Evaluation of energy-saving retrofit projects of existing rural residential envelope structures from the perspective of rural residents: the Chinese case

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Abstract

The existing residential envelope in rural areas has low energy efficiency, with low energy utilization and serious energy waste for winter heating. However, in recent years, farmers have not undertaken energy efficiency retrofit projects for existing buildings in rural areas. This study proposed an evaluation model based on the logistic-AHP-TOPSIS method from the perspective of farmers. First, this study conducted a questionnaire survey of 208 rural households and used logistic models to determine which existing evaluation indicators significantly impact farmers’ willingness to participate in energy efficiency retrofit projects. Second, the weights of the eight indicators were determined using AHP. Finally, this study evaluated the retrofit program of a case in Gansu Province using the TOPSIS method. In the analysis, total investment, annual winter heating costs and energy efficiency improvements were found to be the most important factors for farmers. The highest score for existing buildings was 0.3747 because there is no additional investment required; the option of partial retrofitting according to the actual needs of households scored 0.3350 because it balances economic performance with energy efficiency performance; The entire retrofit program has the highest investment and a long payback period, and its score is the lowest with 0.2904. Furthermore, the study recommended that a self-build and self-repair organization led by village collectives be developed to unify the retrofit design and construction and lower renovation costs. Bulk purchases could enable farmers to increase their power in negotiations.

Keywords Energy-saving retrofit · Rural residential · Evaluation models · Policy recommendations

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1 Introduction

Recently, there has been an increased emphasis on the sustainable development of rural areas. With the continuous promotion of the ‘rural revitalization strategy’, the income of Chinese farmers has continued to grow, and the area of rural resident housing has increased significantly to 24 billion m². Data published by China’s National Bureau of Statistics show that rural residents’ per capita housing floor area reached 47.3 m² in 2018, increasing by 39.2 m² or 4.8 times more than the area in 1978. However, most of these buildings lack fundamental energy savings, and the utilization rate of heating energy in winter is inefficient. The Energy consumption of rural buildings in China is about 924.6 billion kWh, which is more than twice the energy consumption of urban residential buildings and accounts for about 40% of the total energy consumption (Zheng & Bu, 2018). In terms of energy consumption per unit of floor area, rural buildings consume 38.8 kWh/m², which is also more significant than the urban residential energy consumption of 29.0 kWh/m² (He et al., 2014).

Gansu is an economically underdeveloped region in Northwestern China. According to the Gansu provincial government, 13.63 million people live in rural areas, accounting for approximately 50% of the total population, and the vast majority are concentrated in the central part of Gansu. Since 2013, the Gansu provincial government has launched guidelines on the construction of green farmhouses. It calls for changing the traditional enclosure structure of farmhouses, improving the rural energy structure, improving living comfort, and reducing energy consumption. However, various issues have accompanied this initiative, including low local farmer acceptance, poor project performance, and sluggish promotion of the retrofit program. Rural residential energy retrofit programs have become an essential part of the response to climate change and ecological sustainability. Effectively promoting the green and energy-efficient retrofitting of existing rural residential buildings will help improve the rural living environment in the region and contribute to the strategic goal of reaching the peak carbon emissions by 2030 and neutral carbon emissions by 2060.

The energy-saving retrofit project for existing rural residential buildings is an issue that requires multidimensional considerations. Since 2012, scholars have focused on reducing energy consumption in rural residential buildings (He et al., 2014). Most of the existing models for evaluating the performance of energy-efficient retrofitting of existing rural residential buildings were previously constructed by scholars based on the GBT51141-2015 Assessment standard for the green retrofitting of existing buildings. Chen proposed a model that combines existing green building evaluation standards with value engineering to evaluate the energy-saving renovation project of a farmhouse in Yanhe Village (Chen, 2015). Guo et al. (2020) considered four on-demand retrofit options based on an economic evaluation perspective, providing new ideas for retrofit projects. After comparing the advantages and disadvantages of various mature green building evaluation methods, Gong and Zhang chose the gray system evaluation model based on the triangular whitening power function to evaluate green farmhouse construction standards (Gong, 2014).

The retrofit project is directed at rural residents characterized by low income, low literacy, and poor environmental protection awareness. Therefore, the renovation project was influenced by artificial factors. Wu used the logistic model to analyze the factors affecting villagers’ willingness to build green rural residential houses using Jiangsu Province as an example and suggested corresponding suggestions to improve farmers’ willingness to build (Wu & Jiang, 2015). Green rural residential housing with completed renovation is also a product for rural residents in a broad sense. Many scholars have conducted studies on the
satisfaction of rural residents with various categories of construction projects. Based on a survey of 1000 samples in five provinces across China, Tan and Zhang (2015) used the ordered probit model to investigate rural residents’ satisfaction with housing and the factors influencing it. The results showed that housing quality had a significant positive effect on satisfaction. Some scholars have studied the factors influencing rural residents’ satisfaction with the construction of a rural ecological civilization and concentrated living using factor analysis and logistic regression models. The findings indicate that in the construction of rural ecological civilization, the rural ecological culture, environment, economy and infrastructure have a greater impact on the satisfaction of farmers (Shen & Zhang, 2014). Shi (2015) and Xie and Wang (2011) used logistic models to analyze the factors affecting residents’ willingness for low-carbon consumption and their CO₂ emission behaviors.

The above studies have examined green rural residential buildings from different perspectives. However, the studies described above did not evaluate the projects from the standpoint of the project’s target audience, rural dwellers. If such projects are assessed exclusively from the government’s perspective, they appear to play a positive role in the country’s overall sustainable development. Nevertheless, it is not feasible to force energy efficiency projects in the region and make farmers pay for them because the region’s farmers have low incomes. Therefore, this study argues that it is necessary to evaluate such projects from the perspective of rural residents. It is crucial to obtain farmers’ approval to implement such projects to promote energy savings and emission reduction, the rural revitalization strategy, and the sustainable development of the human living environment. Therefore, this study combines the evaluation models and research methods established by previous scholars, uses a binary logistic model to screen out the evaluation indicators that have a significant impact on farmers’ willingness to participate, uses AHP (analytic hierarchy process) to determine the weights among these indicators, and finally uses TOPSIS (technique for order preference by similarity to an ideal solution) to evaluate the renovation program to assess the project from the perspective of farmers as objectively and honestly as possible. This study will provide a basis for the local government’s decision to implement green farmhouse renovation in future.

The paper is organized and presented in the following structure. Section 2 introduces the three methods of logistic-AHP-TOPSIS that constitute the evaluation model. Section 3 initially determines the evaluation indices through a literature review and questionnaire survey and establishes the TOPSIS evaluation model from the farmers’ perspective after calculations according to both the logistic and AHP methods. Section 4 applies this model to evaluate a case in Gansu Province, China. Based on the results in Sect. 4, further discussion of the findings is presented in Sect. 5. Finally, Sect. 6 draws overall conclusions.

