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Application and Analysis of Renewable Energy in Building Energy Efficiency

Qian Cheng[1,a,*]

[1]*College of Mechanical and Engineering, Qingdao University of Technology, Qingdao, Shandong, 266000, China*
a. 1258409249@qq.com
**corresponding author*

Abstract: With the severe challenge of global climate change and the increasing energy crisis, the construction industry, as one of the main sources of global energy consumption and greenhouse gas emissions, has become particularly critical. Therefore, exploring how to achieve building energy savings through renewable energy has become an urgent and far-reaching research topic. This study aims to discuss the current state, challenges, and potential applications of renewable energy in the building field, by reviewing existing literature and case studies. Additionally, it explores strategies to promote the application of renewable energy in building energy conservation through technological innovation and policy support. After analyzing the existing literature and cases, it is found that the application of renewable energy technologies such as solar, wind, and geothermal energy in buildings can significantly save energy, reduce dependence on fossil fuels, and reduce carbon emissions. Optimizing buildings, including passive design and active system integration, is critical to improving energy efficiency without compromising residential comfort. The intelligent energy management system further improves energy efficiency through real-time monitoring and automatic regulation. Policy and economic incentives have played a key role in promoting the use of renewable energy technologies in buildings.

Keywords: Renewable Energy, Building Efficiency, Solar, Wind, Geothermal

1. Introduction

In the current academic field, building energy efficiency and renewable energy utilization have become hot issues of global concern. How to achieve building energy conservation through renewable energy, reduce fossil energy consumption, and reduce building carbon emissions has become an important research direction in the construction industry due to the intensifying global energy crisis and the improvement in environmental protection awareness. For instance, Scholar A conducted a study on the energy consumption of university dining halls using DeST software simulation, and subsequently analyzed the characteristics of this energy consumption. It is concluded that energy efficiency can be significantly improved through simulated energy consumption analysis and HRES design [1]. Scholar B, aiming at the deficiencies in energy conservation and ecology of rural buildings in Hainan Island and the urgent demand for the utilization of renewable energy. The results show that these schemes can effectively improve the wind and thermal environment of buildings, and improve the quality of rural ecological environment [2].

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This study is linked to previous research in that it focuses on improving building energy efficiency through renewable energy technologies. Specifically, Scholar A's study used DeST software to simulate the energy consumption of university cafeterias, while this study explored the application potential of renewable energy technologies in buildings through literature and case studies. Compared with scholar A's research, the scope of this study is broader, not only focusing on college canteens, but also covering the comprehensive application of solar energy, wind energy, geothermal energy and other renewable energy technologies in buildings. Scholar B's research focuses on the low energy consumption ecological building system scheme of rural buildings in Hainan Island, and proposes a specific design scheme by PHOENICS software simulation. However, this study does not propose a specific design scheme, but focuses on the discussion at the strategic level. In addition, some progress has been made in building energy efficiency and renewable energy utilization, but there are still some research gaps. For example, how to better integrate renewable energy technologies with buildings to improve the economy and reliability of the system. These blank spots provide a potential supplementary direction for the study of this paper. This paper examines what renewable energy technologies can be used to reduce energy consumption, the technological innovations that have been achieved and the dilemmas faced. The report acknowledges the significant social, economic, and environmental benefits of constructing energy efficiency through renewable energy sources as well as the quick growth of renewable energy technologies. Among the social relevance are: 1. By creating a more cozy and healthful indoor atmosphere, energy-efficient buildings aid in raising people's sense of gain and pleasure and improving their quality of life [2]. The application of renewable energy technology reduces the dependence on traditional energy, improves energy security, and helps to ensure social stability.

2. Current situation, problems and prospects of renewable energy in China

Faced with the challenges of energy shortage and environmental deterioration, China's economic and social development is undergoing transformation. At present, fossil energy occupies a dominant position in China's energy structure, resulting in continuous growth of energy consumption. In 2019, China's raw coal production reached 3.85 billion tons, accounting for nearly half (47.3%) of the global total, while coal consumption also accounted for 51.7% of the world, an increase of 1.4% [3]. The current pattern of energy consumption is not only unsustainable, but also exacerbates the challenges China faces in its energy transition. As a result, our nation is now the biggest carbon dioxide emitter in the world, endangering both public health and long-term economic growth.

