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The Survey Research and Evaluation of Green Residential Building Based on the Improved Group Analytical Hierarchy Process Method in Yinchuan

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***Abstract*—**Due to the economic downturn and the deterioration of the living environment, the development of residential buildings as high energy consuming building is gradually changing from "extensive" to green building in China. So, the evaluation system of green building is continuously improved, but the current evaluation work has the following problems: (1) There are differences in the cost of the actual investment and the purchasing power of residents, also construction target of green residential building is single and lacks multi-objective performance development. (2) Green building evaluation lacks regional characteristics and cannot reflect the different regional residents demand. (3) In the process of determining the criteria weight, the experts' judgment matrix is difficult to meet the requirement of consistency. Therefore, to solve those problems, questionnaires which are about the green residential building for Ningxia area are distributed, and the results of questionnaires can feedback the purchasing power of residents and the acceptance of the green building cost. Secondly, combined with the geographical features of Ningxia minority areas, the evaluation criteria system of green residential building is constructed. Finally, using the improved group AHP method and the grey clustering method, the criteria weight is determined, and a real case is evaluated, which is located in Xing Qing district, Ningxia. A conclusion can be obtained that the professional evaluation for this project and good social recognition is basically the same.

***Keywords*—**Evaluation, green residential building, grey clustering method, group AHP.

I. Introduction

WITH the development of economy, the real industry in our country urgently needs to change from extensive development to sustainable development. The deterioration of ecological environment makes people promote the concept of "green". Ningxia, as a national energy conservation focus area, in the continuous improvement of the application of industrial recycling technology at the same time, focuses on promoting energy-saving technology in the construction of a wide range of applications. Ningxia, in 2009, by the Department of housing and urban and Rural Construction, issued "the detailed rules for the implementation of evaluation standard for green building in Ningxia Hui Autonomous Region". However, at the present, high investment of the current green residential building makes developers flinch, the technical measures of green residential building only meet the requirements of low standards and lack the different level demands of green for the owners and the regional characteristics [1], [2]. Huang [3] and Wang [4] only construct the evaluation system of green residential building from the point of view of the construction of the building. In this paper, the questionnaire survey of Ningxia region characteristic is analyzed in order to establish a suitable for Ningxia area evaluation criteria system of green residential building. In addition to the full life-cycle of the construction process, owner satisfaction should be considered in the evaluation criteria system. At the same time, green buildings have an impact on the economy and society, which should be considered in the establishment of the criteria system. Li [5] combines the characteristics of Fujian Province to introduce the concept of green measure of evaluation of green housing, but does not put the opinions of experts together. In this paper, the AHP method of group evaluation is used to gather and determine the important degree of each criterion and sub-criterion.

To sum up, green residential buildings in Yinchuan which is capital city of Ningxia are investigated and analyzed. The evaluation criteria system of green residential of the Ningxia Hui Autonomous Region is proposed, and the grey cluster model is used to evaluate the Sai Shang construction.

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II. Survey Research and Data Analysis

Ningxia which is a gathering place for ethnic minorities is located in the upper reaches of the Yellow River in the western China and is the western margin zone of the central development. The most prominent feature of the climate of Ningxia is the large temperature difference in the daytime, long hours of sunshine, and strong solar radiation. Yinchuan is the capital city of Ningxia, where the resident population is mainly of the Hui and Han nationality. The Yellow River runs through the city and has seven interconnected lakes.

The investigation covers three areas of Yinchuan city; namely, Xing Qing district, Xi Xia district and Jin Feng District. And the questionnaire is divided into two parts; a part of the survey is for residents, and the other part is for the experts. The 10 questionnaires of experts are distributed. The 100 questionnaires of residents are distributed; the effective questionnaires were 90, and the recovery rate was 90%.

A. Expert Survey Data Analysis

The questionnaire includes basic information, comprehensive evaluation, and factor important degree

evaluation. Basic information is a survey of the individual situation, including natural attributes and social attributes. Comprehensive evaluation is a survey of awareness and knowledge of the green residential building and relevant government policies, the factor important degree evaluation is the survey of the important degree of the green residential building influence factor in order to calculate the criteria weight.