## 2 Methods

### 2.1 Logistic regression model

Most of the existing evaluation models from the perspective of audience groups use models such as the ACSI (American Customer Satisfaction Index) (Chen et al., 2018; Chen et al., 2019b) and SERVQUAL (Service Quality) (Carrasco et al., 2017; Shafiq et al., 2017). However, this study argues that the energy efficiency retrofitting of existing farmhouse envelopes is not a commodity or service product, and the evaluation indices of the above two models do not apply to such self-built energy-saving retrofit projects. A logistic
regression model used by other scholars can provide a more objective way to find evaluation indicators or constraints from the farmers’ perspective (Zhang et al., 2020). Therefore, a logistic model was also chosen to objectively identify the evaluation indicators that significantly impact farmers’ willingness to participate in retrofitting from their perspective.

In this study, the dependent variable, farmers’ willingness to participate in energy-efficient housing retrofitting, can be divided into two types. It is a typical binary decision-making problem. Moreover, the explanatory variables in this study consist of both numerical and subtype variables. Binary logistic models can be effective in analyzing issues in such categories (Zhang et al., 2020). In this study, the logistic regression model is used to investigate the factors impacting the dependent variable, the willingness of rural residents to participate in energy-saving renovation, such that \( y = 1 \) indicates willingness and \( y = 0 \) indicates unwillingness. The model-specific formulas are as follows:

\[
P_i = F(y) = F\left(\beta_0 + \sum_{i=1}^{n} \beta_i x_i\right) = \frac{1}{1 + \exp\left(-\left(\beta_0 + \sum_{i=1}^{n} \beta_i x_i\right)\right)}. \tag{1}
\]

\( P_i \) signifies the possibility that farmers will improve their home energy efficiency. The dependent variable, \( y \), indicates whether farmers are participating. The regression coefficient of the influencing factor is denoted by \( \beta_i \). \( n \) represents the number of influencing factors; \( x_i \) is the independent variable, indicating the \( i \)-th influencing factor; \( \beta_0 \) denotes the constant of the regression equation. Appropriate deformation of Formula (1) results in:

\[
\ln\left(\frac{P_i}{1 - P_i}\right) = y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i. \tag{2}
\]

(Li et al., 2014).

### 2.2 Analytic hierarchy process (AHP)

At present, there are many methods to determine the index weights, such as AHP (Zhang et al., 2018) and the superiority chart (Xia et al., 2017) method of subjective assignment into categories. The entropy weight method (Huang et al., 2020) uses information entropy values to calculate weights, factor analysis, and principal component analysis (Pbpa et al., 2020; Tao et al., 2020) using information concentration. The analytic hierarchy process (AHP) has the advantages of providing easy-to-understand interview questions and being easy to calculate, and the interviewees in this study are primarily farmers with low education levels. Therefore, AHP is more suitable for this study.

The analytic hierarchy process (AHP) is a hierarchical, weighted decision analysis method proposed by T.L. Saaty, an American operations researcher and professor at the University of Pittsburgh, in the early 1970s. It is mainly used to solve evaluation problems by establishing a judgment matrix of two-by-two comparisons between factors. After the consistency test of the matrix, the single hierarchical ranking (weights) and total ranking are calculated using a fuzzy quantitative method for qualitative indicators as a systematic method for objective (multi-indicator) and multiprogram optimization decision-making. This study uses this method to determine the weights between factors that significantly influence the dependent variable.
The judgment matrix was derived by comparing factors with a significant influence on each other using a scale of 1–9 (Table 1).

The above scaling method constructs the judgment matrix and defines the judgment matrix as $D(3)$.

$$D = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix} = \begin{bmatrix} \frac{x_1}{X_{11}} & \frac{x_1}{X_{21}} & \cdots & \frac{x_1}{X_{1n}} \\ \frac{x_2}{X_{21}} & \frac{x_2}{X_{22}} & \cdots & \frac{x_2}{X_{2n}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{x_n}{X_{m1}} & \frac{x_n}{X_{m2}} & \cdots & \frac{x_n}{X_{mn}} \end{bmatrix}. \quad (3)$$

The elements of the judgment matrix $D(3)$ are multiplied by rows to create a product of each row’s components, $M_p$, as:

$$M_i = \prod_{j=1}^{n} W_{ij} \cdot W_i = \frac{W_i}{\sum_{j=1}^{n} W_j}. \quad (4)$$

The maximum characteristic root of the judgment matrix is

$$\lambda_{\text{max}} = \sum_{i=1}^{n} \frac{(DW)_i}{nW_i}. \quad (5)$$

where $i = 1, 2, \ldots, n$ (Ocampo et al., 2019).

The analyst builds the judgment matrix based on personal knowledge and experience.

Errors are inevitable. In this study, a consistency test is conducted to make the judgment better match the actual situation. The consistency test formula of the judgment matrix is $C_R = C_I/R_I$, where $C_I$ is the consistency test index; $C_I = (\lambda_{\text{max}} - n)/(n - 1)$; $n$ is the order of the judgment matrix; and $R_I$ is the average random consistency index when $C_R < 0.1$. The consistency of $D$ is generally considered to be acceptable (Table 2).
2.3 The TOPSIS model

Commonly used comprehensive evaluation methods include the TOPSIS method (Wang et al., 2021), gray correlation method (Bai & Liu, 2016), fuzzy comprehensive evaluation (FCE) method (Liang et al., 2006), and RSR method (Wang et al., 2015). Among them, the TOPSIS method applies to the fields of efficiency evaluation and project decision-making. The gray correlation method is suitable for objects with few indicators and needs to determine the optimal sequence. The RSR method is widely used in the health care industry. The FCE method is mainly used for indicators that have unclear boundaries and are not easy to quantify. In this study, the TOPSIS method was selected to evaluate retrofit project options.

The TOPSIS model, or the Technique for Order Preference by Similarity to an Ideal Solution, is a shared decision-making technique for multiobjective decision analysis of finite solutions in systems engineering. It is a distance-integrated evaluation method that can objectively and comprehensively reflect the dynamic changes in a project by defining a measure in the target space. In this way, the performance level of a rural residential energy renovation project can be evaluated by measuring the extent to which the target is close to the positive ideal solution and far from the negative ideal solution (Chen et al., 2020). A set \( A = \{ \) is composed of \( m \) solutions, and the judging indicators \( X_1, X_2, \ldots, X_n \) of each solution form the indicator set \( X = (X_1, X_2, \ldots, X_n) \). The corresponding judging indicators are denoted as \( X_{ij} (i = 1, 2, \ldots, m; j = 1, 2, \ldots, n) \), and \( X_{ij} \) indicates the \( j \)th judging indicator of the \( i \)th solution. \( X_{ij} \) represents the \( j \)th judgment indicator in program \( i \). Then, the initial evaluation matrix is established as

\[
A = (X_{ij})_{m \times n} = \begin{bmatrix}
X_{11} & X_{12} & \cdots & X_{1n} \\
X_{21} & X_{22} & \cdots & X_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
X_{m1} & X_{m2} & \cdots & X_{mn}
\end{bmatrix}.
\]  

(6)

In this study, to eliminate the resulting noncomparability of the indicators, the judged indicators are dimensionless. The elements of the standardized decision matrix \( B = (b_{ij})_{m \times n} \) are calculated as follows.