Energy, resources and the environment are key factors driving national development, and their balanced coexistence has become a top priority in the national strategy. To solve the problems of unsustainability and environmental damage in the current energy system, global efforts are being made to promote the use of renewable energy. Renewable energy sources are highly regarded for their environmental, low-carbon, clean and low operating costs, although the instability of their supply can have an impact on energy continuity. At the same time, while fossil fuels have a stable supply and are easy to store and transport, their environmental pollution and carbon emissions cannot be ignored, and global reserves are dwindling. In order to fundamentally solve these problems, China needs to gradually transition to an energy supply system dominated by renewable energy to promote sustainable development [4].

3. Concept and classification of renewable energy

The term "renewable energy" was first defined in 1981 at the World New Energy and Renewable Energy Conference, which was held in Kenya. It was specifically defined as follows: using new materials and technologies, traditional renewable energy is developed and used in a modern way, and

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it is an endless source of energy that replaces fossil fuels that deplete resources and harm the environment [5]. The People's Republic of China's Renewable Energy Law makes it very clear that non-fossil energy sources like wind, solar, hydro, biomass, geothermal, and ocean energy are all considered renewable [6]. The following five factors are primarily involved in the classification and utilization of renewable energy: One sustainable energy source created by the movement of solar radiation is wind energy. When weighed against other energy sources, wind energy is clearly superior. Its reserves are enormous—ten times larger than those of water energy—it is widely dispersed, never runs out, and it is especially valuable for islands and other distant locations that are disconnected from the main grid and have difficult access to transportation [7].

Sunlight radiation energy is commonly referred to as solar energy. The three main ways to use solar energy are as follows: solar water heaters use the heat from the sun to heat water and then use that hot water to generate electricity [7]; solar cells use photoelectric conversion to turn the energy in sunlight into electricity; and water energy refers to resources like kinetic energy, potential energy, and pressure energy of water bodies. River hydropower, tidal hydropower, wave energy, ocean current energy, and other energy resources are examples of generalized hydropower resources. The primary application scenario for hydropower is hydropower technology, and it is crucial to advance this field in order to support the growth of the national economy, enhance the structure of energy consumption, and lessen the environmental pollution brought on by the use of coal and oil resources [8]. Directly or indirectly obtained from plant photosynthesis, biomass energy is a type of solar energy stored in living things as chemical energy that can be transformed into regular solid, liquid, or gaseous fuels. By gas collection, gasification, combustion, and digestion, organic matter is used as fuel in biomass energy production. The production of geothermal electricity and the direct use of geothermal water for building heating are the two main uses for geothermal energy [9].

4. Application of renewable energy technology in buildings

The usage of renewable energy, primarily solar, shallow earth, biomass, and wind power, is growing in the construction industry.

4.1. Solar energy

There are various forms of solar energy conversion, including photothermal, photochemical and photoelectric conversion, and the application of solar energy in buildings is divided into active and passive two kinds. Active solar systems, such as solar collectors and photovoltaics, can convert solar energy into the energy needed by buildings for heating, cooling and power generation. Passive solar uses natural light to meet the building's cooling or heating needs through building design and material selection. There are two classic ones. One is to collect the heat generated by solar energy using solar collectors, and then connect with the traditional power generation device to achieve power generation; According to the different heat collection equipment, can be roughly divided into trough and tower system; The other is photovoltaic power generation, whose principle is the use of solar energy to absorb its specific wavelength of light, through the photoelectric effect into electricity generation. Solar thermal power generation has reached a mature stage in technology, and as it continues to improve, its applications are expanding. Among them, the area of the solar collector needs to be determined according to the heat load required by the user. In order to calculate easily, the process of calculating the collector area is simplified. After determining the cold and heat load required by the user, the heat required for anaerobic fermenter fermentation and insulation and feeding, it is calculated according to 80% of the time required to meet the user's cold load demand during the summer auxiliary refrigeration. The cooling capacity required for solar-assisted refrigeration can be obtained, and the heat load required for the trough solar unit can be obtained according to the COP

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of the lithium bromide unit, and the heat collection area of the trough solar collector can be obtained according to the formula [10].