The distribution of expert questionnaire at the age of 30-39 is accounted for 81.8%. The engineering work experience and the cognitive maturity of green technology in this stage are more abundant. Senior professional titles are distributed, 45.5% of the experts are management personnel, and the technical and architectural field reached 45.5%. The working life of 10 years and above is accounted for 45.5% and the working life of 3-5 years is accounted 9.1%. Specialists have higher reliability. From the perspective of experts, green building success mainly depends on the design phase, and 54.5% of the experts believe that this stage is very important. 81.8% of the experts believe that China's green resident building market is still in the primary stage, and there is great potential for development. However, 45.5% of the experts believe that the development of the construction market mainly relies on the government guidance, and 36.4% of experts claim that it relies on the market. In addition, 1-9 scale was used to obtain the criteria weight. 9 scales are divided: equally important, slightly important, important, very important, and extremely important. The criteria are compared in pairs by experts and the relative importance of them can be obtained.

B. Residents Survey Data Analysis

The survey of female residents is accounted for 42% of the total, and that of the man is accounted for 48%. The residents surveyed are distributed in each age stage, mainly 20-49 years old, accounting for 92.2% of the total number, of which 30-49 years old is accounted for 75.6%. Because Yinchuan is a minority city, in the survey process, green residential building regional attributes need to be considered, so the survey gives first place to the Hui and Han ethic groups, accounting for 36.7% of the total proportion of Hui nationality. On the composition of the number of households, the proportion of the family of three corresponds to 46.7%, and family of more than four corresponds to 48.9% of total. The content of residential survey can be seen in Table I.

As shown in the survey results, reason for the delay promotion of green residential building accounted for 31.1% of residents is insufficient for government support, 17.8% of the residents believe that this is due to the lack of the technical support and propaganda-dynamic. For the increased costs increased of the green residential building, 60% of the residents accepted are able to accept incremental costs in the 100-200 yuan/m^2, and 21.1% of the residents are able to accept incremental costs in the 200-300 yuan/m^2. Moreover, 84.4% of the residents express their interest and think that it is worth buying, 54.4% of residents hold a wait-and-see attitude, and 36.7% of the residents believe that green residential construction prospects are considerable; that is to say, the residents have a more optimistic acceptance for the development of green residential building. For the housing area demands and unit, 51.1% of the surveyed residents are inclined to 130-150 m^2, and due to the Hui ethnic characteristics, 42.2% of the residents tend to choose the unit of three-bedroom, which is more suitable for the three generations.

TABLE I
THE CONTENT OF THE RESIDENTIAL SURVEY

	Question	Content
1	Purchase housing considerations	Price/area/traffic-condition/surrounding-environment.
2	Understanding of the concept of green residential building	A little/Y/N/very
3	Affecting factors of the extension of green residential building	Technic/government-support/propaganda-dynamic
4	Acceptable price	
5	Whether it is worth buying	Y/N
6	The attitude of green residential building	Not optimistic/optimistic/wait and see
7	Housing area demand(m^2)	90-130/130-150/more than 150
8	Housing units	

III. DETERMINING THE EVALUATION CRITERIA OF GREEN RESIDENTIAL BUILDING

As can be seen from the survey, in the elements of green building, consumers think that "healthy and comfortable working and living environment" is the most important fact. On the contrary, the most experts believe that utilization and allocation of the efficient resources are important. This inconsistent phenomenon shows that we should not simply apply academic theory to screen the factors of affecting green residential building from the point of view of consumers' demand. Considering the inconsistent of the technical experts and consumers' cognition [6] and combining with experts interviews, we build and screen the evaluation criteria system of lifecycle of green residential building [7]-[10]. Therefore, the evaluation criteria system of green residential building mainly consists of five aspects; that is, the preliminary work of construction, construction stage, economic, social, and owners' satisfaction (see Table II).

