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Literature Review on the Renovation Project of Self-Built Residential Buildings in the South Under the Low-Carbon Background

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Abstract: With the continuous exploration and research of low-carbon buildings in China, combined with foreign theories and practices, there are a few basic theoretical and practical projects for low-carbon construction in major cities of China. However, throughout the entire academic research, there is still no comprehensive and clear guidance for the green and low-carbon research and transformation of rural self-built houses. Therefore, the existing development of low-carbon technology for rural self-built houses has been summarized, and some prospects for the future development of rural self-built houses have been summarized. It is hoped that this will have positive help for future rural low-carbon transformation.

Keywords: Low-carbon transformation; Southern rural areas; Self-built houses

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1. Introduction

Since the 21st century, with the rapid development of the rural economy and the continuous expansion of the urbanization scale in China, the ecological environment problems in rural areas have become increasingly prominent. On the one hand, the extensive transformation of rural industries has led to the replacement of intensive agriculture and handicrafts by high-carbon industries such as commerce and tourism, and the blind expansion of high emissions and high energy consumption without being constrained by ecological space and natural resources. On the other hand, under the influence of nearby and on-site urbanization, the natural texture of rural areas tends to be fragmented, and the normal structure and function of green spaces are eroded to varying degrees [1]. The carbon emissions in rural areas have significantly increased. According to the "China Rural Statistical Yearbook" [2], in the past 10 years, the per capita carbon emissions in rural areas have increased by 2.4 times compared to urban areas during the same period, and the total carbon emissions have also exceeded 45% of the total value. Rural areas have become major carbon emitters. The work conference of the 19th National Congress of the Communist Party of China and the No. 1 Central Document of the Central Committee of the Communist Party of China in 2018 have successively proposed that rural revitalization should be guided by ecological civilization, and the high-quality rural development path of quality, ecological livability, and green sustainability should be adhered to. Therefore, exploring the “low-carbon”, “connotative”, and “intensive” development of new rural areas under the goal of “increasing foreign exchange and reducing emissions” has become the key to smoothly promoting new urbanization, rural modernization, and creating an ecological and livable environment.

2. Research background

2.1. Concept of low-carbon buildings

At present, there is no unified definition for low-carbon buildings in the academic community. British scholar Phil Jones believes that reducing building energy consumption and fully utilizing renewable energy are necessary conditions for low-carbon buildings [3]. Gu Lijing, a scholar from Tsinghua University, expressed that low-carbon buildings reduce the use of fossil fuels and improve energy efficiency throughout the entire life cycle of buildings, thereby reducing carbon dioxide emissions. Cao and Liu from Chongqing University proposed the fundamental prerequisites for low-carbon buildings that encompass the entire building life cycle. Their approach includes the following key elements: In the architectural design stage, maximize the utilization of renewable and clean energy sources such as solar energy, geothermal energy, and wind energy. During the construction stage, employ low-carbon building materials and adopt energy-saving and low-carbon technologies. Furthermore, they advocate for a shift in consumption habits, urging people to adopt high-efficiency air conditioning systems, energy-saving lighting fixtures, and electrical equipment to conserve electricity [5]. Li Bing, a scholar from Huazhong University of Science and Technology, asserts that low-carbon buildings encompass a comprehensive approach involving scientific planning and design throughout a building’s entire life cycle. This approach includes the rational use of eco-friendly building materials, energy-saving technologies, innovative processes, and other measures aimed at enhancing energy efficiency and diminishing the consumption of fossil fuels such as coal, oil, and natural gas, ultimately resulting in reduced greenhouse gas emissions [6]. Meanwhile, Yinshi Chao from the Harbin Institute of Technology defines low-carbon buildings as those with minimized carbon emissions quantified across the entire lifespan of the structure [7]. Combining these perspectives, it can be concluded that the core essence of low-carbon buildings involves reducing fossil fuel consumption, maximizing renewable energy utilization, adopting diverse energy-saving technologies, and minimizing carbon emissions over the entire lifespan of the building.

