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Implementation Models and Barriers for Residential Building Energy Retrofits

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Abstract. In the process of long-term use, existing residences are prone to problems such as the decline in the performance of the enclosure structure, the ageing of the equipment and the reduction of energy utilisation efficiency. Energy-saving transformation can reduce the energy consumption of the building to a certain extent and improve the living environment. However, factors such as the dispersion of residential property rights, high early investment, differences in residents' needs and later maintenance make the transformation project face more difficulties in the actual promotion. This paper adopts the methods of literature induction and typical case analysis to analyse the three implementation models of energy-saving transformation of residential buildings: contract energy management, government-led and comprehensive services, and compare their funding sources, subject division of labour, risk bearing and project organisation methods. The analysis found that contract energy management helps to alleviate the early capital pressure. The government-led model has certain advantages in policy support and multi-subject coordination, while the comprehensive service model pays more attention to the connection between different participants and implementation links. The actual effect of different models is affected by factors such as fund recovery, resident participation, organisational coordination and long-term operation and maintenance. The selection of the implementation model of residential energy-saving transformation needs to be combined with the project conditions, the capacity of residents and the management foundation, and the operation, maintenance and energy-saving effect after the completion of the transformation should continue to be monitored.

Keywords: energy efficiency, cost-effectiveness, renovation, residential, integrated

1. Introduction

After a long period of use of existing houses, there may be problems such as the decline in the insulation performance of the enclosure structure, the ageing of the equipment and the reduction of energy utilisation efficiency. Improving the building performance through energy-saving transformation will become an important part of the renewal of existing houses. Unlike the construction of new buildings, residential renovation deals with buildings that have been put into use and with scattered property rights. Residents' needs, cost-bearing capacity and acceptance of the impact of construction are not consistent. At the same time, the early investment in energy-saving transformation is large, and it usually takes a long time to realise the benefits of energy-saving. The

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project also involves many participants such as the government, residents, property and service enterprises. Therefore, the smooth implementation of residential energy-saving transformation depends not only on the technical plan, but is also closely related to capital arrangement, organisational coordination and post-management [1].

Around these problems, studies have discussed different implementation methods. Contract energy management mainly participates in project investment and operation through energy-saving service companies, in which the early investment is recovered through energy-saving revenues. Relevant research focusses more on revenue distribution, contract design and risk assumption [2]. In the renovation of old houses and communities, government investment and social capital participation are also common practices. Some studies discuss the sharing of funds and project promotion conditions between the government, enterprises and residents from the perspective of public-private partnership (PPP) [3]. In addition, with the increasing number of participants in the transformation project, residents' communication, community coordination and collaboration among participants have gradually attracted attention [4]. The existing research provides a basis for understanding the funding and organisation of residential renovation, but different implementation methods are often discussed separately, and the comparison of their funding sources, subject relationships, risk-taking and differences in later operation and maintenance is not sufficient. Some research on the transformation of old communities also focusses on general community governance and improvement of the living environment, which is not the same as the energy-saving transformation with the main goal of reducing building energy consumption.

This article adopts the methods of literature induction and typical case analysis, and selects three implementation models of contract energy management, government-led and comprehensive services for discussion. The analysis mainly focusses on who invests the funds in each model, what responsibilities different subjects bear, how project risks are distributed, and how the management is maintained after the completion of the transformation. Based on the existing cases, this paper further analyses the problems of fund recovery, residents' participation, multi-subject coordination and long-term operation and maintenance encountered in the actual promotion of different models, and discusses their applicable conditions and improvement directions.

2. Key elements of residential building energy retrofits

2.1. Energy-saving transformation measures and main participants

Energy-saving transformation of residential buildings refers to reducing the energy consumption of building operation and improving the quality of the indoor environment. In response to the problems of energy utilisation and operation performance of existing residential buildings, it is carried out by optimising the building enclosure structure, improving the energy system and improving the efficiency of equipment operation. Compared with newly built buildings, existing houses are limited by factors such as building age, structural form and equipment conditions. There are usually problems such as insufficient insulation performance and low energy utilisation efficiency. Therefore, it is necessary to improve the overall energy performance of the building through energy-saving transformation [5].