IV. DETERMINATION OF THE CRITERIA AND SUB-CRITERIA WEIGHT OF EVALUATION SYSTEM OF GREEN RESIDENTIAL BUILDING

The expert evaluation matrix is obtained by using the questionnaire survey in order to avoid the evaluation of a logical error using the MATLAB program. All the expert evaluation matrices need to be tested for consistency. The matrix that does not meet the requirements must be adjusted to meet the consistency requirements (see Fig. 1).

A. Expert Weights

In the evaluation of green residential building, the subjective weight is determined according to the experts' ability level and the evaluation object of familiarity. But, often only the subjective weight cannot truly reflect the influence of the evaluation object. Therefore, aiming at the problem of specific evaluation, the objective weights need to be determined by the

experts scoring for the criteria and the correlation between criteria.

TABLE II
THE EVALUATION CRITERIA SYSTEM OF GREEN RESIDENTIAL BUILDING

Objective	Criteria	Sub-criteria
Green residential building	B1.Preliminary work of construction	C1.Site selection
		C2.Site quality
		C3.Pre-service facilities planning
		C4.Pre-traffic planning
		C5.Preliminary planning of water resources
		C6.The efficiency use of land
		C7.Indoor and outdoor environment design quality
		C8.Section material and material resources
		C9.Energy saving and Energy utilization
		C10.Water saving and water resource utilization
	B2.Construction process	C11.Site water saving and water resource utilization
		C12.Energy saving and energy utilization in construction site
		C13.Section material and resource utilization of construction site
		C14. Construction site environment
		C15.Construction, living garbage and waste disposal
		C16. Noise control
	B3.Economic	C17. National economic evaluation
		C18. Full life cycle cost
		C19.Green price
	B4.Social	C20.Regional
		C21. Peripheral facilities
	B5.Owners' satisfaction	C22. Green management
		C23. Material resources
		C24. Energy utilization
		C25. Water resource

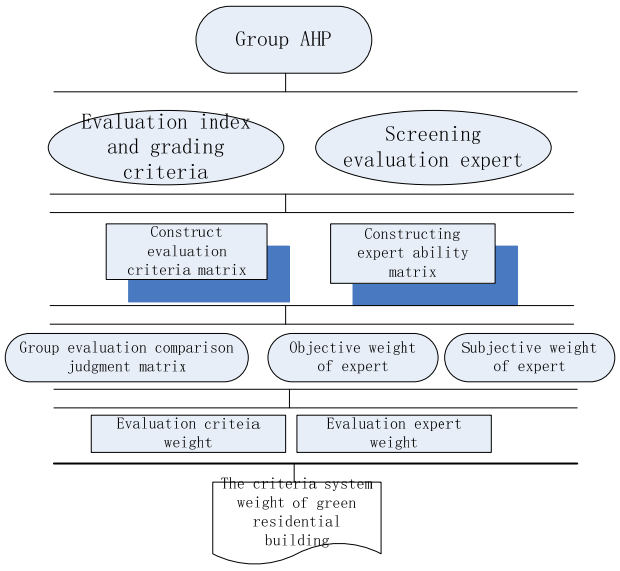

Fig. 1 The frame of the post-evaluation criteria weight and expert weight

We can obtain the objective weights of criteria by means of gathering the criteria judgment matrix of the experts.

$$\beta_k^{(1)} = (0.2682, 0.2680, 0.2689, 0.2688, 0.2687, 0.2691, 0.2688, 0.2690, 0.2687, 0.2687)^T$$

Based on the AHP, the subjective weights of the experts are as:

$$\beta_k^{(2)} = (0.0312, 0.0444, 0.0997, 0.0638, 0.0919, 0.0520, 0.0997, 0.1743, 0.1656, 0.1775)^T$$

The weight coefficient is put into (1), the final criteria weights of green residential building are determined.

