農村建築節能評價及預測研究

ANALYSIS OF THE ENERGY-SAVING BUILDING EVALUATION SYSTEM

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摘 要

我國建築節能工作正處於大力發展的新階段，但對農村節能建築評價體系的研究卻嚴重滯後，要切實實現農村建築節能標準落實到實處，加強對農村節能建築評價體系分析研究勢在必行。從建築的節能角度出發，建立農村建築節能評價指標體系，通過專家打分，利用模糊綜合評價法對農村節能住宅進行評價並得出評價等級。最後運用集對勢預測農村節能建築指標體系，為建築節能評價及其發展趨勢提供借鑒。

關鍵詞：節能建築、評價體系、指標體系、節能評價。

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ABSTRACT

The energy conservation work in our country construction is in a new stage, but the study of it is quite behind. So it is necessary to make the building energy efficiency standards play a good role in the construction and strengthen the analysis of energy efficiency building evaluation system research. This paper is from the perspective of building energy efficiency. Firstly, the evaluation index system of rural building energy conservation is established, and then the evaluation index is scored by experts. Next, the fuzzy comprehensive evaluation method is used to evaluate the rural residential energy conservation and get the evaluation grade. Finally, the index system of rural energy saving buildings is predicted systematically with set pair potential, which provides reference for the evaluation and development trend of building energy saving.

Keywords: Energy-saving building, Evaluation system, Indicator system, Energy-saving evaluation.

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With the rapid development of China's economic construction, people's quality of life has been significantly improved. Energy saving and realizing sustainable development have become the main theme of our times (Ye *et al*., 2006). China has a large population and is a big resource consuming country. China has a large population and is a big consumer of resources. Especially with the development of economy, the consumption rate is faster and faster, which makes the shortage of energy more and more serious. Among them, the energy consumption of the construction industry accounts for 30% of the total energy consumption of the whole society, and it is a "big consumer" of energy consumption. However, people have gradually raised the awareness of energy saving, and the government has also taken the energy consumption of the construction industry as the key energy saving target of national economic development. Building energy saving has become an urgent problem in today's society (Ye *et al*., 2006). It is imperative to solve the problem of resource shortage and improve people's awareness of building energy saving, which is a key step to realize the harmonious coexistence of man and nature.

Under the background of advocating energy saving, a large number of new energy-saving technologies have been widely used, and a series of a series of laws related to energy saving buildings have been introduced and implemented, which put forward higher requirements for building energy conservation (Li and Fu *et al*., 2006). However, the research on building energy saving evaluation lags behind. It is not possible to comprehensively assess the energy-saving performance of buildings by giving only a small number of indicators or evaluating only a particular aspect. In order to realize the goal of energy saving, we must have a complete evaluation system, which can accurately evaluate the energy efficiency and energy consumption of buildings, It will provide reference for the determination and development of building energy saving.

1. Evaluation System of Rural Energy-saving Buildings

1.1 Characteristics of Evaluation System of Rural Energy-saving Buildings

In order to achieve the overall evaluation of building energy-saving level and grade, the evaluation system of rural energy-saving buildings realizes the description of the energy-saving characteristics of buildings by quantifying the energy consumption and economic benefits of buildings in a certain stage or a certain period of time. (Yang and Wang *et al*., 2017).

The objective of the evaluation system of energy-saving buildings in rural areas is to consider reasonable energy-saving building design and materials and equipment that meet the requirements of energy-saving buildings, to use effective energy rationally, to reduce building energy consumption and to improve energy efficiency, to achieve the unity of social, economic and environmental benefits, and to promote the sustainable development of building green energy.

1.2 Evaluation of Rural Building Energy Efficiency Based on Hierarchical Fuzzy Mathematics

1.2.1 Construction of Energy-saving Building Index System and Its Weight Determination

In order to reduce the energy consumption of buildings and deal with the relationship between environment, personal safety and health, urban planning and so on, China promulgated the "Residential performance Evaluation Standard" in 2005, which unified the evaluation index and evaluation method of residential performance. There are also mature evaluation index systems for energy-saving buildings in the world, such as BREEAM evaluation system in Britain, LEED evaluation system in the United States, GBTOOL evaluation system in Canada and CASBEE evaluation system in Japan (Xiong and Ma *et al*., 2017). Synthesizes the above evaluation system and consults the relevant experts, that is, the expert screening method is used to adjust the evaluation index. Building energy efficiency indicators were initially screened on the basis of relevant basic literature [12], and these indicators were grouped into four categories: economic, safety, environmental assessment, and durability. The initial selection of indicators was then analysed and screened through expert consultation, and 12 tertiary indicators were finally screened out. The analytic hierarchy process

(AHP) is used to compare the factors, so as to establish the numerical judgment matrix, and find its feature vector. After normalization, the weight of the index is determined, and the maximum eigenvalue and weight of the judgment matrix are calculated.

