonably utilized, and feasible reference can be provided for architectural design in cold regions of China. Based on the "dual carbon" goal, the application of photovoltaic technology in building skins is discussed. Through the research of this project, it is possible to clarify ways to reduce carbon emissions and promote local green and sustainable development. Examples were provided to illustrate the main manifestations of photovoltaic building integration. Through the specific application and analysis of photovoltaic housing projects, photovoltaic curtain walls, photovoltaic components, and photovoltaic materials in the skin system, it is explained that photovoltaic materials can play an important role in participating in the shaping of building form and space. The key to the integration of photovoltaic building technology is to find the best balance between energy, comfort, indoor lighting environment, economy, and design aesthetics.

1. Introduction

Solar energy, as a clean and pollution-free renewable energy, is increasingly attracting people's attention in today's increasingly depleted conventional energy and increasing environmental awareness. At the same time, building air temperature regulation consumes a large amount of energy. In China, it accounts for approximately 70% of the total energy consumption of buildings[1]. How to reduce the dependence of buildings on external energy and generate clean and efficient energy on their own has become an important basis for research on solar architecture. The utilization of solar energy in the construction field mainly adopts two methods: photothermal conversion and photoelectric conversion. Through the development of the times, photovoltaic conversion has gradually developed into an integrated form of photovoltaic building in the 1990s. As a technological strategy for sustainable building, it is bound to lead the innovation and development of green buildings and even the entire construction industry, becoming a new trend in solar energy applications. Photovoltaic power generation technology can be applied in the field of construction in daily life, by converting solar energy into other energy needed inside the building and providing it to refrigeration, ventilation, and hot water systems. There are two main forms of this application: one is to match the photovoltaic array with the building, such as placing photovoltaic panels on the roof of the building or installing photovoltaic panels on the wall; Another approach is to integrate photovoltaic arrays into a part of the building, such as directly using special photovoltaic devices to serve as building roofs, curtain walls, sunshades, etc. Building photovoltaic integrated facade refers to the integration of photovoltaic cells into the building facade system, replacing the original building components and making them a component of the building energy system[2]. At present, the combination forms of photovoltaic and building in foreign photovoltaic applications are mainly divided into three categories: first, the combination of building and photovoltaic system, or photovoltaic attachment design; second, the combination of building and photovoltaic module, or integrated design of photovoltaic and building; third, the use of photovoltaic components as building materials, in accordance with relevant technical standards for building components. The application of photovoltaic technology in cold regions is influenced by various factors. DDNguyen established an output characteristic model of photovoltaic cells and found that the output of photovoltaic systems in cold regions is affected by solar radiation, environmental temperature, and other factors. At the same time, the inclination and orientation of photovoltaic installation, as well as the obstruction between photovoltaic modules, can also have an impact on photovoltaic power generation[3]. In China, the integration of photovoltaics and buildings is an important, rapid, and fundamental way for China's sustainable and low-carbon energy development. As mentioned in the review, although the application of

Maoqing Cao*: cwr000129@163.com

Ministry of Education of the Cold Region Urban and Rural Construction Sustainable Development Collaborative Innovation Center

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).
photovoltaic curtain walls in buildings has gradually begun and is in a rapid development stage, there is still a lack of cross research with architectural design. Most research is still focused solely on discussing photovoltaic materials and components, and there is relatively little research on the integration of photovoltaic buildings. There are significant climate differences in China's vast territory, and there are few design schemes for extreme climate adaptability in cold regions, making it difficult to achieve the optimal comprehensive energy consumption of buildings. Therefore, how to incorporate solar energy technology into building design, use spatial means to solve the technical problems of photovoltaic technology, and obtain sufficient clean energy in cold areas with incomplete energy infrastructure, promoting local economic development and environmental improvement, will become the focus of attention and exploration in this project. The aim of this study is to explore the potential value and innovative application of photovoltaic application technology in the field of integrated art design of building exterior finishes. We will delve into how to combine solar photovoltaic technology with building exterior design to achieve an organic integration of aesthetics, functionality, and sustainability. In addition, we will also focus on the latest research and practice in this field, exploring innovative design methods and material applications to achieve energy production and aesthetic requirements for building exterior finishes[4].

2. Methods

2.1. Research content

This project is based on the dual carbon target requirements, starting from two aspects: photovoltaic application technology and building skin, and utilizing the guiding ideology of green innovation, with cold regions as the design application area, to study the design innovation and specific practical application of photovoltaic building integration. Using parameterized models and digital technical indicators, explore the inherent construction logic of integrating photovoltaic application technology with building skins: analyze the comprehensive energy consumption of different types of building skins in the integrated design of photovoltaic buildings in cold regions; Introduce the integrated design and construction strategy of low energy overall design oriented photovoltaic buildings in cold regions; focus on researching the cold adaptation design of photovoltaic systems that match the low energy overall design oriented photovoltaic integrated construction strategy in cold regions: sort out relevant data for comprehensive benefit analysis of economic, energy, environmental, and ecological benefits, Prove that the integrated design strategy of photovoltaic buildings guided by low energy consumption overall design in cold regions has feasibility and promotion application value.