2.2. International and domestic low carbon development

The United Kingdom is the most active practitioner in advocating for a low-carbon economy and developing low-carbon buildings. In 2003, the UK took the lead in proposing the concept of a “low-carbon economy” in “The Future of Our Energy” [8]. In December 2006, the UK released the Sustainable Housing Code, which evaluated the carbon footprint of buildings from nine aspects including building use, building maintenance, and energy utilization [9].

Starting from April 2007, the UK has required new buildings to comply with the requirements of the Sustainable Housing Code, and starting from 2016, all new homes must meet the 6-star standard, which is zero carbon housing. In March 2008, the UK government proposed new requirements for new public buildings, which require all new public buildings to be zero carbon from 2019 onwards. In addition, the UK’s Climate Change Act was officially passed and came into effect in 2008. In the bill, the UK proposed to reduce 20% of carbon emissions by 2020 based on 1990 levels and achieve the goal of reducing 80% of carbon emissions by 2050, which fully reflects the UK’s determination to reduce carbon emissions. The Science and Technology Innovation Park of the British Institute of Building Science and Technology is a technology park dedicated to showcasing low-carbon buildings. There are 11 low-carbon demonstration buildings built in the park, which use renewable green building materials and efficient energy-saving insulation technology for the building envelope, achieving low-carbon or even zero-carbon emissions in the building. Among these 11 low-carbon demonstration projects, the most famous is the London Beddington Zero Emission Community, which was built in 2002. Through the use of recyclable building materials, solar collectors, and photovoltaic panels, as well as the installation of rainwater harvesting devices and natural ventilation chimneys, it has achieved high standards of zero carbon emissions and is a successful example of zero carbon emission communities and low-carbon building development in the UK and even around the world [10].

Japan is one of the first countries to propose the construction of a low-carbon society, and its low-carbon development strategy was launched earlier. In April 2004, the "Japan Low-Carbon Society Scenario for 2050" research program was established by the Global Environmental Research Fund established by the Japanese Ministry of Environment. In February 2007, the project team published a research report titled "Japan's Low Carbon Society Scenario: Feasibility Study on Reducing Carbon Dioxide Emissions by 70% from 1990 Levels by 2050", fully affirming the feasibility of the low-carbon society concept. In May 2008, Japan issued the "Action Plan for a Low-Carbon Society Planning," proposing technical measures to achieve the construction of a low-carbon society. In July of the same year, the Japanese Cabinet meeting passed the "Action Plan for Building a Low-Carbon Society," proposing to vigorously promote the development and use of renewable low-carbon energy and accelerate the process of building a low-carbon society [11].

Copenhagen, Denmark is a pioneer in the construction of low-carbon cities. In August 2009, the Copenhagen Climate Plan 2009 was officially introduced, proposing carbon dioxide emission reduction targets, which were implemented in two stages. The first stage is to achieve a 20% reduction in carbon dioxide emissions by 2015 based on 2005 levels, and the second stage is to achieve zero carbon emissions by 2025, making Copenhagen the world's first carbon-neutral city. To achieve the goal of reducing 500,000 tons of carbon dioxide emissions annually, the Copenhagen Climate Plan 2009 proposes 50 action plans in six major areas: energy supply renovation, green transportation, energy-saving buildings, citizen action, urban development, and future climate adaptation. Among them, energy supply renovation, green transportation, and energy-saving buildings are key areas for achieving emission reduction goals [12]. A typical representative of low-carbon urban development in Denmark is the solar wind community in Beder, Denmark. This public residential community was spontaneously organized and built by residents, and completed in 1980, with a total of 30 households. The main forms of energy in this community are solar and wind energy, which fully utilize renewable energy and reduce carbon dioxide emissions [13].