Tab. 1. Each index system of energy saving building.

Evaluation objectives	Level 2 indicators	Level 2 indicator weights	Level 3 indicators	Level 3 indicator weights
Evaluation index system of energy saving in rural buildings	Economic indicator	0.403	Purchase cost	0.162
			Building energy conservation	0.309
			Construction cost	0.529
	Security indicators	0.118	Building fire-proof and anti-theft performance	0.545
			Safety performance of building structures	0.273
			Daily safety precautions	0.182
	Environment pointer	0.277	Degree of comfort	0.476
			Noise and air quality	0.333
			Green spaces and venues	0.191
	Durable indicators	0.202	Construction life	0.790
			Structural engineering	0.133
			Construction material	0.077

1.2.2 Expert Rating

A total of 14 experts were invited to score the buildings in this paper. The experts all have extensive expertise in the field of construction, have studied energy efficiency in buildings in depth and have experience in similar evaluations. The evaluation set was then formed. The composition of the experts is shown in Tab. 2 below.

Tab. 2. Participants'characteristics.

Years of Experience	Age (year)	Position	Speciality
11±3.6	37.7±2.86	Professor	Energy efficiency investment and financing management
16.3±2.8	42.7±2.3	Professorial Senior Engineer	Energy efficiency in buildings
12.7±3.8	37.7±3.3	Dean, Professor	Sustainable development of the built environment
11.3±1.2	35.7±2	Researcher	Building physics, solar energy
11.4±2.2	34.8±2.2	President, Professor and Senior Engineer	Building Energy Management

1.2.3 Determine the corresponding grade of energy saving evaluation

The general evaluation matrix B :

$$B = A * R = A * \begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \end{bmatrix} \quad \text{......} (1)$$

A refers to the multiplication of the weight of the and expert score value. R is a 2-level index fuzzy matrix.

Tab. 3. Evaluation of grade division.

Energy saving score	≥85	75～84	65～74	55～64	40～54	≤40
Energy saving grade	Very good	Okay	Good	General	Poor	Difference

2. Prediction of Building Energy Saving Based on Set-pair Analysis

2.1 Basic principle of set pair analysis

Set pair analysis is a dialectical analysis and mathematical treatment of certainty and uncertainty as a system of opposites. This theory holds that any system is composed of deterministic information and uncertain information. The two kinds of information are interrelated, affected and restricted. Under certain conditions, information can be transformed into each other. Using the contact degree to describe the uncertainty system of the object and Using three aspects of the same difference and inverse to express whether the corresponding system is connected or transformed, It can solve the complex problem of building energy saving evaluation (Wang *et al*., 2019). Set pair analysis is made up of two sets to predict the energy saving trend of buildings. One set is made up of the specific values of each quantitative index of energy saving buildings, and the other set is made up of the standard values determined by each evaluation index.

2.2 Connectivity

It is assumed that set A and set B constitute set pair H, and N characteristics are obtained from the analysis results. There are S common features of two sets and P opposite features of two sets, and F are non-common and non-opposite features of two sets, which are the same-indefinite-contrary system. The same degree A the set is represented by a S/N as a. The degree of difference the set A is expressed as F/N as b. The opposition of the set A is represented by P/N as c. Its relation formula can e written

$$m = \frac{S}{N} + \frac{F}{N} i + \frac{P}{N} j = a + bi + cj \quad \text{..........................(2)}$$

In the formula, a, b, c should satisfy the condition $a + b + c = 1$. There are two meanings of i and j: first, i and j refer to difference coefficient and opposite coefficient respectively under uncertainty, $i \in [-1, 1]$, j usually takes-1, second, i and j represent difference coefficient and opposite coefficient only and have nothing to do with value [11]. These two meanings can be selected according to the actual situation of the problem.

2.3 Set pairwise potential

The expression of set pair analysis connection degree is $m = a + bi + cj$, a, b, c, is the same degree, different degree and contrast degree of two sets. The set pairwise potential is represented by *shi*, $c \neq 0$, as

$$shi(H) = \frac{a}{c} \quad \text{..(3)}$$

Among them, the order and expression of each rank of set potential are shown in Tab. 4, and the order relation represents the uncertainty of the object. In the set pair analysis, the same potential, the opposite potential and the balance potential refer to the three situations of the same trend, the opposite trend and the balance of power in the two sets, respectively.