The energy-saving transformation of residential buildings mainly includes two aspects: the transformation of the enclosure structure and the transformation of the energy system. The transformation of the enclosure structure is mainly aimed at the outer protective parts of the building, such as exterior walls, roofs, doors and windows. By improving the insulation performance, it reduces the cold and heat load of the building and reduces the energy consumption

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in the heating and refrigeration process [6]. The transformation of the energy system mainly involves equipment such as heating, refrigeration, lighting and domestic hot water. By improving the efficiency of equipment operation and introducing renewable energy technology, the energy demand in the operation stage of the building can be further reduced. In addition, different types of renovation measures usually need to be selected comprehensively in combination with building conditions, residents' needs and investment costs [7].

The energy-saving transformation of residential buildings involves multiple participants, and each subject plays different roles in the project implementation process. Government departments are mainly responsible for formulating relevant policies and technical standards, and reducing the difficulty of project implementation through financial subsidies and policy support. Residential owners are the main beneficiaries and decision-making participants of the renovation project, and their willingness and ability to bear the cost directly affect the implementation of the project. Property service enterprises are usually responsible for residents' communication, coordination and daily management, and assist in the smooth implementation of renovation projects. Energy-saving service companies and construction enterprises undertake technical scheme design, project implementation and later operation and maintenance, and provide professional technical support for the project. The capital investment, interest claims and risk-taking methods between different subjects also further affect the formation of the business model of energy-saving transformation of residential buildings.

2.2. Cost recovery and risk sharing

The energy-saving transformation of residential buildings is usually characterised by high early investment and long investment recovery cycle. Its cost not only includes the engineering investment in the implementation stage of renovation, but also includes related expenses such as early evaluation and design, equipment installation and later operation and maintenance. Because energy-saving benefits usually need to be gradually reflected in the long-term operation process, there is a time gap between the initial capital investment of the project and the later income acquisition. Therefore, the source of funds, the cost recovery method and the revenue distribution mechanism have become important factors affecting the implementation of energy-saving transformation of residential buildings.

At present, the sources of funds for energy-saving renovation of residential buildings usually include government financial support, financial institution financing, enterprise investment and residents' self-financing. Different sources of funds correspond to different cost recovery models, such as reducing the early investment pressure of residents and enterprises through government subsidies, meeting the capital needs of the project construction stage through financing, or obtaining long-term benefits from the implementing entity according to the energy-saving effect after transformation through energy-saving revenue sharing. The way of capital investment and revenue distribution between different subjects directly affects the implementability of energy-saving transformation projects, and also forms different types of business models [8].

In the process of energy-saving transformation of residential buildings, projects usually face multi-faceted risks in terms of technology, capital, market and management. The technical risk mainly comes from the mismatch between the renovation plan and the actual building conditions, which may cause the energy-saving effect to be lower than expected. Capital risk is mainly manifested in high early investment, long investment recovery cycle and uncertainty in return forecast. Market risk is related to changes in energy prices and residents' willingness to pay, which will affect the economic income of the project. Management risk comes from the difficulty of

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coordination between the government, enterprises, property and residents. Therefore, the core differences between different business models are not only reflected in the source of funds and the way of obtaining income, but also in the way the participating subjects bear the risks of the project. A reasonable cost recovery mechanism and risk sharing mechanism are an important foundation for promoting the continuous implementation of energy-saving transformation projects in residential buildings [9].

2.3. Main business models and typical cases

2.3.1. Contract energy management model

Energy Performance Contracting is a market-oriented energy-saving transformation model based on energy-saving effects. In this model, the Energy Service Company (ESCO) is responsible for building energy evaluation, renovation scheme design, capital investment, project implementation and later operation and maintenance. Residential owners do not need to bear all the early renovation costs. After the renovation is completed, ESCO will recover the investment through the energy-saving revenue sharing method agreed in the contract, and the owners will obtain long-term profits by reducing energy consumption and improving the building use environment [10]. Compared with the traditional model in which the owner directly bears the cost of renovation, contract energy management can alleviate the capital pressure in residential energy-saving transformation and improve the feasibility of project implementation [5].