For positive indicators,

\[
b_{ij} = \frac{X_{ij} - \text{min}_j (X_{ij})}{\text{max}_j (X_{ij}) - \text{min}_j (X_{ij})}.
\]

(7)

For inverse indicators,

\[
b_{ij} = \frac{\text{max}_j (X_{ij}) - X_{ij}}{\text{max}_j (X_{ij}) - \text{min}_j (X_{ij})}.
\]

(8)

The weighted normalized decision matrix \( C \) is obtained by multiplying each column of matrix \( B \) with the weight \( w_n \) of each indicator determined by hierarchical analysis, expressed as follows.
The ideal solution for the calculation of the closeness of the judged object is

\[
C^+ = \left\{ \left( \max_i c_{ij} / j \in J_1 \right), \left( \min_i c_{ij} / j \in J_2 \right) \right\},
\]

\[
C^- = \left\{ \left( \min_i c_{ij} / j \in J_1 \right), \left( \max_i c_{ij} / j \in J_2 \right) \right\},
\]

where \(C^+\) and \(C^-\) are positive and negative ideal solutions, respectively, and \(J_1\) and \(J_2\) are benefit-based and cost-based indicator sets, respectively.

The distance of the judged object from the ideal solution is

\[
d_i^+ = \sqrt{\sum_{j=1}^{n} \left( c_{ij} - c_j^+ \right)^2},
\]

\[
d_i^- = \sqrt{\sum_{j=1}^{n} \left( c_{ij} - c_j^- \right)^2}.
\]

The closeness of the judged object to the positive ideal solution is as follows:

\[
E_i^+ = d_i^- / d_i^+ + d_i^-, \quad 0 \leq E_i^+ \leq 1.
\]

The closeness \(E_i^+\) reflects the degree of the judging object near the positive ideal solution and far from the negative ideal solution. When the judging thing is a positive ideal solution, \(E_i^+ = 1\), and when the judging object is a negative ideal solution, \(E_i^+ = 0\). Nevertheless, generally, the closeness of the judging object is between 0 and 1, so only the correspondence of the judging thing near the positive ideal solution is considered, and the judging object can be selected and evaluated in descending order of the closeness value. The descending order can make the selection and evaluation of the evaluation objects of the closeness values. The vector \(\mathbf{F}\) of the combined evaluation results of the evaluation objects is

\[
\mathbf{F} = \mathbf{W} \times \mathbf{E}.
\]

\(\mathbf{E}\) is the evaluation matrix consisting of the closeness of each evaluation object to the positive ideal solution; \(\mathbf{W}\) is the weight of each mining method calculated by the AHP method.

The logistic, analytic hierarchy process (AHP), and TOPSIS models were integrated into this study to evaluate rural residential energy retrofit projects, and the specific methodological steps are shown in Fig. 1.
3 Establishing the logistic-AHP-TOPSIS evaluation model

3.1 Survey and sample

The government of Gansu Province published the population statistics of Gansu Province in 2019. The central region of Gansu (Fig. 2) is the main population gathering area in Gansu Province. Thus, this study focuses on this region. This study used the data from a questionnaire survey of 213 rural households in six cities including Lanzhou, Dingxi, Pingliang, Tianshui, Baiyin, and Linxia Autonomous Prefecture in the central region of Gansu Province from December 6, 2020 to February 21, 2021.

The climate in central Gansu Province is generally arid, with an average annual precipitation of about 327 mm; the highest average temperature month is July (15 °C) and the coldest month is January (−12 °C). The total annual solar radiation is ample, more than 6000 MJ/m² (Li & He, 2010). The region’s total population is approximately 14,137,100 people, of whom approximately 7,210,100, or 51%, are rural, with a per capita GDP of $4,208.07, ranking the lowest in China. The per capita housing area in villages is 30.16 m². The consumption of various types of energy in rural areas of the province totaled 762 × 10⁴ tec, with heating consumption accounted for 18.9 percent of the overall consumption (Juan et al., 2018).

Since the outbreak of COVID-19, the Chinese government has attached a great importance to the prevention of the epidemic, and due to the epidemic prevention and control requirements to prevent unnecessary movement of people in rural areas during the Chinese New Year in 2021, the local government has requested that residents who do not belong to the village should not enter the village if they not have to. Residents who work outside the village must voluntarily complete a 7-day home quarantine upon
return to the village. Also, because of the epidemic prevention and control requirements, the questionnaire was conducted by members of a group living in rural areas during the winter holidays. They answered the questionnaires and then uploaded the responses to the online platform for centralized statistics. A total of 217 questionnaires were distributed in this study, 208 were valid responses, with a pass rate of 95.8%. The specific source regions are shown in Table 3, corresponding to the composition of the population in the area.

### 3.2 Preliminary selection of evaluation indices

This study was found in the relevant national standards, documents from the Ministry of Housing and Urban–Rural Development of China, surveys, and previous studies.

The object of the retrofitting project is the farmhouse, and the long construction duration will have a particular impact on the life of the farmers, and the farmers do not accept the more extended construction volume and duration. In the “Assessment standard for the green retrofitting of existing buildings GBT51141-2015” and “Energy Conservation

| Sample source region                 | Sample number | Percentage (%) |
|--------------------------------------|---------------|----------------|
| Lanzhou                              | 56            | 26.9           |
| Dingxi                               | 37            | 17.8           |
| Pingliang                            | 15            | 7.2            |
| Tianshui                             | 44            | 21.1           |
| Baiyin                               | 27            | 13.0           |
| Linxia autonomous prefecture         | 29            | 14.0           |
Design Standard for Rural Residential Buildings GBT50824-2013”, there are also corresponding regulations on the number of renovation works.

Some farmers are very concerned about whether the renovation project will reduce the building area of the original building, and if the renovation project reduces the building area, it is often considered unworthy. There are specific considerations for changing building area farmhouses in the Evaluation Standard for Green Buildings GBT50378-2019, GBT50824-2013, and GBT51141-2015.

The reduction of the heat transfer coefficient of the envelope structure is the primary goal of the renovation project (GBT50824-2013; GBT51141-2015), which reduces the waste of energy through the renovation of the envelope structure. Thus, it’s achieves the purpose of energy saving. It is also one of the indicators included in various relevant evaluations.

In the evaluation studies on green buildings and green farmhouses, the amount of green building materials used in buildings, as a crucial indicator in the whole life cycle evaluation (GBT51141-2015; GBT50378-2019; Chen, 2015), has been mentioned and selected many times.

Green building or green construction methods are implemented in the refurbishment construction and are emphasized heavily in national standards such as the GBT51141-2015 and the GBT50378-2019, as an essential indication in the evaluation.

Since rural houses are primarily built in the form of self-build and mutual self-build, the project lacks design, and the quality is difficult to guarantee (Chen, 2015; Gong, 2014). In all the guidelines or documents issued by the central or local government about rural construction, employing a professionally qualified construction team is a critical evaluation criterion in rural construction to ensure the safety of farmers’ lives and properties and the quality of construction works.