Tab. 4. Sets and expressions of each rank of the pair of potential.

a, b, c size	grade	Set pairwise potential	meaning
a>c, b=0	The same trade	Quasi homogeneity	Identification of the same trends
a>c, c>b		Strong homogeneity	Focus on the same trend
a>c, a>b>c		Weak homogeneity	The same trend is a little weak
a>c, b>a		Micro homogeneity	The same trend is weak
a=c, b=0	The balance of power	Quasi-equilibrium	The opposite of the opposite trend
a=c, a>b>0		Strong equilibrium	The same and opposite trends are clearly comparable
a=c, b=a		Weak equilibrium	Equivalence of the same and opposing trends under uncertainty
a=c, b>a		Micro equilibrium	In the case of weak uncertainty, the identity is equal to the opposite trend

a, b, c size	grade	Set pairwise potential	meaning
a<c, b=0	The opposite trend	Quasi reaction	Opposing trends
a<c, 0<b<a		Strong reaction	The main trend of opposition
a<c, a<b<c		Weak reaction	The opposite trend is a little weak
a<c, b>c		Micro reaction	The opposite trend is weak

2.4 Prediction model of rural building energy conservation based on set-pair analysis

According to the same and different inverse connection number, expand M $m = a + bi + cj$ multi-level function in b_i A term. The number of multiple connections is normalized as follows, *a,b,c,d,e,f,…, x* is the connection component. The corresponding *i,j,k,l,m,…, y* is called the contact component coefficient. The first coefficient is 1, the last coefficient is -1, and the rest are in the interval and decreasing. The determination of weights is critical to the accuracy of the system. Weight refers to the contribution of each index to the system, reflecting the coefficient of the value position of each index in the evaluation system, which can be expressed as: W = [W_1,W_2,…,W_M]. The multi-connection number model of energy-saving in rural buildings can be expressed as:

$$u = W * R * E$$
$$= (W_1, W_2, \cdots, W_M) * \begin{bmatrix} a_1 & b_1 & c_1 & \cdots & x_1 \\ a_2 & b_2 & c_2 & \cdots & x_2 \\ a_3 & b_3 & c_3 & \cdots & x_3 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_n & b_n & c_n & \cdots & x_n \end{bmatrix} * \begin{bmatrix} 1 \\ i \\ j \\ \vdots \\ y \end{bmatrix}$$

....(4)

$W = (W_1, W_2, \cdots, W_n)$ is the weight coefficient. E is the contact matrix. R is a meta-evaluation matrix with more similarities and differences.

3. Results and analysis

3.1 Evaluation Model of Rural Building Energy Efficiency

3.1.1 Expert rating and weight determination

Taking the rural project of Shati Village in Shangjie Town, Minhou County, Fuzhou City as an example, the total construction area of the project is about 1500 square meters and the building height is about 18 meters. During the design process, the same indoor environmental parameters were strictly ensured in accordance with the design requirements of the Energy Conservation Design Standards for Rural Residential Buildings. Finally, through measures such as enhancing the thermal insulation of the building maintenance structure and improving the energy efficiency ratio of heating and air conditioning equipment, the energy-saving index was ensured to reach 50%. The building has been awarded the "Good" building energy efficiency evaluation mark.

We invite 10 experts to rate the building's energy-saving project using a percentage scoring method. The evaluation set was formed and the weight coefficients were 0.1, 0.15, 0.05, 0.1, 0.05, 0.05, 0.2, 0.15, 0.1, 0.05, respectively.

3.1.2 Energy-saving grade evaluation

The evaluation matrix of building energy saving system, then

$$B = A * R = A * \begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \end{bmatrix}$$
$$= \begin{bmatrix} 0.403 & 0.118 & 0.277 & 0.202 \end{bmatrix} * \begin{bmatrix} 75.4 \\ 65.4 \\ 75.4 \\ 70.35 \end{bmatrix} = 71.62$$

....(5)

According to Tab. 2 and Equation (1), a score of 71.62 can be calculated, which corresponds to the evaluation grade of "good" for building energy efficiency, which is ultimately consistent with the evaluation grade of the project.