The core of contract energy management is to coordinate the interests between different participants through reasonable revenue distribution and risk-taking mechanisms. During the project implementation, ESCO usually needs to evaluate the energy consumption of the building and formulate energy-saving transformation plans according to the characteristics of the building. The renovation funds can be invested by ESCO in advance, and the energy-saving revenue after the project operation will be distributed between ESCO and the owner according to the contract. Depending on the form of the contract, the common models include energy-saving benefit sharing and energy-saving guarantee. Among them, the energy-saving benefit sharing type is mainly distributed according to the actual energy-saving income, and ESCO recovers investment through long-term income; in the energy-saving guarantee type, ESCO promises to achieve a certain energy-saving effect and bears some of the risks caused by insufficient energy-saving effect. Therefore, this model provides a market-oriented implementation path for residential energy-saving transformation through redistribution of capital investment, income acquisition and risk-taking [1].

Studies have analysed the subject relationship and revenue distribution in the contract energy management model through actual transformation projects. For example, Lu and others took a building energy-saving renovation project in Maryland, the United States, as a case to analyse the decision-making relationship between owners, energy service companies and other participants in energy performance contracts. The study points out that ESCO usually undertakes early renovation investment and obtains economic returns through future energy-saving benefits, while residents or building users obtain long-term benefits by reducing energy costs. However, the actual energy-saving effect will be affected by factors such as residents' usage behaviour, changes in energy prices and differences in operating conditions, thus changing the project income and contract cycle. The case shows that contract energy management can reduce the capital barriers to the energy-saving transformation of buildings, but the successful implementation of the project still depends on reasonable revenue forecasting, contract design and risk distribution mechanism [11].

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In general, the contract energy management model can effectively solve the problem of insufficient investment in the early stage of residential energy-saving transformation, and use the technical and management capabilities of professional energy-saving service companies to improve the efficiency of project implementation. However, this model still faces problems such as uncertainty of energy-saving returns, long investment recovery cycle, and high difficulty for residents to coordinate. Therefore, contract energy management is more suitable for residential energy-saving transformation projects that have stable energy-saving potential, can form long-term revenue returns, and have the conditions for the participation of professional institutions.

2.3.2. Government-led model

Energy-saving renovation of residential buildings often involves high upfront investment, and it also needs to coordinate residents, communities, property, design and construction and other participating subjects. For existing houses with relatively scattered property rights, it is usually difficult to complete projects involving the whole building or the whole community, such as exterior wall insulation and public equipment renewal, relying only on the independent transformation of a single resident. The energy-saving benefits of some projects also take a long time to be reflected, and the willingness of social capital to participate is limited in the absence of a stable return mechanism. In this case, government leadership has become a common implementation method in the renovation of existing residences and old neighbourhoods. The government usually formulates renovation plans, provides financial support, determines technical and construction requirements, and coordinates the participation of communities, residents and related enterprises in projects. Compared with the individual implementation of residents, this method can integrate the scattered transformation needs into the unified project, and it is also convenient for the overall arrangement of design, construction and acceptance.

An important feature of the government-led model is that the government not only provides policy and partial financial support, but also undertakes project organisation and multi-subject coordination. The renovation of old houses involves a large number of residents. Different households may have different degrees of acceptance of the content of the renovation, the cost bearing and the impact of construction. Therefore, the coordination of residents often directly affects the smooth progress of the project. Research on the transformation of old communities in the core area of Beijing shows that government departments need to continuously collect and respond to residents' demands during the project implementation process, and different types of problems also need to be handled jointly by communities, streets and relevant functional departments [12]. Although this study mainly focusses on the government's response to the transformation of old communities, it also shows that the government-led project does not simply rely on financial investment to complete the transformation, and residents' communication and departmental coordination are also important links in the implementation process. For the energy-saving transformation of residential buildings, the government can rely on the community and property to carry out preliminary consultation, coordinate the design and construction arrangements, and organise the transformation contents involving public spaces and buildings. This can reduce the coordination cost brought about by individual residents' separate decisions, which is also conducive to maintaining the consistency of engineering plans and construction standards.

