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Research on Old Building Renovation Strategies by Using Green Building Technologies

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Abstract: In light of the accelerated pace of economic growth and urbanisation, the transformation of green buildings has emerged as a prominent area of research. A considerable number of existing buildings have been constructed and are still in use. However, the energy consumption and environmental impact throughout the entire life cycle of these buildings are not adequately considered in the renovation design. This results in high energy consumption and poor indoor comfort. In this work, we include improving the thermal insulation of buildings, such as thickening the insulation of external walls and replacing energy-efficient windows to reduce energy losses caused by temperature differences between indoor and outdoor buildings; Adopt energy-efficient HVAC systems to reduce energy consumption and improve indoor air quality by upgrading equipment efficiency, optimizing duct design, and intelligent control systems; At the same time, we will introduce renewable energy sources such as solar energy, and we will not only install solar photovoltaic panels to generate electricity, but also use solar thermal collector systems to provide hot water and heating, so as to achieve diversified and sustainable use of energy. Combined, these measures can effectively reduce the overall energy consumption of the building, reduce carbon emissions, and improve the comfort and health of the indoor environment. During the experimental analysis, the energy consumption and indoor comfort before and after the renovation were evaluated, and the results showed that the energy consumption was significantly reduced and living comfort was improved.

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1. Introduction

In light of the growing scarcity of global energy resources, there is a growing emphasis on energy conservation at the national level. The topic of building energy efficiency has emerged as a significant technical area of focus within the global building sector. It is also recognised as an effective means of addressing the energy crisis and improving environmental quality. In developed countries, the majority of energy consumption is attributed to industrial, transportation, and civil sectors. Among these, residential energy consumption is predominantly influenced by building energy consumption [1]. The data indicate that buildings are responsible for approximately 30 to 40 percent of the total energy consumption in these countries. Such high energy consumption not only represents a significant waste of resources but also has a considerable negative impact on the environment. Consequently, strengthening building energy efficiency is of great significance for social progress and economic development [2].

Over the past three decades, numerous experts and scholars have underscored the significance of building energy efficiency, propounding the theory of sustainable building development and

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advocating heightened awareness of environmental protection and resource utilisation. The dissemination of this theory has led to a heightened awareness of building energy efficiency among governments and society at large, and has contributed to the global advancement of building energy efficiency technology and concepts [3]. The fact that buildings account for a significant proportion of total energy consumption in many countries demonstrates the critical importance of building energy efficiency in global energy management.

In response to the global energy crisis, countries have intensified their research and practice of building energy efficiency, resulting in a notable reduction in building energy consumption. This has been achieved by enhancing the thermal insulation performance of building materials, optimising building design, integrating renewable energy sources, and adopting intelligent control systems [4]. These endeavours not only diminish reliance on conventional energy sources but also facilitate the advancement of a sustainable economy. The pursuit of enhanced building energy efficiency has become an unavoidable phenomenon within the global construction industry. With the collective backing of policy initiatives, technological advancement and societal involvement, the domain of building energy efficiency will continue to witness significant breakthroughs and advancements in the future [5].

A study conducted by Tsinghua University examined the electricity consumption of public buildings and determined that these structures account for 20 to 25 percent of the country's total annual electricity consumption. Despite the relatively minor contribution of the existing floor area to the total building area in the country, its electricity consumption is nevertheless significant, reaching 22%. This illustrates that, in the context of high population density and accelerated urbanisation, there are significant challenges in the management of energy efficiency in old buildings [6]. This work addresses these challenges by proposing strategies such as improving thermal insulation, upgrading heating, ventilation and air conditioning (HVAC) systems, and integrating renewable energy sources such as solar. These measures are designed to reduce energy consumption and improve indoor comfort.

2. Related Work

Meena [7] discusses recent advancements in green building technologies (GBTs) and their potential to contribute to sustainable development. It covers various aspects of GBTs, including the balanced use of energy, water, and other resources to improve environmental conditions, reduce operating costs, and enhance occupant health and productivity. The study also highlights future research directions in green building technologies, emphasizing the importance of renewable energy integration and environmentally friendly materials.

