Green building design evaluation based on grey clustering method

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Abstract. This paper sets up a green building evaluation system based on grey clustering method for the rational evaluation of green building design. First, the index weight is determined by the analytic hierarchy process (AHP), and then the grey clustering method based on the triangular whitening weight function is used. Finally, the green building design is evaluated according to the green building evaluation standard in this area.

1. Preface
With the rapid economic growth of the construction industry in China. This economic growth mode has a certain impact on our country's ecology and environment. The construction industry is one of the three energy consuming industries in China. The construction industry has great potential for optimization [1]. The green development of the national economy is the only way for China's environmental protection. Therefore, it is an inevitable choice for China's construction industry to develop green building vigorously. This idea is being paid more and more attention and advocated by many people [2]. In recent years, China has promulgated a series of relevant green building assessment criteria and evaluation methods. Many scholars are fuzzy in the assessment of "regional characteristics" in the assessment of existing buildings. In order to fully reflect the concept of green buildings, the evaluation of green buildings should be combined with "regional characteristics". There are great differences in climate, environment, resources, economy and folk culture in Qinghai province. In the evaluation, we should consider the characteristics of the area where the building is located, and follow the principle of local conditions [3]. This paper draws on the existing evaluation theory of green buildings both at home and abroad, and combines "Qinghai green building evaluation standard" [4], taking a residential district in Haidong city as an example, to establish an evaluation model in accordance with this region.

2. Evaluation model of green building design based on Grey Clustering

2.1. The construction of the index system
There are many evaluation indexes in green building design. In order to make the evaluation system concise and applicable, we should select representative indexes. The target layer of the evaluation system is A, the standard layer is B, and the standard layer is evaluated from the aspects of land saving,
energy saving, water saving, timber saving, indoor and outdoor environmental quality according to the green building evaluation standard of Qinghai province. The index layer is C, including the item. The evaluation index system of green building design is shown in Table 1.

**Table 1. Evaluation index system of green building design**

| Target layer A | Standard layer B | Index layer C |
|----------------|------------------|---------------|
| Evaluation of green building design | Ground and outdoor environment B1 | Setting green land C1 |
| | | Rational exploitation and utilization of C2 in underground space |
| | | Indoor air environment C3 |
| | Energy saving and energy utilization B2 | External wall insulation system C5 |
| | | Solar hot water system C6 |
| | | Super quiet new wind system C7 |
| | Water saving and water resources utilization B3 | Rainwater reinfiltation C8 |
| | | Use of water-saving apparatus C9 |
| | | Using water saving technology C10 |
| | | Use of non-traditional water source C11 |
| | Utilization of material and material resources by B4 | Use the local material C12 |
| | | Repeated use of C13 |
| | | Using prefabricated C14 |
| | | Existing materials using C15 |
| | Indoor and outdoor environmental quality B5 | Noise reduction measures C16 |
| | | Indoor light environment C17 |
| | | Indoor and outdoor air quality C18 |

### 2.2. Determination of weight by analytic hierarchy process

Analytic hierarchy process (AHP) is a quantitative and qualitative evaluation method, which is simple and feasible. Select the knowledgeable experts to determine the relative importance of the index, and then determine the weight of the index through analysis.

1. Establishing analytic hierarchy process
   - First, the problems to be solved are organized and the structural models are established hierarchically.

2. Structural judgment matrix
   - Different levels of factors are compared to construct judgement matrix. According to the 1-9 comparison scale, we can determine the important sequence and judge the scale and definition of matrix as shown in Table 2.

**Table 2. Judgement matrix scale**

| Scale value | Rank of importance |
|-------------|--------------------|
| 1           | Compared to the two factors of a and b, they are equally important. |
| 3           | Compared to the two factors of a and b, a is a little more important than the b factor |
| 5           | Compared to the two factors of a and b, a is more important than the b factor |
| 7           | Compared to the two factors of a and b, a is more important than the b factor |
| 9           | Compared to the two factors of a and b, a is more important than the b factor |
| 2, 4, 6, 8  | The importance of X and Y two factors is between the above figures. |

3. Calculation of relative weight
   - First, the relative weight is calculated by the eigenvalue method, and the maximum eigenvalue and eigenvector are calculated by geometric mean method.
④ Consistency test
In order to ensure the validity of the result, we need to carry out consistency checking, and do not accord with the requirement of consistency.

⑤ Weight of calculation index
After calculating the importance of each factor relative to the target layer, the absolute weight is calculated from top to bottom.