$$\omega_k = t \cdot \beta_k^{(1)} + (1-t)\beta_k^{(2)}, k = 1, 2, ..., s \quad (1)$$

$$W = (0.1023, 0.1115, 0.1504, 0.1253, 0.1449, 0.1171, 0.1504, 0.2027, 0.1965, 0.2040)^T$$

B. Criteria and Sub-Criteria Weight of the Evaluation

Assuming that there are some experts to participate in determining the important degree of the criteria and sub-criteria of green residential building, experts respectively give the n order judgment matrix using AHP. The group matrix of the decision-making can be constructed as:

$$A = (a_{ij})_{n\times n} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & & 1 \end{bmatrix}$$

$$a_{ij} = \left[\prod_{k=1}^{s} a_{ij}^{(k)}\right]^{\frac{1}{s}}$$

The element of the matrix A is composed of the average geometric value which is corresponding to element of the expert judgment matrix. For each k, if the matrix $A^{(k)}$ meets the consistency, the matrix A is also consistent. After calculating the group evaluation matrix, the weight of the evaluation criteria and sub-criteria is obtained by AHP method, and the consistency test is also carried out. The relative weight and absolute weight of the criteria and sub-criteria of green residential building can be seen in Table III.

V. A CASE STUDY-SAI SHANG PROJECT IN YINCHUAN

In the evaluation, the rank of green residential building needs to be assessed. The extension of concept is very clear; that is, the rank of green needs to be determined, but it is not clear for the specific lines of rank. So, the evaluation of the green residential building is a typical grey system problem. In this paper, from the five factors (namely, the preliminary work, the construction process, the social, economics and owners' satisfaction), Sai Shang-green residential building is assessed

and graded by the grey clustering method to evaluate this project. In the evaluation system, the value range of each criterion is divided into three categories; respectively corresponding to one star, two stars, and three stars. The implementation values of each sub-criterion are shown in Table IV.

TABLE III
THE RELATIVE WEIGHT AND ABSOLUTE WEIGHT OF THE CRITERIA AND SUB-CRITERIA OF GREEN RESIDENTIAL BUILDING

Criteria	weight	Sub-criteria	Relative weight	Absolute weight
B1. Preliminary work of construction	0.3946	C1.Site selection	0.1652	0.0652
		C2.Site quality	0.0952	0.0376
		C3.Pre-service facilities planning	0.0850	0.0335
		C4.Pre-traffic planning	0.0915	0.0361
		C5.Preliminary planning of water resources	0.0924	0.0365
		C6.The efficiency use of land	0.0903	0.0356
		C7.Indoor and outdoor design environment quality	0.0845	0.0333
		C8.Section material and material resources	0.0949	0.0374
		C9.Energy saving and Energy utilization	0.0951	0.0375
		C10.Water saving and water resource utilization	0.1059	0.0418
B2. Construction process	0.1571	C11.Site water saving and water resource utilization	0.2017	0.0317
		C12.Energy saving and energy utilization in construction site	0.1860	0.0292
		C13.Section material and resource utilization of construction site	0.1490	0.0234
		C14. Construction site environment	0.1538	0.0242
		C15.Construction, living garbage and waste disposal	0.1577	0.0248
		C16. Noise control	0.1516	0.0238
B3. Economic	0.1524	C17. National economic evaluation	0.4364	0.0665
		C18. Full life cycle cost	0.2114	0.0322
		C19.Green price	0.3522	0.0537
B4. Social	0.1584	C20.Regional	0.5673	0.0899
		C21. Peripheral facilities	0.4327	0.0685
B5. Owners' satisfaction	0.1375	C22. Green management	0.2341	0.0322
		C23. Material resources	0.1659	0.0228
		C24. Energy utilization	0.2192	0.0301
		C25. Water resource	0.1913	0.0263
		C26. Indoor environmental quality	0.1895	0.0261

According to the sub-criteria of three different grey class whitening weight functions, all the criteria of the three different grey class whitening weight function values were calculated, and finally we get the values shown in Table V.

The grey clustering coefficient of K is calculated as:

$$\sigma^1 = \sum_j f_j^1(x_j)\eta_j = 0.3648$$

$$\sigma^2 = \sum_j f_j^2(x_j)\eta_j = 0.7722$$

$$\sigma^3 = \sum_j f_j^3(x_j)\eta_j = 0.4005$$

Due to the $\max\{\sigma_i^k\} = 0.7722 = \sigma^2$, the project of Sai Shang belongs to the grey class K=2, which belongs to the class of "two stars".