There are strict regulations on the guarantee period of engineering quality in the national guiding standards such as GBT51141-2015 and GBT50378-2019, but there are no laws and regulations on the engineering quality of rural houses. It is related to farmers’ satisfaction in the use phase, and a shorter guarantee period will lead to an increase in maintenance costs, so some scholars (Chen et al., 2018) and farmers have developed a vital concern about the guarantee period engineering quality.

The economic performance of this type of project is an indicator that has been given more importance in various related studies (Chen et al., 2018; Copiello et al., 2017; Jeong & Ramírez-Gómez, 2018; Ruparathna et al., 2017). During the interviews and researches, farmers also showed great concern about the economic performance of the retrofit projects.

Energy efficiency retrofitting aims to reduce energy waste, improve energy use efficiency, and achieve the least energy required for the same room temperature conditions. Greenhouse gas emissions are a crucial indicator in evaluating green buildings, and the reduction of greenhouse gas emissions is one of the primary purposes of retrofitting. The noise evaluation is also one of the indicators paid attention to the national norms such as “GBT51141-2015” and “GBT50378-2019”. The improvement of the indoor environment is also the focus of many national norms and scholars on the evaluation of energy-saving renovation of rural buildings, which includes indoor air quality, temperature, relative air humidity.

In several studies by scholars on farmers’ subjectivity, the results show (Tan & Zhang, 2015) that government actions significantly impact farmers’ acceptance to a large extent. It includes support for economic, technical, and policy aspects.

In summary, this study selected evaluation indices for the energy efficiency retrofitting of existing rural residential buildings based on Principles of applicability, systemic
principle, and farmer subjectivity. These include the design and architecture evaluation index, construction management index, economic evaluation index, environmental performance index, and government service index, among 20 evaluation indices in 5 main dimensions, as shown in Table 4.

### 3.3 Final selection and determination of evaluation indicators

#### 3.3.1 Establishing the logistic regression model

Based on the work described above, this study developed a logistic regression model in which ‘willingness to participate in energy-saving renovation’ was used as the dependent variable. Twenty evaluation indicators were used as explanatory variables, as shown in Table 5. The purpose is to identify the indices that significantly affect farmers’ willingness from 20 indicators based on the farmers’ perspective.

#### 3.3.2 Results of logistic regression model

This study used IBM SPSS 26 software to conduct a binary logistic regression analysis of the data collected by the group members through the online terminal, and the results are shown in Table 6. The Hosmer and Lemeshow testing of the model is significant at 0.632, which is greater than 0.05, indicating that the binary logistic regression results for the subsequent analysis can truly and reliably reflect the relationship between the original variables.

In Table 6, \( B \) denotes the bias regression coefficient, which indicates the bias regression coefficient of each independent variable in the regression equation, a negative value indicates that the independent variable has a significant negative effect on the dependent variable. \( SE \) is the standard error, which indicates the mean error of the estimate. \( Wals \) is used to test whether the independent variable has an effect on the dependent variable, and the larger the \( Wals \), or the smaller the sig corresponding to the \( Wals \), the more significant the effect of the independent variable on the dependent variable. \( df \) is the degree of freedom, which is not interpreted in this study. \( Sig \) is the significance level whose less than 0.05 indicates that the independent variable has a significant effect on the dependent variable, and \( Exp(B) \) is the inverse natural logarithm of \( B \) (Zhang et al., 2020). Based on the analysis of Table 6, this study selected variables with sig values less than 0.05 as significantly impacting on farmers’ willingness to participate in energy-saving retrofits. The specific results are as follows.

(1) Design and building evaluation index: the number and duration of projects had a significant adverse effect on “willingness.” Specifically, the more projects there were, the less willing farmers were to participate in energy efficiency retrofits. Thermal performance improvement of the building envelope had a significant positive effect on willingness to participate. Thermal performance improvement of the envelope is one of the primary purposes of the project. The better the progress of the envelope’s thermal performance after the retrofit, the more worthwhile the investment is considered by farmers, and the willingness to participate in the retrofit program is bound to increase accordingly. The longer the quality assurance period is, the more likely farmers will join in the energy-efficient renovation project. Since most rural houses are self-built
Table 4  Preliminary selection of evaluation indices

| Evaluation indicators                              | Factors                                                   | Code                  | Source                                                      |
|---------------------------------------------------|-----------------------------------------------------------|-----------------------|------------------------------------------------------------|
| Design and architecture evaluation index          | Quantity and duration of work                             | $X_{11}$             | GBT51141-2015, GBT50824-2013                               |
|                                                   | Change in building area                                   | $X_{12}$             | GBT51141-2015, GBT50378-2019, GBT50824-2013               |
|                                                   | Duration of project quality assurance                     | $X_{13}$             | GBT51141-2015, GBT50378-2019, Chen et al. (2018)         |
|                                                   | Thermal performance improvement of the building envelope  | $X_{14}$             | GBT51141-2015, GBT50378-2019                             |
|                                                   | Utilization Rate of Green Materials                      | $X_{15}$             | GBT51141-2015, GBT50378-2019, Chen (2015)                |
|                                                   | Effective dust and noise reduction measures               | $X_{21}$             | Chen (2015), Gong (2014), GBT51141-2015                  |
| Construction management index                     | Employment of professionally qualified construction teams| $X_{32}$             | Chen (2015), Gong (2014), GBT51141-2015                  |
|                                                   | Total investment                                          | $X_{31}$             | Ruparathna et al. (2017), Chen et al. (2018)             |
| Economic evaluation index                         | Annual winter heating costs                              | $X_{32}$             | Copiello et al. (2017), Jeong and Ramírez-Gómez (2018)   |
|                                                   | Maintenance cost                                          | $X_{33}$             | Copiello et al. (2017), Ruparathna et al. (2017)         |
|                                                   | Investment payback period                                 | $X_{34}$             | Copiello et al. (2017), Ruparathna et al. (2017)         |
|                                                   | Energy efficiency improvement                             | $X_{41}$             | GBT50378-2019, Copiello et al. (2017)                     |
| Environmental Performance index                   | Noise pollution                                           | $X_{42}$             | GBT50378-2019, Copiello et al. (2017)                     |
|                                                   | Greenhouse gas emissions                                  | $X_{43}$             | GBT50378-2019, Copiello et al. (2017)                     |
|                                                   | Indoor ventilation improvement                            | $X_{44}$             | GBT33658-2017, GBT50378-2019                             |
|                                                   | Local characteristics and appearance change              | $X_{45}$             | GBT50824-2013, GBT50378-2019                             |
|                                                   | Surrounding environment improvement                      | $X_{51}$             | Chen et al. (2018), Tan and Zhang (2015)                 |
|                                                   | Financial assistance from the government                 | $X_{52}$             | Chen et al. (2018), Tan and Zhang (2015)                 |
| Government Service index                          | Technical assistance from the government                 | $X_{53}$             | Chen (2015), Gong (2014), Zhang (2012)                    |
|                                                   | Efficiency of the approval service                       | $X_{54}$             | Chen et al. (2018), Tan and Zhang (2015)                 |
Table 5  Variable Description and Descriptive Statistics