2.3. The establishment of grey clustering evaluation model
By using the grey clustering method, we must first define the classification and classify the measured data and objects by whitening weight function. In order to make the same level factors consistent, the triangle whitening weight function is selected as the grey clustering evaluation method because of the fuzzy and correlation factors in the evaluation of the green building design.

The triangle whitening weight function based on the endpoint [5] is set “w” as a cluster index, and “n” as a grey class number and \( \chi_j \) as an index (\( j = 1, 2, \ldots, W \)) the sample observation value, the grey clustering evaluation object has the number of “n”, the range of “J” \([a_1, a_{n+1}]\) can be divided into \([a_1, a_2], \ldots, [a_{k-1}, a_k], \ldots, [a_{n-1}, a_n], [a_n, a_{n+1}]\), for the evaluation datum is not consistent, the range of the value of the \( a_k \) is determined according to the actual situation. Set \( a_k \) and \( a_{k+1} \) the value of the midpoint \( \frac{a_k + a_{k+1}}{2} \) triangle whitening weight function \( f_j^k \left( \frac{a_k + a_{k+1}}{2} \right) = 1 \), connect \( \left( \frac{a_k + a_{k+1}}{2} \right), a_k, a_{k+1} \) these three points and join, and get the whitening weight function “K” of grey index “J”: \( f_j^k \left( \bullet \right) \left( j = 1, 2 \ldots w; k = 1, 2, \ldots n \right) \). \( f_j^1 \left( \bullet \right) \) and \( f_j^n \left( \bullet \right) \) expand the range of the index “j” to the left to the right to \( a_0, a_{n+2} \), as shown in Figure 1:

![Figure 1. Trigonometric whitening weight function](image)

In the middle class whitening weight function, the observation value “x” of the index of “j” . The membership function of grey class \( k \left( k = 1, 2, \ldots n \right) \) is expressed as follows:

\[
f_j^k \left( x \right) = \begin{cases} 
0, x \notin [\sigma_j, \sigma_{j+1}] \\
\frac{x - \sigma}{\sigma_j - \sigma_{j+1}}, \ x \notin [a_j, a_{j+1}] \\
\frac{\sigma_j - x}{\sigma_j - \sigma_{j+1}}, \ x \notin [a_j, a_{j+1}] \\
\left( a_j + a_{j+1} \right) / 2 
\end{cases}
\]

(1)
2.4. Determination of the weight of each level of evaluation index

In this paper, the expert scoring method is used to obtain the data structure judgment matrix, and the experts of the green building in Qinghai province are invited to score the standard layer, and the quantitative analysis of the green building technology related data is made. The weight of data is obtained after analyzing and processing data.

Table 3. AHP model evaluation index weight value

| Standard layer | Absolute weight | Index layer | Code | Relative weight | Absolute weight |
|----------------|-----------------|-------------|------|----------------|-----------------|
| Ground and outdoor environment B1 | 0.2100 | Setting green land C1 | X11 | 0.3868 | 0.0812 |
| Rational exploitation and utilization of C2 in underground space | | | X12 | 0.2312 | 0.0486 |
| Indoor air environment C3 | | | X13 | 0.3820 | 0.0802 |
| Energy saving and energy utilization B2 | 0.2500 | External wall insulation system C5 | X21 | 0.3334 | 0.0834 |
| Solar hot water system C6 | | | X22 | 0.3521 | 0.0880 |
| Super quiet new wind system C7 | | | X23 | 0.3145 | 0.0786 |
| Water saving and water resources utilization B3 | 0.1800 | Rainwater reinfiltiration C8 | X31 | 0.3962 | 0.0713 |
| Use of water-saving apparatus C9 | | | X32 | 0.1094 | 0.0197 |
| Using water saving technology C10 | | | X33 | 0.1094 | 0.0197 |
| Use of non-traditional water source C11 | | | X34 | 0.3850 | 0.0693 |
| Utilization of material and material resources by B4 | 0.1700 | Use the local material C12 | X41 | 0.3813 | 0.0648 |
| Repeated use of C13 | | | X42 | 0.1862 | 0.0317 |
| Using prefabricated C14 | | | X43 | 0.3566 | 0.0606 |
| Existing materials using C15 | | | X44 | 0.0759 | 0.0129 |
| Indoor and outdoor environmental quality B5 | 0.1900 | Noise reduction measures C16 | X51 | 0.3881 | 0.0737 |
| Indoor light environment C17 | | | X52 | 0.3119 | 0.0593 |
| Indoor and outdoor air quality C18 | | | X53 | 0.3000 | 0.0570 |