TABLE IV
THE IMPLEMENTATION VALUES OF THE SUB-CRITERION OF "SAI SHANG"

Criteria	weight	Sub-criteria	Score	weight
B1.Preliminary work of construction	0.3946	C1.Site selection	90	0.0652
		C2.Site quality	85	0.0376
		C3.Pre-service facilities planning	80	0.0335
		C4.Pre-traffic planning	15	0.0361
		C5.Preliminary planning of water resources	20	0.0365
		C6.The use efficiency of land	27	0.0356
		C7.Indoor and outdoor design environment quality	9	0.0333
		C8.Section material and material resources	30	0.0374
		C9.Energy saving and Energy utilization	70	0.0375
		C10.Water saving and water resource utilization	85	0.0418
B2.Construction process	0.1571	C11.Site water saving and water resource utilization	5	0.0317
		C12.Energy saving and energy utilization in construction site	6	0.0292
		C13.Section material and resource utilization of construction site	18	0.0234
		C14. Construction site environment	5	0.0242
		C15.Construction, living garbage and waste disposal	7	0.0248
		C16. noise control	3	0.0238
B3.Economic	0.1524	C17. National economic evaluation	80	0.0665
		C18. Full life cycle cost	70	0.0322
		C19.Green price	1.3	0.0537
B4.Social	0.1584	C20.Regional	80	0.0899
		C21. Peripheral facilities	85	0.0685
B5.Owners' satisfaction	0.1375	C22. Green management	7	0.0322
		C23. Material resources	15	0.0228
		C24. energy utilization	80	0.0301
		C25. water resource	80	0.0263
		C26. Indoor environmental quality	85	0.0261

VI. CONCLUSION

Green building assessment can ensure the effective implement construction of green building. In this research, we mainly do the following work: first, by the survey of the experts and residents in Yinchuan City, we found out the differences of the green building' concept of the experts and residents, so the evaluation criteria of green residential building are re-screened. Next, we gather the opinions of experts using group AHP method to determine the weight of criteria and sub-criteria, and use the grey clustering method to evaluate. Finally, a real case-Sai Shang is to be verified the evaluation criteria system and evaluation method.

The project of Sai Shang is considered for the green building requirements with reasonable planning, emphasizing the safety

and comfort of indoor environment and outdoor environment, and according to the characteristics of the region, the implementation and application of green technology is selected, rather than applying mechanically green measures and methods. From the final evaluation results, the project fully reflects environmental protection, livability, and sustainability, which belong to the ranking of two star, and the evaluation result is basically consistent with the existing evaluation in recent years and good social approval degree.

TABLE V
THE GREY CLASS WHITENING WEIGHT FUNCTION VALUES OF THE SUB-CRITERIA OF SAI-SHANG PROJECT

Sub-criteria	$f_j^1(x)$	$f_j^2(x)$	$f_j^3(x)$	Sub-criteria	$f_j^1(x)$	$f_j^2(x)$	$f_j^3(x)$
C1	0.0000	0.5000	0.8000	C14	0.0000	0.5000	0.8000
C2	0.2000	0.7500	0.6000	C15	0.0000	0.5000	0.8000
C3	0.4000	1.0000	0.4000	C16	0.8000	0.5000	0.0000
C4	0.3750	0.9412	0.2500	C17	0.4000	1.0000	0.4000
C5	0.5000	0.8889	0.3077	C18	0.8000	0.5000	0.0000
C6	0.1538	0.8333	0.5000	C19	0.3333	1.0000	0.2500
C7	0.6667	0.6667	0.0000	C20	0.4000	1.0000	0.4000
C8	0.9020	0.4314	0.0000	C21	0.2000	0.7500	0.6000
C9	0.8000	0.5000	0.0000	C22	0.0000	0.5000	0.8000
C10	0.2000	0.7500	0.6000	C23	0.1333	0.7692	0.5714
C11	0.6667	0.6667	0.0000	C24	0.4000	1.0000	0.4000
C12	0.3333	1.0000	0.4000	C25	0.4000	1.0000	0.4000
C13	0.5000	0.8333	0.1818	C26	0.2000	0.7500	0.6000

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