| Variable Category                     | Name                                               | Code | Variable Definition               | Mean  | Variance | SD  |
|---------------------------------------|----------------------------------------------------|------|-----------------------------------|-------|----------|-----|
| Dependent variable                    | Willingness to participate in energy-saving renovation | Y    | 0 = Unwillingness 1 = Willingness | 0.49  | 0.251    | 0.501 |
| Explanatory variables                 | Design and architecture evaluative index           |       |                                   |       |          |     |
| Quantity and duration of work         | $X_{11}$                                           | 1    | Strongly disagree                 | 3.36  | 1.622    | 1.273 |
| Change in building area               | $X_{12}$                                           | 2    | Disagree                          | 3.49  | 1.198    | 1.094 |
| Duration of project quality assurance| $X_{13}$                                           | 3    | Generally agree                   | 2.73  | 1.849    | 1.722 |
| Thermal performance improvement of the building envelope | $X_{14}$ | 4 | Agree                           | 3.44  | 1.475    | 1.214 |
| Utilization Rate of Green Materials   | $X_{15}$                                           | 5    | Strongly agree                    | 3.35  | 1.238    | 1.533 |
| Construction management index         | Effective dust and noise reduction measures         | $X_{21}$ |                                    | 3.42  | 1.501    | 1.225 |
| Employment of professionally qualified construction teams | $X_{22}$ |                                    | 3.37  | 1.395    | 1.181 |
| Economic evaluation index             | Total Investment                                    | $X_{31}$ |                                    | 3.46  | 1.340    | 1.158 |
|                                      | Annual winter heating costs                         | $X_{32}$ |                                    | 3.37  | 1.181    | 0.812 |
|                                      | Maintenance cost                                    | $X_{33}$ |                                    | 3.49  | 1.198    | 1.129 |
| Environmental performance index       | Investment payback period                           | $X_{34}$ |                                    | 3.21  | 1.221    | 1.094 |
|                                      | Energy efficiency improvement                       | $X_{41}$ |                                    | 3.30  | 1.420    | 1.192 |
|                                      | Noise pollution                                     | $X_{42}$ |                                    | 3.35  | 1.158    | 1.340 |
|                                      | Greenhouse gas emissions                            | $X_{43}$ |                                    | 3.49  | 1.257    | 1.129 |
|                                      | Indoor ventilation improvement                      | $X_{44}$ |                                    | 3.06  | 0.817    | 0.688 |
|                                      | Local characteristics and appearance change         | $X_{45}$ |                                    | 3.08  | 1.017    | 1.035 |
| Government service index              | Surrounding environment improvement                 | $X_{51}$ |                                    | 3.13  | 1.221    | 1.108 |
|                                      | Financial assistance from the government            | $X_{52}$ |                                    | 2.94  | 1.771    | 1.221 |
|                                      | Technical assistance from the government            | $X_{53}$ |                                    | 3.38  | 1.589    | 1.621 |
|                                      | Efficiency of the approval service                  | $X_{54}$ |                                    | 2.74  | 1.373    | 1.108 |
without corresponding laws as a guarantee, the project quality assurance period of the retrofitting contractor has a significant effect on farmers’ willingness.

(2) Economic evaluation index: total investment had a significant negative impact on willingness. The annual winter heating costs also had a significant adverse effect on willingness to participate; the higher the cost of winter heating after retrofitting, the lower the probability of investment. The investment payback period had a significant negative impact on the willingness to participate. The shorter the payback time of the investment in retrofitting through energy savings is, the higher the probability that farmers will be willing to retrofit. The region is clearly an economically underdeveloped area. The village’s per capita annual disposable income is approximately 10,000 RMB, and an excessive investment, heating cost, and long payback period are not acceptable to the farmers.

(3) Environmental performance index: energy efficiency improvement has a significant positive impact on willingness. Specifically, the better the improvement in energy efficiency due to the renovation project, the greater the probability of farmers’ willing-

Table 6 Results of the regression model

| Code   | B       | SE     | Wals   | df | Sig   | Exp (B) |
|--------|---------|--------|--------|----|-------|---------|
| Design and Architecture evaluation index   |
| Quantity and duration of work             | $X_{11}$ | -3.613 | 1.671  | 4.675 | 1 0.031 | 0.027   |
| Change in building area                   | $X_{12}$ | -2.447 | 1.451  | 2.844 | 1 0.150 | 0.087   |
| Duration of project quality assurance     | $X_{13}$ | 5.817  | 2.238  | 6.756 | 1 0.009 | 335.96  |
| Thermal performance improvement of the building envelope | $X_{14}$ | 4.604  | 2.120  | 4.716 | 1 0.030 | 99.883  |
| Utilization rate of green materials       | $X_{15}$ | -2.431 | 2.237  | 1.181 | 1 0.391 | 0.088   |
| Construction management index             |
| Effective dust and noise reduction measures | $X_{21}$ | 1.463  | 2.045  | 0.512 | 1 0.462 | 4.319   |
| Employment of professionally qualified construction teams | $X_{22}$ | 1.005  | 1.431  | 0.493 | 1 0.483 | 2.732   |
| Economic evaluation index                 |
| Total investment                          | $X_{31}$ | -7.535 | 3.043  | 6.131 | 1 0.013 | 0.001   |
| Annual winter heating costs               | $X_{32}$ | -4.235 | 1.862  | 5.173 | 1 0.023 | 0.014   |
| Maintenance cost                          | $X_{33}$ | -1.047 | 1.548  | 0.457 | 1 0.499 | 0.351   |
| Investment payback period                 | $X_{34}$ | -3.848 | 1.725  | 4.976 | 1 0.026 | 0.021   |
| Environmental performance index           |
| Energy efficiency improvement             | $X_{41}$ | 2.414  | 1.766  | 1.869 | 1 0.017 | 11.179  |
| Noise pollution                           | $X_{42}$ | -1.077 | 1.414  | 0.580 | 1 0.957 | 0.341   |
| Greenhouse gas emissions                  | $X_{43}$ | -0.753 | 1.182  | 0.406 | 1 0.052 | 0.471   |
| Indoor ventilation improvement            | $X_{44}$ | 2.026  | 1.309  | 2.396 | 1 0.122 | 7.581   |
| Local characteristics and appearance change | $X_{45}$ | -2.526 | 1.716  | 2.167 | 1 0.141 | 0.080   |
| Surrounding environment improvement       | $X_{46}$ | 3.812  | 1.774  | 4.617 | 1 0.139 | 45.241  |
| Government service index                  |
| Financial assistance from the government  | $X_{51}$ | 4.232  | 1.671  | 6.414 | 1 0.011 | 68.855  |
| Technical assistance from the government  | $X_{52}$ | 2.363  | 1.461  | 2.616 | 1 0.512 | 10.623  |
| Efficiency of approval service            | $X_{53}$ | 3.842  | 1.579  | 5.920 | 1 0.437 | 46.619  |
| Constants                                |         | 5.969  | 3.479  | 2.944 | 1 0.086 | 391.02  |
ness to participate in envelope renovation. The progress of energy efficiency and the reduction in energy consumption are the primary goals of the retrofit project; therefore, the improvement in energy efficiency saves heating fuel and can motivate farmers to participate in retrofitting.