2.2. Research Objectives

This project attempts to explore the comprehensive energy consumption and applicability of photovoltaic technology in the integrated design of building skins based on the dual carbon goal, and proposes corresponding optimization design strategies, namely the low energy overall design oriented integrated design strategy for photovoltaic buildings in cold regions, to promote the application and practice of the "dual carbon" goal in the construction field.

2.3. Key scientific issues

Constructing an integrated design strategy for the application of photovoltaic resources in cold regions to the field of building skins, adhering to the principle of combining low energy consumption with overall design, while improving the efficiency of building energy utilization, reducing energy consumption, and maintaining aesthetic characteristics. Propose a photovoltaic system layout method and contribution rate calculation method that matches the integrated design strategy, and propose a photovoltaic system optimization method and matching method based on the characteristics of building energy consumption and photovoltaic production capacity. The organic integration of photovoltaic technology with double skin, curtain wall system skin, window wall system skin and other cold area building skins verifies the design effect.

The research technical route is shown in Figure 1.

Fig. 1. Framework of research technology

2.4. Key Technologies

Guided by the ideas of energy construction, energy consumption theory, and green development theory, the key technology of this project is to effectively integrate photovoltaic technology with the design of building skins such as double-layer skins, curtain wall system skins, and window wall system skins, forming a real, effective, and highly feasible scientific research achievement. The design of an integrated design strategy for photovoltaic application technology and building skins in cold regions is the key technology. When dividing cold regions, reference was made to the new climate zoning model proposed by Sun Dezi, a researcher at the Chinese Academy of Building Sciences. This model comprehensively considers climate factors and lighting...
factors, and divides China into severe cold, dry and hot high radiation areas, severe cold and medium radiation areas, cold radiation areas, cold summer and hot medium radiation areas, mild high radiation areas, humid and hot winter cold areas, and hot and high humidity areas. When studying the potential and contribution rate of photovoltaic systems, the mathematical model for calculating the contribution rate of photovoltaic systems to buildings is shown in formula (1)

$$\eta = \frac{E_t S}{Q_{load} A}$$  \hspace{1cm} (1)

In the equation: $\eta$ is the photovoltaic contribution rate, $E_t$ is the photovoltaic system's power generation, kW • h; $Q_{load}$ is the building energy consumption, kW • h/m²; $A$ is the building area, m²; $S$ is the total area of the photovoltaic module, m². The mathematical model for calculating photovoltaic potential is shown in formula (2):

$$\eta_p = \eta_c (1 - \varepsilon (T_c - T_a))$$  \hspace{1cm} (2)

In the equation: $\eta_p$ is the operational efficiency of photovoltaic assembly; $\eta_c$ represents the efficiency of the photovoltaic assembly under standard operating conditions; $\varepsilon$ is the temperature correction coefficient: $T_c$ represents the operating temperature; $T_a$ is the monthly average ambient temperature.

This project integrates other indicators such as energy efficiency indicators in the "Green Building Evaluation Standards" (GB/T 50378-2019), "Health Building Evaluation Standards" (T/ASC02-2016), and "Near Zero Energy Consumption Building Technical Standards" (GB/T 5130-2019), and constructs a comprehensive benefit evaluation index system for photovoltaic building integration under the dual carbon target from four dimensions of economic benefits, energy benefits, environmental benefits, and ecological benefits. It is further refined into 16 indicators layer by layer. This indicator system plays a technical supporting role. As shown in Tables 1 and 2, the integrated benefit evaluation index system for photovoltaic application technology and integrated design of building skins in cold regions [6].

<table>
<thead>
<tr>
<th>Economic benefit index B1</th>
<th>Energy efficiency index B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct economic benefit C11</td>
<td>Comprehensive value of building energy consumption B21</td>
</tr>
<tr>
<td>Net present value C12</td>
<td>Building comprehensive energy-saving efficiency B22</td>
</tr>
<tr>
<td>Internal rate of return C13</td>
<td>Utilization ratio of renewable energy B23</td>
</tr>
<tr>
<td>Dynamic payback period C14</td>
<td>-</td>
</tr>
<tr>
<td>Benefit-cost ratio C15</td>
<td>-</td>
</tr>
</tbody>
</table>

### Table 2. Integrated benefit evaluation index system of photovoltaic application technology and building skin integrated design in cold region 2

#### Environmental benefit index B3
- Thermal comfort B31
- Visual comfort B32
- Relative humidity B33
- Air velocity B34

#### Ecological benefit index B4
- Carbon oxide emission reduction B41
- Sulfur dioxide emission reduction B42
- Hydroxide emission reduction B43
- Smoke emission reduction B44

### 3. Expressions of photovoltaic building integration

The deep integration of photovoltaic and building materials can be divided into building materials photovoltaic systems and component photovoltaic systems, and component photovoltaic systems can be extended to demonstrate the utilization of photovoltaic systems in building skins [6].