3.2 Forecast of Development Trend of Energy-saving Buildings

According to the score of the above experts, formula (4) and the building energy saving prediction model based on set pair analysis, the evaluation results are as follows:

$$u = W * R * E$$

$$= (W_1, W_2, \cdots, W_M) * \begin{bmatrix} a_1 & b_1 & c_1 & \cdots & x_1 \\ a_2 & b_2 & c_2 & \cdots & x_2 \\ a_3 & b_3 & c_3 & \cdots & x_3 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_n & b_n & c_n & \cdots & x_n \end{bmatrix} * \begin{bmatrix} 1 \\ i \\ j \\ \vdots \\ y \end{bmatrix}$$

$$= 0.2305 + 0.2812i + 0.3617j + 0.0844k + 0.0422l \quad \cdots\cdots (6)$$

We can see that a = 0.2305, b = 0.2812, c = 0.3617. Compared with Tab. 4, the development trend of this energy-saving building is expressed as weak reversal. From the overall analysis, the energy saving grade of the building is good. Comparing the predictions of the set-pair analysis with the actual situation of the project reveals that our predictions match the actual situation. And from the development trend, it has a weak unfavorable direction. Therefore, this building should pay attention to energy saving, strengthen energy saving management, take corresponding measures to rectify consumption factors, and strive to improve the energy saving state of the building.

4. Conclusion

In this paper, the evaluation index system is constructed from the point of view of building energy saving, and the evaluation model of building energy saving based on hierarchical fuzzy mathematics method is established. The development trend of rural building energy saving is effectively predicted by combining the analysis theory. This method studies the problem quantitatively and the evaluation results tend to be more practical. From the analysis results, the method is feasible and effective. The combination of the two methods provides a new method and way for the energy saving evaluation and prediction of rural energy-saving buildings. It also provides reference for construction and effective implementation of energy conservation evaluation management, and has theoretical and practical significance for improving energy-saving management.

Reference

1. Ye, L., Yao, Y., and Wang, Q. Q., "Elementary study on evaluating index system of energy-efficient buildings," *Journal of The Building Science*, Vol. 22, No. A6, pp. 1-5, 2006.
2. Lei, L. I., *et al*, "Discussion about residential building energy efficiency evaluation", *Journal of The China Housing Facilities*, Vol. 7, pp. 50-54, 2006.
3. Liu, A. F., Zhang, C. Q., and Duan, J., "Construction of evaluation criterion system of building energy conservation," *Journal of The Power Demand Side Management*, Vol. 1, pp. 39-42, 2006.
4. Wang, L., and Gao, Z., "Application of gray-fuzzy comprehensive assessment based on AHP in energy efficient residential buildings techno-economic assessment," *Technoeconomics and Management Research*, Vol. 6, pp. 23-25, 2008.
5. Yang, M., *et al*, "Research on optimization method of building energy efficiency design evaluation index based on PCA," *Journal of The Architecture Technology*, Vol. 48, No. 7, pp. 684-687, 2017.
6. Xiong, X., Xiaoguo, M. A., and Ouyang, Q., "Design and application on evaluation of green intelligence building," *Journal of The Science and Technology Management Researc*h, Vol. 37, No.3, pp, 95-99, 2017.
7. Yang, H.X., *et al*, "Discussion and research on evaluation systems of building energy efficiency," *Journal of The Heating Ventilating and Air Conditioning*, Vol. 36, No. 9, pp. 42-44, 2006.
8. Lu, N., Zhao L. P., Guo, Y., Ma, H. J., and Zhu, L., "Comprehensive evaluation model of urban residential building energy conservation. *Value Engineering*. Vol. 30, No.2, pp. 69-71, 2011.
9. Ministry of Construction of the People's Republic of China, "Technical standard for performance assessment of residential buildings: GB/T 50362-2005," *China Construction Industry Press*, 2006.
10. Wang, A. J., *et, al*, "Analysis of environmental protection

and energy saving evaluation model for green building materials," *Environmental Science and Management*, Vol. 44, No. 1, pp. 71-76, 2019.

11. Zyoud, S. H., Kaufmann, L. G., Shaheen, H., Samhan, S., Fuchs-Hanusch, D., "A framework for water loss management in developing countries under fuzzy environment: Integration of fuzzy AHP with Fuzzy TOPSIS," *Expert Systems With Applications*, Vol. 61, pp. 86-105, 2016.
12. Liang, H. L., *et al*, "Role of Artificial intelligence algorithm for taekwondo teaching effect evaluation model," Vol. 40, No. 2, pp. 1064-1246, 3239-3250, 2021.
13. Yin, J., *et al*, "Safety assessment and prediction of the tailing pond based on fuzzy hierarchy analysis and set pair analysis," *Metal Mine*, No. 10, pp. 159-161, 2010.

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