(4) Government service index: there is a significant positive impact on farmers’ willingness to participate in energy efficiency retrofitting; the greater the degree of financial assistance given by the government in the retrofit project is, the greater the farmers’ probability of participation. The willingness of farmers in the region to actively participate in energy-saving renovation projects is not high according to the survey. A certain amount of financial assistance from the government can reduce the proportion of funds farmer households must commit and increase their willingness to participate (Table 7).

### 3.4 Establishing an AHP model to determine the weight of indices

The team members who interviewed the farmers obtained the judgment matrix $D$. The statistical information of the interviewees, shown in Table 8, is roughly similar to the
demographic structure of the villages in the region. This study posits that these inter-
view results can reflect the willingness of the farmers in the area in a more objective
way.

Based on Table 2, the consistency index CI = 0.1391, and the consistency ratio
CR = 0.0987. Because CR < 0.10, the consistency of judgment matrix D is acceptable.
According to Formulas (7)–(10), the following results were obtained by using MAT-
LAB software to code a matrix arithmetic program (Table 9):

$$D = \begin{bmatrix}
X_{11} & 1 & 5 & 1/3 & 1/5 & 1/3 & 1/2 & 1/3 & 1/2 \\
X_{13} & 1/5 & 1 & 1/5 & 1/8 & 1/4 & 1/5 & 1/5 & 1/3 \\
X_{14} & 3 & 5 & 1 & 1/4 & 1/3 & 1/3 & 1/2 & 1/2 \\
X_{31} & 5 & 8 & 4 & 1 & 4 & 3 & 5 & 4 \\
X_{32} & 3 & 4 & 3 & 1/4 & 1 & 3 & 2 & 2 \\
X_{34} & 2 & 5 & 3 & 1/3 & 1/2 & 1 & 1/4 & 2 \\
X_{41} & 3 & 5 & 2 & 1/5 & 1/3 & 4 & 1 & 5 \\
X_{51} & 2 & 3 & 2 & 1/4 & 1/2 & 1/2 & 1/5 & 1 \\
\end{bmatrix}.$$  

### 3.5 Establishment of the TOPSIS evaluation model

The traditional TOPSIS method can only deal with quantitative values of evaluation
indicators (Kumar et al., 2017), and some of the factors derived above that significantly
affect the willingness of rural residents to participate in the energy efficiency retrofitting
of existing houses were not quantitative. Therefore, in this study, the rules for assigning
the value of each indicator were redefined, as shown in Table 10.

| Factors | Arithmetic mean | Geometric mean | Eigenvalue method | Ultimate weighting |
|---------|----------------|----------------|-------------------|-------------------|
| $X_{11}$ | 0.0553         | 0.0526         | 0.0511            | 0.05              |
| $X_{13}$ | 0.024          | 0.0239         | 0.0234            | 0.02              |
| $X_{14}$ | 0.0767         | 0.0711         | 0.0709            | 0.07              |
| $X_{31}$ | 0.3378         | 0.3531         | 0.3513            | 0.35              |
| $X_{32}$ | 0.3594         | 0.1694         | 0.1661            | 0.16              |
| $X_{34}$ | 0.1087         | 0.1058         | 0.1023            | 0.11              |
| $X_{41}$ | 0.1622         | 0.1497         | 0.1635            | 0.16              |
| $X_{52}$ | 0.0759         | 0.0744         | 0.0714            | 0.08              |
4 Case study

Rural houses are buildings located in rural areas for farming households, agricultural production and other activities (Figs. 3, 4, 5 and 6). With the improvement in the quality of living and the development of urban–rural integration, the style of farmers’ self-built houses is increasingly inclined to modernism.

4.1 Project profile

The existing rural residence is located in Yongdeng County, Lanzhou City, Gansu Province, with a residential base area of 200 m², a land area of 112.7 m², a building area of 221.8 m², a usable area of 185.2 m², a functional area coefficient of 0.835, a building density of 56.4%, and a floor area ratio of 1.1. The permanent population is four people. Compared with urban buildings, rural houses are generally built on collective house bases, and the construction form is mainly scattered single buildings, which are mainly self-financed.
Fig. 4  The ground floor plan of exciting building

Fig. 5  The second-floor plan of exciting building
and self-built, with characteristics such as lack of design planning, poor seismic resistance and low energy-saving performance.

The region is a nonmajor crop-producing area, and farm households have a low reliance on farm income. With the relaxation of the urban settlement policy in the area, young laborers tend to move to cities for work at an accelerated pace. Only the elderly or preschool children remain in the countryside (Ma et al., 2019).

According to the GBT50824-2013 Energy Conservation Design Standard for Rural Residential Buildings, JGJ 26-2018

Fig. 6 The section view of exciting building

Fig. 7 Option 1 simulation model

Fig. 8 Option 2 simulation model
Assessment Standard for the Green Retrofitting of Existing Buildings, the Technical Specification for Interior Thermal Insulation of External Walls JGJT 261-2011 and the Research by scholars (Guo et al., 2020) and guidance documents from the Ministry of Housing and Construction of China, two transformation plans are proposed for the building envelope (Figs. 7 and 8). One is to renovate the whole building envelope, install an external insulation layer on all the original external walls, replace the doors and windows with energy-saving models, and perform insulation treatment on the roof and ground floor. The second alternative is to remodel the structure based on the household’s specific needs, habits, and winter resident population (Chen et al., 2019a; Liu et al., 2018; Ma et al., 2019). A winter heating sunroom can be built on the balcony outside the second-floor bedroom, internal insulation can be set in the external wall of the second-floor bedroom, roof insulation measures can be taken, and doors and windows can be replaced with insulated models; when all these measures are taken, the ground floor does not require insulation treatment (Fig. 9).

The specific construction methods are shown in Table 11. Prices for the envelope were averaged from quotes from five local suppliers. The contractor for the retrofit project guaranteed the quality of work and materials for the envelopes for Option 1 and Option 2 for an average of five years, according to the “Civil Building Energy Efficiency Regulations.”

eQUEST 3.65 software was used to simulate the energy consumption of the original building and the two retrofit options (Ma et al., 2017). The design temperature was 26 °C indoors in summer and 18 °C indoors in winter. The heating load and energy consumption costs for each retrofit option and the original residence are shown in Table 12. Because coal is the primary winter heating fuel in this region (Wang & Jiang, 2017), in this study, all energy sources are converted into standard coal equivalent (Li et al., 2016) to present a more realistic cost of winter heating in this case.