Although the development of low-carbon buildings in China started relatively late, many efforts have also been made. In 2008, the National Development and Reform Commission and the World Wildlife Fund (WWF) selected two cities in China, Shanghai and Baoding, as low-carbon city pilots to explore low-carbon models for urban development. Among them, Shanghai focuses on developing energy-saving buildings, while Baoding focuses on the application of new and renewable energy. In January 2010, the Ministry of Housing and Urban-Rural Development of China approved Shenzhen as the first low-carbon ecological demonstration city in China. Shenzhen actively promotes the development of low-carbon buildings, playing a leading and exemplary role in the construction of low-carbon ecological cities in China. In July of the same year, the Climate Department of the National Development and Reform Commission issued a notice on carrying out pilot work in low-carbon provinces, regions, and cities, establishing the first batch of low-carbon pilot areas in China, including Guangdong, Yunnan, Hubei, Shaanxi, Liaoning provinces, and eight cities in Tianjin, Shenzhen, Xiamen, Nanchang, Guiyang, Chongqing, Hangzhou, and Baoding. In December 2012, the National Development and Reform Commission issued a notice on conducting the second batch of national low-carbon pilot projects in provinces, regions, and cities, establishing the second batch of low-carbon pilot projects in China, including 29 provinces and cities such as Beijing, Shanghai, Hainan, and Shijiazhuang. On September 19, 2014, the National

Development and Reform Commission officially issued the "National Climate Change Response Plan," which clearly stated that by 2020, China will build around 150 low-carbon industry demonstration parks, carry out around 1,000 low-carbon community pilot projects, and create around 1,000 low-carbon commercial pilot projects [14].

Building low-carbon cities is a necessary path for future urban development, and the development of low-carbon buildings is also an inevitable trend. So far, China has successfully constructed many low-carbon buildings. For example, Beijing Guoao Village has integrated and applied dozens of low-carbon technologies, including green building materials, reclaimed water reuse, renewable water source heat pump systems, solar domestic hot water systems, and power generation, greatly reducing energy consumption and greenhouse gas emissions, reaching the international leading level of green residential areas. There is also Fengshang International Apartment in Nanjing, which is China's first "zero energy" residential project. It uses renewable energy such as solar energy and shallow geothermal energy to replace traditional energy, effectively reducing carbon emissions [15].

2.3. Current status of rural areas research

2.3.1. Research status of China's rural areas as compared to overseas

The energy consumption level per unit area of buildings in China was on par with that of the United States and Japan in the past but now declined to only 40% to 60% of the current levels seen in the United States and Japan. If no effective actions are taken, it is expected that China's energy consumption per unit area will naturally catch up to those higher levels in 15–20 years. To provide some context, South Korea initiated similar efforts in the early 1980s, and after about 15 years, their energy consumption per unit building area began to rise in tandem with per capita GDP. After this rapid development period, South Korea's building energy consumption currently matches that of Japan. China's urban and town construction is progressing rapidly, and if the number of urban buildings doubles and the energy consumption per unit area doubles over the next 20 years, the total energy consumption for building operations could match the current national total energy consumption. This situation poses significant challenges in terms of energy sourcing, energy transportation, and carbon emissions post-energy conversion. China's ability to handle such a substantial increase in energy consumption is constrained by factors such as its large population, limited land area, finite resources, and the impracticality of relying extensively on foreign natural resources, as the United States and Japan have done during different phases of their development. Hence, the imperative for China is to balance the demands of social and economic development with the improvement of living standards while keeping the actual operational energy consumption per unit building area at or near current levels. Alternatively, further reductions in energy consumption can be pursued based on the existing foundation [16].

2.3.2. Current situation of rural areas in China

According to 2021 data from the State Council, China's rural population totals 556 million people, and rural housing covers approximately 40% of the nation's total building area. Carbon emissions originating from rural housing contribute to about 20% of the overall carbon emissions within the construction industry [17]. Encouraging environmentally friendly and low-carbon development in rural housing offers several advantages. It not only prolongs the lifespan of rural homes but also reinforces efforts for energy conservation and emission reduction. This, in turn, helps farmers reduce expenses and boost their income. Moreover, it enhances the comfort and safety of rural dwellings, elevates the quality of rural living, and accelerates the creation of aesthetically pleasing rural areas. Additionally, it facilitates the dissemination of green technology and building materials to rural regions, contributes to regional air pollution control, supports adjustments in industrial structures, and promotes economic transformation and upgrading.