Additionally, Wang [8] provides a comprehensive scientometric analysis of green buildings research over the past two decades, highlighting key trends, research hotspots, and future directions. The study identifies significant contributions from various countries and institutions in the field of green building technologies. It emphasizes the integration of renewable energy, use of sustainable materials, and application of artificial intelligence (AI) as promising future directions. Chen [9] reviews the integration of renewable energy, specifically solar and wind energy, in green building practices. It discusses various technologies such as photovoltaic systems, solar-assisted heat pumps, and building-integrated photovoltaics, highlighting their benefits in reducing energy consumption and greenhouse gas emissions.

3. Methodologies

The renovation of existing buildings represents a significant avenue of inquiry within the field of green building research. The application of green building technologies has the potential to significantly enhance the energy efficiency and environmental performance of older buildings. The

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objective of this study is to investigate specific strategies and methodologies for enhancing building insulation, optimising heating, ventilation and air conditioning systems, and harnessing renewable energy sources.

3.1. Improve building insulation

Improvements in building insulation can be achieved by thickening exterior wall insulation and replacing energy-efficient windows. Assuming that the heat transfer of a building is mainly through walls and windows, we can quantify the reduction in energy loss using the following Equation (1).

$$Q = \sum_{i=1}^{n} U_i \cdot A_i \cdot \Delta T \tag{1}$$

Note that Q is the total heat loss and U_i is the heat transfer coefficient of the ith material (W/m²· K), A_i is the surface area of the material (m²), and ΔT is the temperature difference between indoor and outdoor (K). By reducing U_i and increasing the thickness of the insulation, Q can be lowered and energy loss can be reduced. Energy-efficient HVAC systems reduce energy consumption by improving equipment efficiency, optimizing duct design, and intelligent control systems. The total energy consumption of the E_{HVAC} system is determined by the equipment efficiency η and the load demand L, which is expressed as Equation (2).

$$E_{HVAC} = \frac{L}{\eta} \tag{2}$$

E_{HVAC} can be effectively reduced by increasing η and reducing L (by optimizing the system design to reduce unnecessary loads). The use of solar photovoltaic panels (PV) to generate electricity and solar thermal systems (hot water and heating) in buildings can reduce dependence on traditional energy sources. Suppose the total energy output E_{solar} of the solar system is determined by the solar radiation intensity I, the photovoltaic panel area A, the conversion efficiency η_{solar} and expresses ad Equation (3).

$$E_{solar} = I \cdot A \cdot \eta_{solar} \tag{3}$$

By optimizing A and η_{solar}, solar energy can be maximized and the net energy consumption of the building can be reduced.

3.2. Model Establishment

To quantify the combined effects of each strategy, the following multi-objective optimization model was established to minimize total energy consumption E_{total} and maximize indoor comfort C, which is described as Equation (4).

$$\begin{gathered} \min E_{total} = E_{thermal} + E_{HVAC} - E_{solar} \\ \max C = f(T_{indoor}, RH_{indoor}, CO_{2level}) \end{gathered} \tag{4}$$

where $E_{thermal}$ is the heat loss through the building envelope, and T_{indoor}, RH_{indoor}, and CO_{2level} represent the indoor temperature, relative humidity, and carbon dioxide concentration, respectively, which together affect the comfort of the indoor environment C. In order to solve the problem of building energy efficiency optimization, the particle swarm optimization algorithm is used to solve the above model. The particle swarm optimization algorithm is an optimization method based on swarm intelligence, which simulates the collective behavior of a flock of birds or fish when looking for food. The particle swarm optimization algorithm searches for the best solution in multi-dimensional space by adjusting the position and velocity of particles to find the optimal combination of strategies.

We first encode decision variables such as insulation material thickness, HVAC system efficiency, and solar energy utilization ratio to form the particle dimension. Each particle represents a possible solution, and its location represents a specific combination of design parameters including

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the thickness of the wall insulation, the energy efficiency ratio of the HVAC equipment, and installed area of the solar photovoltaic panels.

The renovation strategy proposed in the model emphasizes improving the building's energy consumption and indoor comfort across the board by combining multiple green technologies, including insulation, HVAC optimization, and renewable energy integration. This is different from some existing green building renovation standards or guidelines, which may focus more on a single aspect rather than overall optimization.