The local government gives a subsidy of 2000 RMB (277€) per household for self-built houses with energy efficiency measures. According to the year-by-year rate of return, the

![Option 2-second floor retrofitting diagram](image)
Table 11 Retrofit options structural practices

| Structure          | Structural practices/mm                                                                 | Heat transfer coefficient/ (W (m² K)^−1) | Retrofitting Cost/ (RMB m²) | Construction Area/ m² |
|--------------------|-----------------------------------------------------------------------------------------|------------------------------------------|------------------------------|-----------------------|
| Existing building  | Exterior Walls 20 white plaster mortar + 240 brick wall + 20 cement mortar + exterior finish (From inside to outside) | 1.312                                     |                             |                       |
|                    | Roofing 20 cement mortar + 80 furnace slag + 200 reinforced concrete (From top to bottom) | 1.607                                     |                             |                       |
|                    | Ground Floor tiles + 20 cement mortar + 40 gravel or pebbles (From top to bottom)        | 12.400                                    |                             |                       |
|                    | Exterior Windows Single pane windows                                                    | 5.700                                     |                             |                       |
|                    | Door Single-layer wooden doors                                                          | 5.930                                     |                             |                       |
| Option 1 (Retrofit)| Exterior Walls 20 white mortar + 240 brick wall + 20 cement mortar leveling + adhesive + 70 expanded polystyrene board + 5 anti-cracking mortar alkali-resistant glass fiber mesh cloth + exterior finish (From inside to outside) | 0.434                                     | 105.5 (14.6€)              | 228.0                 |
|                    | Roofing 20 cement mortar + protective layer + waterproof layer + 90 expanded polystyrene board + 20 cement mortar leveling + 80 slag + 200 steel reinforced concrete + plasterboard ceiling (From top to bottom) | 0.091                                     | 138.5 (19.2€)              | 127.2                 |
|                    | Ground Floor tile + 20 cement mortar + 5 anti-cracking slurry alkali-resistant glass fiber mesh + 40 extruded polystyrene board + 20 cement mortar leveling + 100 concrete bedding (From top to bottom) | 0.720                                     | 35.3 (4.9€)                | 127.2                 |
|                    | Exterior Windows Aluminum alloy ordinary hollow glass casement window (6 + 12 + 6)       | 2.900                                     | 289.8 (40.2€)              | 25.6                  |
|                    | Door Aluminum double-layered flush door                                                 | 3.120                                     | 215.6 (29.8€)              | 22.06                 |
| Option 2 (Retrofit)| Interior wall insulation 20 white mortar + 240 brick wall + 20 cement mortar + 50 expanded polystyrene board + 8 thick powder plaster, glass fiber mesh cloth reinforcement layer + finish layer (From inside to outside) | 0.943                                     | 125.7 (17.4€)              | 26.4                  |
|                    | Roofing Same as Option 1                                                                | 0.091                                     | 138.5 (19.2€)              | 127.2                 |
|                    | Ground Same as existing buildings                                                       | 12.400                                    |                             |                       |
|                    | Exterior Windows Same as Option 1                                                       | 2.900                                     | 256.5 (35.5€)              | 56.1                  |
|                    | Door Same as Option 1                                                                   | 3.120                                     | 215.6 (29.8€)              | 22.06                 |
rate of return is the total price of repaying the investment in energy efficiency measures. Since rural residents are accustomed to assessing the economic effects of projects by calculating a static payback period, a fixed payback period is used in this study. According to the formula

\[ T_Q = \frac{K_{pr}}{P_r}, \quad (14) \]

\( T_Q \) is the investment payback period/a; \( K_{pr} \) is the total investment amount/RMB; and \( P_r \) is the annual net income or average annual income, RMB/a. The payback period for the retrofit investment through winter heating fuel savings is 25.1 years for Option 1 and 20.8 years for Option 2.

### 4.2 Evaluation of the scheme

Based on Table 12 and Eq. (6) for the above two retrofit options, a preliminary evaluation matrix \( A \) is obtained.

\[
A = \begin{pmatrix}
0 & 0 & 115.12 & 0 & 4578.24 & 0 & 5.02 & 0 \\
530.0 & 5 & 43.92 & 58336.4 & 2252.64 & 25.1 & 2.47 & 2000 \\
300.0 & 5 & 55.16 & 40081.5 & 2653.92 & 20.8 & 2.91 & 2000
\end{pmatrix}
\]

The weighted normalization matrix \( C \) and the final ranking and scores of exciting building, Option 1 and Option 2 are derived from Eqs. (7–13).

\[
C = \begin{pmatrix}
0.9173 & 0 & 0 & 0.9544 & 0 & 0.9586 & 0 & 0 \\
0 & 0.7071 & 0.7649 & 0 & 0.7704 & 0 & 0.7704 & 0.7071 \\
0.3982 & 0.7071 & 0.6441 & 0.2986 & 0.6375 & 0.1689 & 0.6375 & 0.7071
\end{pmatrix}
\]

The final score of original building is 0.3747, and Option 1 is 0.2904, Option 2 is 0.3350, which shows that the original building is chosen as the preferred option for this building envelope energy-saving retrofit case. The results show that farmers prefer not to retrofit their existing houses; their second choice is Option 2, retrofitting according to actual needs; and Option 1 has the lowest evaluation.

Matrix \( C \) shows that the original building has the worst energy performance among the three options, but it has no additional economic investment, which is the type of indicator most relevant to farmers in the area, so it becomes the preferred option. Retrofit option
Evaluation of energy-saving retrofit projects of existing…

1 has the best energy performance, and it saves 50.1% of heating energy compared with the original building, but it has the worst economic performance and becomes the least good option for farmers. Although the energy-saving performance of retrofit option 2 is not the best among the three options, it can also save 42.1% of heating energy consumption compared with the original building. However, its economic index is better than Option 1, which can reduce 31.3% of investment and 17.1% of payback period, and farmers’ overall attitude it’s better than Option 1. If farmers must participate in the retrofitting program, Option 2 should be considered and promoted.

According to the above analysis, the retrofitting effect shows that the existing farmers’ envelope energy efficiency retrofitting program reduces heating energy consumption by reducing the heat transfer coefficient of the building envelope. The improvement of energy utilization efficiency of existing dwellings after retrofitting has a tremendously positive effect on improving the rural living environment, reducing greenhouse gas emissions, and improving residents’ living comfort and health. It also helps accelerate the achievement of the “peak carbon emission and carbon neutrality” target promised by the Chinese government.

5 Discussion

With the increasing demand for environmental protection and energy conservation, the energy-saving renovation of existing building envelopes has been carried out in many areas. In China, there are still many people living in the countryside, and scholars have shown that the energy consumption of rural buildings is much higher than that of urban buildings. Since farmers build their own houses, the envelope structure of farmhouses is constructed according to rural traditions and habits, and the heat transfer coefficient of exterior walls, roofs, and ground structures cannot meet energy-saving building design standards. The overall insulation performance of the envelope structure of houses is low, which leads to high heating energy consumption but low indoor temperature, resulting in a large amount of wasted energy. Therefore, energy-saving renovation of the building envelope is a critical way to achieve energy savings and emission reduction. However, the results obtained by using the existing national evaluation standards for the green renovation of existing buildings and green buildings do not well reflect farmers’ wishes. Therefore, the purpose of this study is to evaluate energy efficiency retrofit projects from the perspective of farmers, thereby providing a true reflection of their attitudes toward the retrofit projects.