From the perspective of the implementation conditions, the government-led model is more suitable for projects with concentrated demand for transformation, limited independent investment capacity of residents, or projects that are difficult to form stable returns by simply relying on the market mechanism. Financial subsidies can reduce the preliminary capital pressure of residents and

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implementation subjects, and unified organisation is also conducive to expanding the coverage of projects and reducing the disconnect between design, construction and residents' coordination. At the same time, this model also has obvious limitations. The project is highly dependent on the capacity of local financial and administrative organisations, and there are differences in financial conditions and transformation needs in different regions. Therefore, it is difficult to rely on the government to bear a high proportion of renovation costs for a long time. When the proportion of government investment is relatively high, the motivation for the participation of enterprises and other social capital may be insufficient, and the project is likely to form a promotion method focussing on the completion of construction tasks. After the completion of the transformation, if property management, equipment maintenance and energy-saving effect tracking are not established synchronously, the transformation results formed by the early investment may be difficult to maintain for a long time.

Therefore, the role of the government-led model is not only to solve the financial problems at the beginning of the project, but more importantly, to organise the scattered needs of residents, public policies and project implementation. In the subsequent application, it is necessary to determine the scope of government investment according to the local financial capacity, the type of housing and the capacity of residents to bear costs, and at the same time further clarify the responsibilities of residents, property and enterprises in the project. For the part that can form stable energy-saving income, energy-saving service enterprises or other social capital can also be appropriately introduced to reduce the long-term dependence of the project on financial funds. This can not only give full play to the role of the government in organisational coordination and public support, but also improve the continuity of the follow-up operation and maintenance of residential energy-saving transformation.

2.3.3. Comprehensive service model

The energy-saving transformation of residential buildings involves many links such as scheme design, resident coordination, engineering construction, quality acceptance and post-maintenance. The participants usually include government departments, communities, residents, property service enterprises, design units and construction enterprises. Different subjects undertake different tasks. If each link is promoted separately, it is easy to have problems such as untimely information transmission, unclear connection of responsibilities, and untimely feedback of residents' demands. The main feature of the comprehensive service model is that the service subject with organisational coordination ability coordinates the transformation process, links early communication, programme design, project implementation and follow-up management, and establishes a relatively stable information communication mechanism between different participants [4]. This method does not change the original responsibilities of each subject, but reduces the disconnect between different links through unified coordination, so that the project can be promoted according to a more continuous process.

In the actual transformation process, residents' participation and multi-subject coordination often directly affect the implementation of the project. The transformation of Yangzhong community in Guangzhou is a typical case, in which the community neighbourhood committee has undertaken more organisational and coordination work to establish communication channels between residents, streets, design units and construction units [13]. Before the implementation of the project, the community understands the needs of different households through residents' opinions and plan communication; after entering the construction stage, the neighbourhood committee and the street organise residents' representatives, construction units and other participants through regular

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meetings to discuss construction arrangements and on-site issues. Residents can also give feedback through the building manager or directly contact the construction personnel. For general construction problems, they can be handled at the on-site or community level, and matters involving more departmental responsibilities can be further coordinated with relevant functional departments to solve them. This case mainly reflects the role of the comprehensive coordination mechanism in residents' communication and construction organisation, which shows that the transformation project needs to establish a stable collaborative relationship outside of technical implementation to reduce the contradictions arising in the process of programme adjustment and construction.

This organisation has a certain reference value for the energy-saving transformation of residential buildings. Energy-saving renovation usually involves the public parts of the building and the daily life of residents. For example, the construction of exterior walls, doors and windows, heating or other public energy facilities may affect multiple households, and it is difficult to complete all the coordination work by relying on design or construction units alone. The community, professional service institutions or other coordinating subjects are responsible for communication, and the needs of residents can be centralised in the early stage, and relevant opinions can be fed back to the design and construction links. The formation of a fixed communication channel during the construction process is also conducive to timely handling of conflicts between project arrangements and residents' use needs. Compared with the way each subject carries out work separately, the comprehensive service model emphasises the connection in the whole process of transformation. Its main role is not only to add a new participating subject, but also to reduce information breakpoints and responsibility gaps between different units.

However, the implementation effect of this model depends largely on the professional ability and coordination ability of the coordinating subject. If the service subject lacks experience in building transformation, engineering management or communication with residents, unified coordination may not necessarily improve project efficiency. At the same time, it is still necessary to clarify the scope of responsibilities between the government, the community, residents, property and construction units to avoid unclear responsibilities in the event of project quality, cost or later maintenance problems. The operation and maintenance after the completion of the transformation is also a problem that needs to be solved by the comprehensive service model. If the project only focusses on the coordination of the construction stage and does not clarify the responsibilities of later facility maintenance, effect evaluation and problem handling, the coordination mechanism formed in the early stage will be difficult to sustain. Therefore, the comprehensive service model is more suitable for residential renovation projects with more participants and high residents' coordination needs. Its role is mainly reflected in improving the degree of connection between different implementation links, and the long-term effect still needs to be guaranteed by a stable division of responsibilities and operation and maintenance mechanism.