4.2. Wind energy

The conversion of wind energy into electricity through the installation of wind turbines on the roof of a building or in an open area is designed to take into account wind speed, noise, visual impact and compatibility with the building structure. The basic idea behind wind power generation is to use the wind to propel an impeller to revolve, converting wind energy into mechanical energy. This mechanical energy is then transformed into electrical energy via a generator. As a kind of clean renewable energy, wind energy is known as "inexhaustible" energy. Generally speaking, the characteristics of wind turbines have been determined during the manufacturing process, and the optimal installation height and power output curve are fixed. The power output curve of a wind turbine is shown in Figure 1 [1]. The cut-in wind speed (Vcut-in), the rated wind speed (Vmtcd), and the cut-out wind speed (Vcut-off) are classified into four circumstances based on the actual wind speed: 1. The actual output power of the fan Pmtcd when the actual wind speed is less than the cut wind speed.

If the overall power loss of the system is not reached, the fan cannot start normally; 2. When the wind speed is between the cut wind speed and the rated wind speed, the fan needs to increase the output, increase exponentially, and quickly reach the rated wind speed; 3. When the wind speed is between the rated wind speed and the cutting wind speed, the output power of the fan exceeds the rated value, and it is necessary to implement protective measures for the fan and appropriately reduce the power of the fan to maintain the rated wind speed; 4. When the wind speed is greater than the cutting wind speed, stop the fan immediately to avoid equipment damage or burnout.

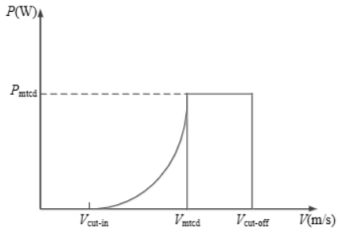


Figure 1: Linear relationship between power output of wind turbine and wind speed[1]

4.3. Geothermal and biomass energy

Geothermal energy and biomass energy are also important renewable energy sources in green buildings. Geothermal energy uses heat from underground hot water or steam to provide heating and cooling services to buildings through geothermal heat pump technology. Biomass energy generates energy through the combustion or biochemical transformation of organic matter and is often used for heating or the production of biomass gas, which helps to reduce the dependence on fossil energy and promote the reuse of agricultural waste and forestry residues [11]. As a kind of low-temperature thermal resource, shallow geothermal energy is mainly stored in shallow rock and ground water. It is used for building heating and cooling through soil-source air conditioning system and other technologies. Buried pipe heat transfer system, surface water heat transfer system and groundwater heat transfer system are the three common utilization methods of shallow geothermal energy, and their selection depends on local water quality, geological conditions and available land area.

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5. Technological innovation:

In terms of technological innovation, efficient solar cells, wind turbine optimization, advanced energy storage technologies, and system integration such as smart grids and multi-energy systems are increasing the efficiency of renewable energy use. Research in materials science, such as low-cost materials and self-cleaning surfaces, helps reduce costs and improve power generation efficiency. Improvements in manufacturing processes, including automated production and 3D printing technology, are also driving cost reductions and efficiency gains.

Policies and market mechanisms, such as subsidies, tax incentives, green certificates and carbon trading, provide incentives for renewable energy projects. Energy management strategies, including demand response management and energy audits, help optimize energy use. Education and training to raise public awareness, professional training to promote the development of the industry. Continued investment in research and development is key to exploring new technologies and improving the performance of existing ones. These measures have jointly promoted the extensive application and sustainable development of renewable energy in the field of construction [12].

