Application Research on the Integrated Design of the "Gas-Electricity-Heat-Fertilizer" Device with Rural Architecture

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Abstract: In response to issues such as energy utilization, environmental pollution, inefficient winter heating, and improper waste disposal in rural areas of China, this study innovatively proposes a "Gas-Electricity-Heat-Fertilizer" quadruple integrated device. The device utilizes anaerobic fermentation technology to efficiently convert rural waste such as straw, livestock manure, and household waste into clean energy and high-quality organic fertilizer, thereby achieving closed-loop recycling of resources. This study explores the integrated design method of the "Gas-Electricity-Heat-Fertilizer" device with rural architecture, aiming to contribute new strategies and solutions to the sustainable development of the ecological environment in China's rural areas.
***Keywords*:** rural energy utilization; "Gas-Electricity-Heat-Fertilizer" inheritance device; rural architectural design

1. Introduction

For a long time, the traditional energy consumption pattern has not only contributed to the trend of global climate change but also had a profound impact on the local ecosystem. In response to issues such as energy utilization in rural China, environmental pollution in traditional village spaces, and the ineffective utilization of agricultural, pastoral, and human waste generated in rural areas, this study uses the "Gas-Electricity-Heat-Fertilizer" integrated device to explore applicable design methods for household energy use in rural dwellings. The aim is to enable sustainable development of the rural ecological environment.

2. Research Background Analysis

Figure 1: Germany's Schwenndt Biomass Power Plant

Figure 2: Hotchkiss Biomass Power Plant, USA

Internationally, many countries have begun to explore innovative models for rural energy supply and waste management. For instance, Germany's "Energy Village" project has achieved rural energy self-sufficiency by establishing small biomass power plants and solar energy facilities (Figure 1). In terms of architectural style, the power plant presents an ecological aesthetic form. Its design is transparent, light, and easy to understand. The main structure of the power plant is a cubic frame of glass and steel, which, as the technical core, reveals its internal construction in full view. Externally, it is covered with a cylindrical layer made of larch wood panels, forming a natural, floating filter that isolates the surrounding environment.

In the United States, the "Rural Energy Cooperative" (Figure 2) Hotchkiss Biomass Power Plant project is not only infrastructure but also a biological classroom. It showcases eco-friendly technologies and the use of sustainable building materials to students and visitors. Inside the building, there is an informal exhibition room equipped with various informative charts and interactive computer consoles for tracking performance indicators.

Table 1. Power generation from renewable energy sources in German energy villages

Energy Type	Share of Electricity Generation (%)
otal Renewable Energy Generation	55
Biomass Energy Generation (including Biological Waste)	18

3. Design Approach for Rural "Gas-Electricity-Heat-Fertilizer" Integrated Devices

In order to deeply observe, analyze, and effectively utilize the biomass energy resources in rural areas to ensure their efficient operation, this study adopts the following methods:

3.1 Remote Sensing Data Statistics

Firstly, a detailed analysis of the existing energy sources in rural areas is required. By utilizing remote sensing technology and data from various remote sensing application platforms, we can collect and statistics on crop planting areas, types, scale of livestock and poultry breeding, and the amount of household waste produced. This data can accurately analyze the types and storage quantities of rural biomass in different regions, and can also assess the energy potential of the area. Based on these assessments, we can set the installation scale for the corresponding integrated "gas-electricity-heat-fertilizer" devices.

3.2 BIM Digital Modeling and Renovation Plan Development

Through the use of BIM (Building Information Modeling) digital modeling technology, detailed design prototype simulations are conducted for selected typical villages. Firstly, the feasibility of the integrated "gas-electricity-heat-fertilizer"(device) in practical applications is verified through four-dimensional simulation analysis. Secondly, BIM technology is

used to optimize the design of the integrated device, ensuring that it can seamlessly integrate with rural architecture and the environment.

4. "Gas-Electricity-Heat-Fertilizer" Integrated Equipment Architectural Design

4.1 Adhering to the Two Core Principles of Modularity and Scalability

Modular design allows the device to be customized according to the specific conditions of different regions, adapting to diverse energy needs and environmental characteristics. This flexibility ensures that the device can serve various rural environments efficiently, whether in remote mountain areas or in densely populated rural communities.

4.2 Emphasizing the Protection of Traditional Rural Architectural Styles

Without damaging the original appearance of traditional high-platform residential buildings, the design reasonably configures the appearance and layout of anaerobic fermentation equipment, biomass direct combustion power generation equipment, and organic fertilizer processing equipment, as well as the placement of pipelines. By cutting and combining the device's container bodies, construction is carried out in areas that do not disrupt the village's appearance, with minimal intervention in the architectural style to protect the historical building facade and maintain the texture of traditional villages.

4.3 Discussing the use of BIM (Building Information Modeling) digital modeling to simulate the design of energy-efficient rural dwellings.

Taking the design of new rural residences in the central Shandong region as an example, this rural residential design inherits the traditional layout of siheyuan (courtyard houses) and the sloped roof style of the area. Building on this foundation, and using technologies such as BIM (Building Information Modeling) digital modeling, the design integrates the integrated linkage device with rural architectural design. The functional layout has been improved to meet modern needs, creating a basic pattern of living in the front courtyard and production in the back courtyard. In terms of architectural style, traditional elements such as green bricks, gray tiles, and white walls are emphasized, and traditional components like gate towers and screen walls are incorporated. Additionally, the new rural residence design also considers the integration of functions such as farm-to-table dining and homestays, to adapt to the development of the rural tourism industry. This design not only realizes the circular utilization of resources from the source to the source but also allows for flexible adjustments according to the specific conditions of rural areas. Ultimately, it ensures the efficient operation of the device while minimizing the impact on the rural environment.

5. Economic and Social Benefits Forecast

As the Chinese government advances the strategy for rural revitalization, the transformation of rural energy has become an important direction for national development. Against this backdrop, the integrated design of the "Gas-Electricity-Heat-Fertilizer" device with traditional dwellings has a very broad prospects for promotion. Currently, the government's support for renewable energy projects, along with the expanding market size for rural waste disposal and energy supply in rural buildings, provides a favorable market environment for the promotion of the integrated device and new opportunities for the development of related industries.

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References

[1] Fu Kai, Tong Lin, Guo Nan, Song Wei, Zhang Yuan. Current Status and Case Analysis of Composting Technology for Rural Domestic Waste [J]. Tianjin Science and Technology, 2023, 50(8).

[2] G Samudro, Syafrudin, I W Wardhana and T Imai. Comparison of leachate and mixed waste generated electricity in Compost Solid Phase Microbial Fuel Cells (CSMFCs) [C]. IOP Conference Series: Earth and Environmental Science, Volume 623, Issue 1. 2021. PP 012098-M.

[3] Thawatchai Maneerung, Xian Li, Chunyu Li, Yanjun Dai, Chi-Hwa Wang.Integrated downdraft gasification with power

generation system and gasification bottom ash reutilization for clean waste-to-energy and resource recovery system [J]. Journal of Cleaner Production, Volume 188, 2018. PP 69-79MT.
[4] Wang Fang, Liu Xiaofeng, Chen Lungang, Lei Tingzhou, Yi Weiming, Li Zhihe. Research status and development prospect of energy and high value utilization of biomass resources [J]. Transactions of the Chinese Society of Agricultural Engineering, 2021, 18: 219-231.
[5] Liu Qiang, Liu Hanfang, Lin Zhiyi. Adaptive Optimization Design of Local Architecture Construction under Ecological Heritage [J]. Building Structure, 2021, 51(5).

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