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

Yun-na Wu, Zhen Wang

**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

Yun-na Wu is with the North China Electric Power University, Beijing, China (e-mail: wu_yunna@163.com).
Zhen Wang is with the North China Electric Power University, Beijing, China. She is also a lecturer with the Ningxia university, Ningxia, China (corresponding author; phone: (086)13995281983; e-mail: 464345819@qq.com).

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.

## 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

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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

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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.

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

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

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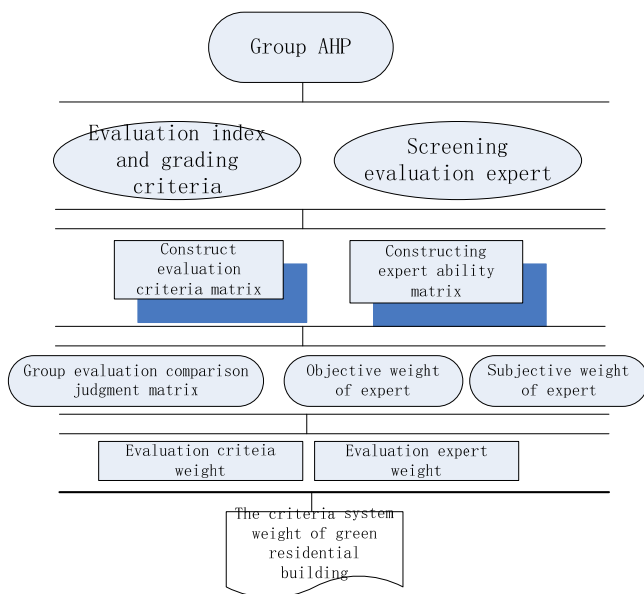
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and graded by the grey clustering method to evaluate this project. In the evaluation system, the value range of each criterion is divided into three categories; respectively corresponding to one star, two stars, and three stars. The implementation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

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 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 |

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 |

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:

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

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

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

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

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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 |

REFERENCES

[1] Wang, Z.Z., Jing, "the evaluation system of green building based on AHP". Construction Economy (J). Vol 11: p. 79-82,2013.
[2] Zhang, S.L., Wei., "Construction and comprehensive evaluation of green building system". Statistics & Decision(J). Vol 4: p. 69-71,2007.
[3] Huang, H., The Whole Process Green Management Method and Evaluation of Construction Engineering Based on Grey Theory. 2013: Zhejiang University.
[4] Wang, X., The realization of low carbon construction based on life cycle theory. 2012: Shandong Jianzhu University.
[5] Li, Z.H.X., "Fuzzy comprehensive evaluation model for green housing's green measure-Taking Fujian Province as an example". Journal of Civil, Architectural & Environmental Engineering(J). Vol 36: p. 37-40,2014.
[6] Huang, X.L., Tao; Kang, Jin., "The survey report on the status and trends of China's green real estate development in 2012": Beijing, China, 2012.
[7] He, Y., Establishment and application of the post-evaluation index system for residence development project. 2011: Xi'an University of Architecture and Technology.
[8] Liu, P.L., Junhong, "The comparative study on green building assessment system". Journal of Jilin Institute of Architecture & Civil Engineering (J). Vol 31(4): p. 72-74,2014.
[9] Xu, Y.Z., Shiyang, The evaluation of green building based on lige cycle. 2012: Tianjing University of Technology.
[10] Zheng, J., The evaluation index system of low carbon buildings. 2012: Southwest Petroleum University.

**Yunna Wu** was born in Jilin province, china in 1956. She received Master of Engineering degree in Civil Engineering from North China Electric Power University in 1981. She is employed as professor in North China Electric Power University. Her main research activities are: engineering and project management.

**Zhen Wang** was born in Ningxia, china, in 1979. She received her Master of Engineering degree in Beijing University of Civil Engineering and Architecture in 2008. She is employed as lecturer in Ningxia University and She is currently working toward the Ph.D. degree in engineering and project management, College of Economic and Management, North China Electric Power University. His research mainly concerns on engineering and management.