6. Limiting factors of renewable energy in building energy conservation

The problems facing renewable energy in building applications fall into two main categories: technology maturity and cost competitiveness.

First of all, in terms of technological maturity, some renewable energy technologies are not yet fully mature. The "system cost" of wind and photovoltaic power generation will rise significantly with the quickly increasing percentage of wind power in the power system, particularly once its share of power generation surpasses 20%. According to the British Energy Research Center's estimate of the British power grid, when the proportion of solar power is 30%, its system cost is about 10 pounds/megawatt hour (about 8.6 points/KWH). If wind power PV accounts for 50% of the electricity generation, then the cost of backup power requirements alone will climb significantly to 45 pounds/megawatt-hour (0.39 yuan/KWH). In other words, with the further increase in the share of volatile renewable energy, its system costs will rise faster. Thus, even though the technical and kilowatt-hour cost factors are adequate to sustain the increasing amount of wind and photovoltaic power generation, it is imperative to take system costs and benefits into account when evaluating wind and photovoltaic power generation for 2030 and 2050[13]. Second, in terms of cost competitiveness, the initial investment costs of renewable energy systems are relatively high, especially when the technology is not yet widely available. Market acceptance of new technologies, economic rate of return and payback period are all important factors affecting the adoption of renewable energy [14].

Apart from the aforementioned issues, the actual implementation encounters the hurdle of geographic location and climate conditions, as these factors impact the efficacy of renewable energy sources. For example, solar power is more efficient in sunny areas, while wind power is more appropriate in areas with higher wind speeds. The lack of effective policy incentives and regulatory support will also limit the application and spread of renewable energy technologies. In addition, for intermittent energy sources such as solar and wind, the lack of efficient and economical storage solutions is a limiting factor. Some renewable energy systems may require regular maintenance and professional operation, increasing long-term operating costs. The lack of public awareness and acceptance of renewable energy may affect its widespread application. In the building design phase, the integration of renewable energy systems needs to be fully considered, which may require interdisciplinary expertise and innovative design. Financing difficulties and investment risks can be obstacles. Finally, the production and transportation of renewable energy equipment can face supply chain and logistical challenges, especially in remote areas.

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In terms of technical services, for the promotion of energy, it is necessary to solve its technical support and technical service problems at the same time. Do a good job in technical services, you can use regular return visits to help residents in time to prevent damage for too long and lead to scrapping. The user's education level is also one of the important factors affecting the promotion of renewable energy technology. For energy construction, it is also very important to improve residents' scientific and cultural literacy and popularize scientific knowledge, which is not only reflected in educational background and cultural education, but also in the promotion of renewable energy. Relevant energy promoters should do a good job in popularizing the knowledge of the promoted energy. So that users can use energy independently. The industrial development of renewable energy not only helps to reduce dependence on fossil fuels and reduce energy costs, but also significantly reduces environmental pollution and promotes sustainable development. Renewable energy industry upstream and downstream enterprises, related projects investment, credit, as well as related product standards and technical specifications, all need relevant laws and regulations to provide support, which requires more mature and standardized laws or systems [15].

7. Conclusion

Buildings that use renewable energy technologies—such as solar, wind, geothermal, etc.—have the potential to save a large amount of energy. By using these technologies, buildings' energy consumption and carbon emissions can be decreased, as well as their reliance on conventional fossil fuels. To increase energy efficiency, building design optimization—passive design techniques and active system integration, in particular—is crucial. Energy consumption can be decreased with reasonable design without compromising comfort. Energy-efficient building practices have been mostly fueled by policy and financial incentives. To achieve widespread acceptance of renewable energy technology, two key components are government backing and the enhancement of market mechanisms. Although this study provides a comprehensive overview of the current application of renewable energy in the field of building energy efficiency, there are some limitations: Research methods may rely too much on qualitative analysis and lack the support of quantitative data. Future studies can adopt more empirical research methods to provide more accurate analysis and conclusions. In view of the above shortcomings, future research can adopt mixed research methods, combining qualitative and quantitative analysis, to improve the accuracy and reliability of the research.

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