#### 3.1. Building Material Photovoltaic System

Building materials photovoltaic system is a system that uses solar cells and building materials to form an inseparable building material or component for power supply. Such as photovoltaic bricks, photovoltaic tiles, photovoltaic coils, etc. Taking photovoltaic tiles as an example, photovoltaic tiles embed photovoltaic modules into the supporting structure, integrating solar panels and building materials, and are directly applied to the roof, just like ordinary roof tiles, installed on the roof structure. Photovoltaic tiles not only play the role of traditional tiles, but also have innovative functional integration. They have a long service life, high strength, light weight, energy-saving and environmentally friendly production process, while also meeting the aesthetic characteristics of architecture. Replacing some building materials with photovoltaic building components can not only meet the performance requirements of building materials, but also be used for energy generation and utilization, thus forming a composite function. At the same time, this design reduces the use of building materials and saves resources, making it a good way to promote low-carbon buildings [6].

#### 3.2. Component based photovoltaic systems

A component based photovoltaic system is a form of combining photovoltaic components with building components or forming building components independently. It mainly manifests as photovoltaic house items, photovoltaic curtain walls, and small photovoltaic components such as sunshades, awnings, and fence boards.

(1) Photovoltaic housing project

The roof has great advantages as a lighting source for solar energy, with a large solar radiation area, no obstruction, and minimal interference from external...
forces. Its form includes a combination of photovoltaic building projects, skylights, and atriums. Photovoltaic Roof - Integrated design of photovoltaic and roof, where photovoltaic materials can replace the insulation layer of the roof to shield the roof, reducing roof costs and forming a composite function of the roof. At the same time, the use of photovoltaic materials in building roofs is no longer limited to flat or sloping roofs, but can be in the form of arcs or circles to absorb more solar energy. The photovoltaic module design of the Kaohsiung Stadium adopts a short curve approach, which integrates photovoltaic panels into the curved architectural form. Not only does it add momentum to the form through repeated rhythms, but the unique texture of photovoltaic panels also makes the building refreshing. As the fifth facade of a building, the roof often becomes the focus of design. From the above examples, we can see that the combination of photovoltaic panels and the roof can serve as a linear structure to form the entire roof, and the roof also has a unique material texture. The segmented roof form can enable rigid solar cells to fit well into the ever-changing shapes, achieving a unity of form and material characteristics [8].

(2) Photovoltaic curtain wall
The combination of photovoltaic and architectural elements on building facades is more manifested as photovoltaic curtain walls, which have many similar industrial characteristics with photovoltaic materials, making it easier to implement and deepen design. The design principle of photovoltaic curtain walls should be to replace unit or integral photovoltaic modules on the premise of first meeting the external enclosure function of the curtain wall. The integrated photovoltaic curtain wall can not only meet the enclosure function of the curtain wall, but also play the role of the photovoltaic system. The use of photovoltaic panels in different ways on building facades can showcase a variety of temperaments and styles for the building. The key in design is still to grasp the characteristics of photovoltaic panel materials, as well as to have a deep understanding and application of the characteristics of battery modules displayed by different scales and cell gaps [8-10].

4. Conclusion
Against the backdrop of vigorously promoting green energy in the country, photovoltaic buildings and their materials have been vigorously developed. At the same time, with the continuous promotion and development of photovoltaic building integration, the combination of photovoltaic and building will also become rich and colorful. From the analysis of the above forms and cases, it can be concluded that the deep integration of photovoltaic technology with architecture should not only focus on the technical level of photovoltaic materials, but also involve more in shaping architectural forms and spaces. Photovoltaic materials and components have also opened up new design ideas and technical methods for the construction field. But the key to the problem lies in how to find the best balance between the integration of photovoltaic technology and architecture in terms of energy, comfort, indoor lighting environment, economy, and design aesthetics, so that architecture and photovoltaic technology complement each other and integrate into one. This is the true knowledge that our generation of architectural practitioners constantly explore.

Acknowledgments

<Research on Integrated Design of Photovoltaic Application Technology and Building Skin in Cold Region with Double Carbon Target> HICT 2023-05.

References