While China has been actively promoting green rural housing in recent years, there are persistent challenges, including insufficient technical support, an incomplete management system, and inadequate promotion mechanisms. China currently stands at a critical juncture in its social and economic development. Over the past decade, the GDP has consistently grown at a rate exceeding 10% per year, urban built-up areas have expanded at a rate close to 10% per year, and annual energy consumption has continued to rise significantly, hovering around 10% [18].

Over the past three decades, developed countries like the United States and Japan have placed substantial emphasis on building energy efficiency. They have provided substantial financial support, instituted legislative oversight, and guided public opinion through various government and societal avenues. This concerted effort has spurred the emergence of a constant stream of new buildings that incorporate various energy-saving technologies. All of these experiences offer valuable guidance and serve as a reference point for the construction of energy-efficient and low-carbon self-built rural houses in China's evolving low-carbon landscape.

2.4. Countermeasures for energy consumption reduction

2.4.1. Countermeasures for reducing energy consumption in foreign countries

The concept of ultra-low energy buildings, also referred to as passive buildings, was initially introduced by German physicists [19]. These buildings are characterized by their extensive applications of energy-saving technologies in various aspects, including building envelopes, energy and equipment systems, lighting, intelligent control, and the utilization of renewable energy [20]. Ultra-low energy buildings exhibit significantly reduced energy consumption levels compared to conventional structures and prioritize the utilization of renewable energy over primary energy sources whenever feasible [21].

2.4.2. Countermeasures for reducing energy consumption in China

Ultra-low energy consumption buildings in China are typically defined based on annual calculations of energy usage as well as terminal energy consumption as key performance indicators. For newly constructed buildings, these structures exhibit a remarkable energy efficiency improvement, with heating and cooling energy consumption being over 70% more efficient compared to buildings constructed according to standard energy-saving guidelines (with residential buildings achieving a 65% energy-saving rate and public buildings achieving a 50% energy-saving rate as the baseline for improvement [22]).

Urban and rural construction represents a significant source of carbon emissions, and as urbanization continues to advance rapidly and industrial structures undergo substantial adjustments, the carbon emissions stemming from urban and rural construction are expected to rise as a proportion of total societal carbon emissions.

To expedite progress toward the "dual carbon" goals, the Ministry of Housing and Urban-Rural Development and the National Development and Reform Commission have officially unveiled the "Implementation Plan for Carbon Peak in Urban and Rural Construction." This plan introduces new requirements aimed at comprehensively enhancing the level of green and low-carbon buildings, optimizing the energy mix in urban development, and encouraging the adoption of renewable energy sources. These requirements include the ongoing implementation of green building initiatives, the target of achieving an 83% reduction in energy consumption for new residential buildings in extremely cold regions by 2030, a 75% reduction in energy consumption for new residential buildings in regions with four seasons, and a 78% reduction in energy consumption for new residential buildings in mild weather regions.

2.5. Impact of building structures and types on carbon emissions

In 2009, Ambrose and colleagues conducted a comprehensive study on the carbon emissions associated with building materials [9]. Their analysis encompassed the entire lifecycle of building materials, including mining and production, the impact of these materials on building energy consumption during use, and the potential for recycling. They specifically compared the carbon emissions of wooden and concrete structures and determined that the carbon emissions ratio between wooden and concrete structures was approximately 4:5.

Moving to 2010, Verbeeck and his team performed an exhaustive assessment of lifetime energy consumption and carbon emissions for five different types of residential buildings in Belgium [23]. They conducted a comparative analysis among buildings with distinct structural designs and found notable differences in carbon emissions throughout the entire lifespan of buildings with varying structures.