Firstly, following the generalization of relevant studies and relevant national standards of China, combined with the interviews with farmers. Initially, 20 evaluation indicators of relevant existing farmhouse envelope energy-saving renovation projects were screened out, including five dimensions: Design and Architecture evaluation index, Construction Management index, Economic evaluation index, Environmental Performance index, and Government Service index. Next, questionnaires were designed using a Likert scale to describe the selected indicators. Logistics regression models were used to objectively analyze the indicators, from which the indicators that have a significant impact on farmers’ participation in energy efficiency retrofit projects were identified. Then a Topsis evaluation model was established based on the screened indicators to evaluate the original residential and the two retrofit options implemented by the government. After the final evaluation, this study found that keeping the original building and not participating in the retrofit was the...
preference of the farmers, followed by partial retrofit and finally total retrofit. This result can explain the slow implementation of energy-efficient retrofitting in this region.

The analysis of evaluation indicators through the logistic regression model can more objectively reflect the absolute preferences of farmers. As observed in other research, the influence of economic indicators on people’s investment in green environmental projects is significant (Chen, 2015; Sindhu et al., 2016; Zhao et al., 2019). However, the results show that most of the evaluation indicators selected in previous scholarly studies and national standards do not truly reflect farmers’ attitudes toward such projects, and this study objectively analyzes the indicators that have a significant impact on farmers’ willingness in the process of indicator selection, which to a certain extent reflects farmers’ actual attitudes.

From the results of the AHP model, farmers believe that economic indicators and the retrofitted energy-saving effect occupy a greater weight in the performance of the whole project. Farmers believe that economic indicators and energy efficiency after retrofitting represent a large share of the overall project performance. The top three factors were a total investment, annual winter heating costs, and energy efficiency improvement. This result was foreseen for the region as an economically underdeveloped area in China. Farmers are characterized by lower-income, so they emphasize economic indicators.

According to the simulation analysis of the current rural residential retrofit program of building envelope energy saving, the energy efficiency performance of the building can be greatly enhanced by retrofitting the envelope, with an improvement of approximately 51% for Option 1 and approximately 42% for Option 2.

The results of the TOPSIS model show that the scores of existing buildings, renovation option 1 and renovation option 2 are 0.33747, 0.2904 and 0.3350, respectively. The farmers were most satisfied with the original residential dwelling, followed by Option 2 for partial retrofitting, and in the final ranking was the option of retrofitting the entirety of the envelope. The main reason for this phenomenon is that energy efficiency retrofit projects have a higher investment with a longer payback period. From the perspective of farmers, who are already a low-income group, they are not willing to invest extra money to retrofit their homes for improving energy efficiency. However, the payback period of both options is approximately 20 years, which is longer than the results of previous studies (Guo et al., 2020; Zhang, 2012). This difference may be due to the large floor area of the existing building and the difference in building materials and heating fuel prices. Such a long payback period is often considered uneconomical by farmers. It is shown that if the local government does not increase subsidies, it will be difficult to promote the advancement of the current energy efficiency retrofit projects.

This study proposes that the bargaining form of national health insurance drug negotiation (Limwattananon & Waleekhachonloet, 2019) can be used to bargain for the material suppliers or constructors involved in the renovation project in response to the problem of significant total investment and long payback period for the renovation of this project. The basic idea behind this strategy is to leverage a bigger market in return for a specialized negotiating zone, lowering individual costs. However, at this stage, most of the construction projects for farmhouses are organized by farmers alone in the form of self-build, the workload of building material suppliers and construction teams is minimal, and the bargaining range is small so that the renovation costs cannot be compressed. As a result, local governments should encourage collectively owned village enterprises (Steiner & Teasdale, 2019) to establish special renovation funds and apply for special loans through existing village collectives and cooperative organizations; entrust professionals to renovate the farmhouses of willing farmers; and use “economies of scale” for batch design, batch construction, and batch procurement. It will not only fight for bargaining power for farmers, reduce
part of the burden of farmers, but also make it easy to determine the responsible body for the project’s future quality assurance and maintenance. In terms of heating energy costs, it is suggested that village units build small "self-generating" photovoltaic power plants (Kaya et al., 2019), with dedicated personnel responsible for operation and maintenance, which can help to promote the “coal to electricity” project in rural areas while also solving part of the area’s employment problem. It would not only assist in alleviating some of the area’s employment issues, but it will also aid in the promotion of the "coal to electricity" initiative in rural regions, lowering heating costs and greenhouse gas emissions in the winter. And the government should subsidizes the above organizations and activities.

This study has some limitations. For example, the evaluation indexes selected for this study were based on interviews with farmers, and the results of the case simulations are also based on the climatic conditions and the cost of construction materials in this region. Therefore, the study has solid geographical applicability and may produce different results in different regions or at different times. In this study, the energy efficiency of retrofitting existing residential envelopes was evaluated only from the farmers’ perspective. New energy-efficient heating devices studied by other scholars (Huide et al., 2017; Kaya et al., 2019) can be built upon in future studies and can also be included in the evaluation of retrofit programs.

6 Conclusion

The purpose of this study is to evaluate residential energy retrofit projects from farmers’ perspectives, to truly reflect farmers’ attitudes toward them, and offer a new policy decision basis for local governments. Since few scholars have evaluated rural residential energy efficiency retrofit projects from the farmers’ perspective before. To understand the real attitude of farmers toward retrofitting projects. This study established a logistic-AHP-TOPSIS evaluation model based on previous scholars’ research and relevant national standards to evaluate energy-efficient retrofit projects from farmers’ perspectives. Compared with previous evaluation methods by other scholars, this method focuses more on those indicators that significantly affect farmers’ willingness to participate in energy efficiency retrofit projects in the process of selecting evaluation indicators. It not only satisfies the scientific nature of the evaluation but also reflects the real attitude of farmers.

From the evaluation indicators, farmers are very concerned about the economics of retrofitting projects, and the initial investment, payback period, and savings in heating costs all have a significant impact on farmers’ willingness to participate. The evaluation model shows that farmers are more willing to maintain the status quo of their existing dwellings than to participate in retrofitting. Whereas, farmers prefer to choose the option of retrofitting according to actual needs rather than the option of total retrofitting because it not only improves the energy efficiency of the residence but also takes into consideration the economics. Although farmers were satisfied with the energy efficiency and heating cost savings of the retrofitted dwellings, the high investment in retrofitting and the payback period made them less enthusiastic about participating in retrofitting projects. This result is consistent with the real situation in the local area. In that context, this study proposes to reduce retrofitting costs by purchasing and retrofitting in bulk in exchange for bargaining space through village collective enterprises based on farmers’ actual needs.

This work can be extended to other aspects of energy efficiency retrofitting in future studies, such as insulation structures of different types of materials, evaluation of solar
power equipment retrofitting, and biogas digester construction options. The retrofitting programs are not simply technical issues but also social issues that affect people’s livelihood and long-term rural development. Further research is needed on the feasibility and constraints of the above proposal of establishing rural enterprises and increased government subsidies.

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