4. Experiments

The effects of disparate green transformation measures were evaluated through the utilisation of computer simulations. The simulation experiments employed building energy simulation software to establish baseline data prior to the renovation, including energy consumption and indoor environmental conditions. Furthermore, a range of renovation measures were modelled, encompassing the addition of insulation, the upgrading of the HVAC system and the installation of solar equipment. The objective of the simulations is to analyse the impact of the various renovations on the energy consumption and environmental quality of the building in order to evaluate the potential energy savings and optimisation of different strategies. To evaluate the improvement in indoor comfort and energy consumption before and after renovation, the study used specific indicators, including energy consumption per square meter per year (kWh/m²/year), indoor CO2 concentration, humidity and temperature comfort.

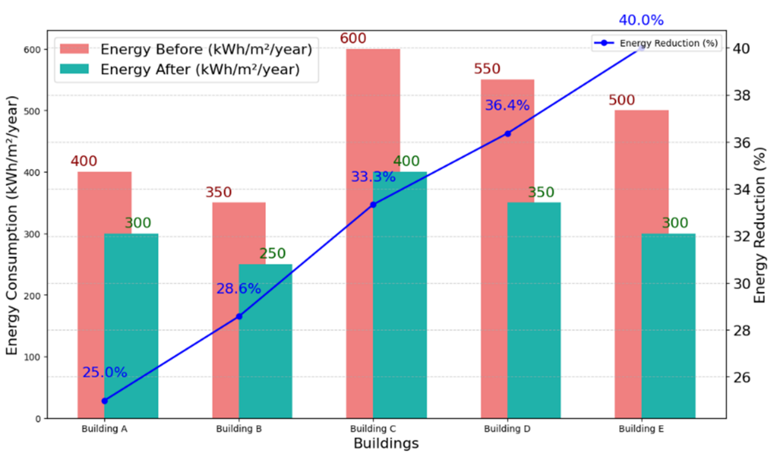

Figure 1. Energy Consumption Before and After Retrofitting.

The energy consumption metric is a key parameter used to evaluate the energy efficiency of a building and is usually expressed in kilowatt-hours (kWh/m²/year) per square meter consumed per year. By comparing the energy consumption indicators before and after the renovation, the effect of the building energy-saving renovation can be quantified, reflecting the contribution of different energy-saving measures to reducing energy consumption.

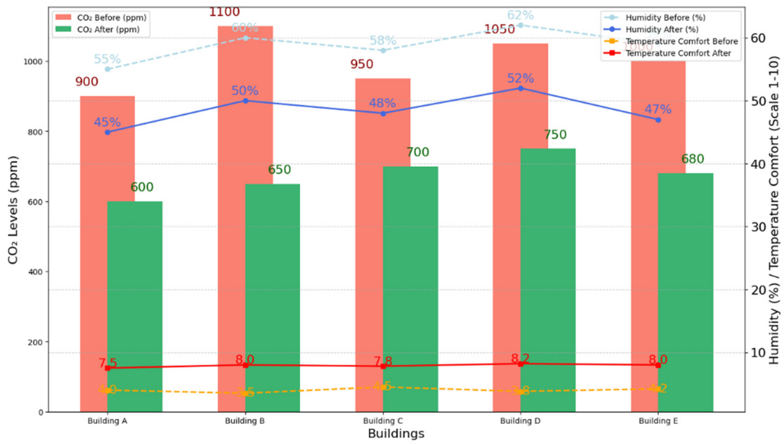

Figure 2. Indoor Environment Quality Before and After Retrofitting.

Figure 1 shows an experimental diagram of the energy consumption indicators, showing the energy consumption of different buildings before and after renovation (in kWh/m²/year) and the percentage reduction in energy consumption. Figure 2 is an experimental diagram of environmental quality indicators, showing the changes in indoor environmental quality of different buildings before and after renovation, including the improvement of carbon dioxide concentration (CO_2) level, humidity, and temperature comfort.

5. Conclusion

In conclusion, retrofitting old buildings through green building technologies can significantly reduce energy consumption and improve indoor environmental quality, helping to achieve sustainable development goals. The results show that the use of optimized insulation, energy-efficient HVAC systems, and renewable energy sources can effectively reduce energy consumption and carbon emissions of buildings, and improve indoor air quality and comfort. In the future, with the continuous progress of technology and policy support, the potential of green building renovation will be further tapped to provide more solutions for sustainable urban development.

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