In 2011, Shang *et al.* selected three single-family building types with identical designs in the northern region, which included wooden structures, light steel structures, and reinforced concrete structures [24]. They calculated and compared their carbon emissions over the complete lifespan of these structures. The results revealed that wooden structures, in contrast to light steel and reinforced concrete structures, exhibited lower lifetime carbon emissions. In addition, all three building types shared a common feature in their carbon emissions profile, with the highest proportion occurring during the operation and maintenance phases.

In 2012, Peng conducted a study focusing on various representative cases of public and residential buildings that had received green building certifications [25]. The study involved calculations of their lifetime energy consumption and carbon emissions, facilitating a comparative analysis of energy consumption and carbon emissions among different building types. The findings indicated that public buildings, over their entire lifespan, had energy consumption and carbon emissions approximately twice as high as those of residential buildings. Green public buildings, in particular, showed a 33% reduction in lifetime energy consumption compared to standard public buildings, while green residential buildings exhibited a 13% reduction in lifetime energy consumption compared to conventional residential buildings.

3. Current challenges and development trends

3.1. Existing challenges

3.1.1. Shortage of expertise

While ultra-low energy buildings offer numerous benefits, they have not yet become a widespread housing option for the general population. Research and case studies have identified shortcomings in various aspects, including material availability, design considerations, and the availability of skilled professionals. These ultra-low energy buildings are relatively new, and as a result, there is a deficit in expertise.

3.1.2. Need for regulatory enhancements

Currently, the National Development and Reform Commission is actively promoting the establishment of a comprehensive policy framework for carbon peak and carbon neutrality. They are working on drafting high-level design documents for carbon peaking and carbon neutrality, as well as formulating action plans for carbon peaking policies related to energy conservation and emission reduction. Within these policy initiatives, the promotion of energy-saving and low-carbon development in the construction sector plays a crucial role. This involves supporting the development of ultra-low energy buildings and retrofitting existing structures for energy efficiency.

3.1.3. Acceptance among rural communities

Elevating the green and low-carbon standards of rural housing entails additional costs. Rural housing is predominantly constructed by individual farmers in a decentralized manner, often resulting in small-scale projects. The incremental cost associated with individual construction can be substantial, posing a significant economic burden on farmers. Furthermore, there is a need to better coordinate efforts with the renovation of dilapidated rural houses and related initiatives to achieve a more synergistic approach. Therefore, it is essential to explore diverse, coordinated, and sustainable promotion mechanisms while continuously increasing efforts to promote these initiatives.

3.2. Emerging trends

In light of the national policies advocating carbon neutrality, energy conservation, and emission reduction, low-carbon energy-efficient buildings have garnered significant attention in recent years. Efforts are made to promote the use of renewable energy sources such as solar energy, geothermal energy, air thermal energy, and biomass energy in rural areas for gas supply, heating, and power supply [26]. Furthermore, there is a push to further enhance electrification in rural regions, encouraging the electrification of various energy-consuming aspects such as entertainment, heating, lighting, transportation, and hot water [27].

3.3. Progress toward low-carbon energy-efficient rural housing

Presently, national and local standards mainly focus on improving building energy efficiency and the design process but overlook other performance requirements and practical needs in construction, operation, renovation, and other phases. Consequently, there is no comprehensive guidance to enhance the green and low-carbon standards of rural housing. This results in suboptimal living conditions in rural homes, high levels of energy resource consumption, insufficient consideration of regional and historical cultural characteristics, incomplete public services and infrastructure support, and significant disparities between urban and rural areas.

4. Proposed research initiatives

4.1. Exploration of clean energy utilization in rural housing

To promote the adoption of eco-friendly and energy-efficient construction in rural areas, it is imperative to undertake energy-saving upgrades to existing rural homes. This involves enhancing the overall energy efficiency of rural residences, moving away from previous extensive building models, and fundamentally addressing the synergistic development of building energy efficiency and heating energy consumption. The goal is to establish a sustainable, long-term mechanism for development.