3. Implementation obstacles and directions for improvement

The energy-saving transformation of residential buildings first of all faces a mismatch between capital investment and revenue recovery. The transformation of enclosure structures, heating systems and lighting equipment usually requires high upfront investment, and the economic benefits brought by energy saving often need to be gradually reflected in the subsequent operation process. For residents, a longer recovery cycle will reduce their willingness to participate. For energy-saving service enterprises and other social capital, if there is greater uncertainty in energy-saving returns and energy prices, it will also increase the risk of project investment. Different implementation models need to reasonably arrange government subsidies, residents' investment and enterprise funds

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according to the project conditions, and clarify the cost assumption and revenue distribution methods before the project starts. For projects that can form relatively stable energy-saving income, energy-saving service enterprises or financial support can be appropriately introduced. For residents with weak bearing capacity and for transformation projects with strong public attributes, certain financial support is still needed [14].

Resident participation and multi-subject coordination are also common difficulties in project promotion. Residential renovation usually directly affects the daily life of residents. There may be differences between different households in terms of renovation needs, cost assumption and acceptance of construction. At the same time, the government, community, property management, design units and construction enterprises have different responsibilities. If the information is not transmitted in time or the division of responsibilities is unclear, it is easy to have differences on programme adjustment, construction arrangements and costs. Therefore, residents' communication should not only focus on the early stage of construction, but should run through the stages of programme determination, construction implementation and acceptance. For projects with a large number of participants, it is also necessary to establish relatively fixed communication channels so that residents' opinions can be conveyed to the design and construction links in a timely manner. At the same time, the scope of problems handled by different units should be clarified to reduce repeated coordination and buck-passing.

The operation and maintenance after the completion of the transformation will also affect whether the energy-saving effect can be maintained for a long time. Some projects lack continuous effect evaluation and equipment maintenance after the completion of construction. Changes in building energy consumption, equipment operation status and residents' usage have not been tracked for a long time, and the effect of early renovation may decline over time. There are also differences in climatic conditions, economic levels, housing types and community management capacities in different regions, and it is difficult for the same implementation model to be applied directly to all projects. Therefore, the choice of implementation model should not only consider whether the project can be completed, but also who will be responsible for the maintenance in the future, how to bear the cost, and how to evaluate the energy-saving effect. For different areas and types of residences, the implementation method can be adjusted according to the capital conditions, residents' needs and management ability, so that a more continuous management process can be formed between renovation, operation and maintenance.

4. Conclusion

This article analyses the implementation models and implementation obstacles of energy-saving transformation of residential buildings, and discusses the main characteristics of the three implementation modes of contract energy management, government-led and comprehensive services in combination with typical cases. The focus of problem solving in different models is different. Contract energy management mainly alleviates the pressure of early funds through the participation of energy-saving service enterprises in investment and revenue distribution. The government-led model relies more on policy support, financial investment and organisational coordination. The comprehensive service model emphasises communication and connection between participants such as residents, communities, design, construction and property. All three models can reduce the difficulty of implementing residential energy-saving transformation under certain conditions, but their application effect is affected by factors such as the source of project funds, the degree of participation of residents, the way of risk distribution and organisational management ability.

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Judging from the actual implementation, high investment in the early stage, long investment recovery cycle, difficulty in unifying residents' needs, and insufficient operation and maintenance in the later stage are still common problems in residential energy-saving transformation. Therefore, the choice of implementation model should not only consider the start-up stage of the project, but also need to be judged in combination with the type of housing, the bearing capacity of residents, local financial conditions and the long-term operation needs of the project. Subsequent residential energy-saving renovation can further improve the way of fund sharing and revenue distribution, strengthen continuous communication between different participating subjects, and integrate operation, maintenance and energy-saving effect assessment into the whole process management of the project. Different implementation modes can also be combined according to the project conditions to improve the continuous operation ability and actual energy-saving effect of the transformation project.

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