4.1.1. Technological advancements

(1) Solar heating and photovoltaic power generation: Achieving the organic integration of solar energy, building energy efficiency, and biomass heating offers a more comprehensive reflection of the advantages and sustainable potential of green energy-efficient heating in rural settings.

(2) Ground source heat pump systems and waste heat recovery fresh air systems: These systems can enhance energy efficiency in rural homes.

(3) Sunlight transmission for lighting and green shading: Innovative solutions for optimizing natural lighting and shading contribute to energy efficiency.

(4) Rainwater collection and on-site drainage: Implementing rainwater harvesting and localized drainage systems can improve resource utilization and reduce environmental impact.

4.1.2. Architectural design enhancements

(1) Space structure and natural ventilation: Implementing thoughtful spatial designs and natural ventilation strategies can enhance energy efficiency.

(2) Building enclosures and windows: Upgrading building enclosures and windows can significantly improve thermal performance.

4.1.3. Utilization of local crop waste

In rural areas of China, there is an abundance of straw resources and forestry residues that can be harnessed for energy production locally, demonstrating the economic and environmental advantages of biomass heating. Encouraging the exchanges of raw materials for processed particles can boost enthusiasm for waste utilization and foster the transition to biomass heating instead of relying on coal-to-gas or coal-to-electricity in rural areas.

4.2. Exploration of local construction techniques in rural housing

Designing low-carbon rural residences necessitates the active exploration of both passive and active technological approaches. Passive design strategies should be prioritized to reduce reliance on active technologies, subsequently lowering construction and operational costs. Simultaneously, active technologies should be employed to further improve energy efficiency, showcasing the pivotal role of technology in achieving energy conservation and consumption reduction [28].

Achieving the low-carbon emissions goal for rural residential buildings is contingent upon the combination of various low-impact technologies. These encompass the rational use of local environmental conditions and the cumulative impact of a series of low-impact technologies. This approach makes it feasible to reduce the carbon footprint of rural housing. Additionally, introducing appropriate low-carbon concepts, advocating a low-carbon lifestyle, cultivating a culture of low-carbon communities, and reasonably using low-carbon technologies are vital to improving the living standards and environmental quality of residents in these regions.

4.3. Preservation of rural housing heritage

The historical environment embodies the essence of urban development, serving as the backdrop for long-term human activities and encapsulating urban history and culture in tangible form. It holds profound cultural and spiritual significance [29]. Thus, the ecological construction of residential buildings must harmoniously integrate with the local historical and regional context to realize the concept of nurturing low-carbon structures within the ecological environment [30].

5. Conclusion

Based on the comprehensive review presented earlier, it becomes evident that several challenges persist in the realm of research on carbon emissions from rural buildings. Currently, most investigations primarily involve qualitative analyses, with a noticeable shortage of quantitative research. Furthermore, the bulk of existing studies predominantly concentrate on carbon emissions from residential buildings, neglecting the broader spectrum of rural construction

The findings from research on carbon emissions from self-built rural homes, especially in rural areas, often lack universal applicability. Moreover, China has yet to establish a sufficiently mature methodology and software for quantifying carbon emissions over the entire lifespan of buildings. These represent pressing issues that require resolution as China strives to develop low-carbon rural buildings and attain the objectives for energy conservation and emissions reduction.

To address these challenges, this research will involve an in-depth analysis of rural communities to discern disparities between self-built low-carbon design strategies and conventional low-carbon design approaches. By exploring optimization strategies tailored to the unique context of rural low-carbon development of villages, this paper aims to identify focal points for low-carbon development specific to southern and northern residential and non-residential structures. Additionally, an examination of the spatial transformation optimization results in self-built rural homes within communities will provide valuable insights for guiding future low-carbon optimization initiatives in the surrounding localities.

Disclosure statement

The authors declare no conflict of interest.

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