2.5. Determination of evaluation criteria

According to the green building evaluation system established in this paper, combined with the green building evaluation standard issued by Qinghai Province, The evaluation of green building performance is based on the system of ten grades, The grading standard is shown in Table 4.
Table 4. Grading standard for green building design

| Two level index                      | Index parameter                                      | Grading standard  |
|--------------------------------------|------------------------------------------------------|-------------------|
|                                      |                                                      | 1-4 point | 4-7 point | 7-10 point |
| Setting green land C1                | Per capita public green space in residential area    | 1.0-1.3   | 1.3-1.5   | ≥ 1.5      |
| Rational use of C2 in underground space | The ratio of the area of the underground building to the ground floor area | 5%-10%  | 10%-20%  | ≥ 20%      |
| Wind environment in the site C3      | Natural ventilation efficiency                       | ≤50%      | 50%-80%  | ≥80%       |
| External wall insulation system C5   | The improvement of the thermal performance of the enclosure structure | ≤5%      | 5%-10%   | ≥10%       |
| Solar hot water system C6            | Performance of the enclosure structure                | ≤1%       | 1%-2%    | ≥2%        |
| Super quiet new wind system C7       | The reduction of energy consumption in the system     | 5%-10%   | 10%-15%  | ≥15%       |
| Rainwater reinfiltration C8          | Utilization of rainwater                              | ≤5%       | 5%-10%   | ≥10%       |
| Use of water-saving apparatus C9     | Saving rate of water                                 | ≤4%       | 4%-10%   | ≥10%       |
| Use of non-traditional water source C11 | Utilization of non-traditional water sources       | ≤5%       | 5%-30%   | ≥30%       |
| Use the local material C12           | Utilization of local materials                       | 60%-70%  | 70%-90%  | ≥90%       |
| Repeated use of C13                  | Reusable partition ratio                             | 30%-50%  | 50%-80%  | ≥80%       |
| Using prefabricated C14              | Prefabricated component                              | 15%-30%  | 30%-50%  | ≥50%       |
| Use of C15 for existing materials    | Availability of existing materials                   | ≤10%     | 10%-40%  | ≥40%       |
| Noise reduction measures C16         | Noise level                                          | >50dB     | 40dB-50dB | ≤40dB      |
| Indoor light environment C17         | Light recovery coefficient                           | ≤1.5%    | 1.5%-1.8%| 1.8-2%     |
| Indoor and outdoor air quality C18   | Standard rate of atmospheric environment quality      | <90%     | 90%-95%  | ≥95%       |

3. Engineering example analysis

3.1. Engineering project survey
Haidong City, a residential area, with a total construction area of 420 thousand square meters. Large number of new materials and technologies for residential use in this area are adopted.

3.2. Construction and grading of evaluation index set of green building
The evaluation range of green building design evaluation is that the index comments of the ten values are: (extremely poor, poor, poor, poor, general, general, good, good, good, very good), the average result of the score of ten experts can get the evaluation of green building, as shown in table 5.
Table 5. Evaluation value of green building design

| Code name | X11 | X12 | X13 | X21 | X22 | X23 | X31 | X32 | X33 | X34 |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Implementation value | 8.1 | 7.0 | 6.9 | 8.0 | 8.5 | 8.2 | 9.2 | 6.9 | 7.9 | 7.9 |

| Code name | X41 | X42 | X43 | X44 | X51 | X52 | X53 |
|-----------|-----|-----|-----|-----|-----|-----|-----|
| Evaluation value | 7.3 | 7.4 | 6.8 | 7.9 | 8.9 | 8.8 | 8.0 |

3.3. Evaluation of classification of grey category and selection of threshold

The evaluation of these three kinds of green buildings are evaluated, that is $k = 1, 2, 3$, the grade of grey category representing green buildings is: one star, two star, and three-star level, and the range of each grey category has three intervals: $[a_1, a_2], [a_2, a_3], [a_3, a_4] = [1, 4], [4, 7], [7, 10]$.

3.4. The establishment of the trigonometric whitening weight function

Set $\left(\frac{a_k + a_{k+1}}{2}\right)$ belongs to the “k” grey class, and the whitening weight is: $f_j^i\left(\frac{a_k + a_{k+1}}{2}\right) = 1$, to connect the three points: $\left(\frac{a_k + a_{k+1}}{2}\right)$, the starting point of the grey class $a_{k-1}$ and the end of the ash class $a_{k-2}$, and get the trigonometric whitening weight function $f_j^i(\bullet)(j = 1, 2, \cdots, w; k = 1, 2, 3)$, and then extend the value range of the $f_j^i(\bullet)$ and $f_j^i(\bullet)$ to the left and right to the right to get the $\nu_j^0$ and $\nu_j^4$, respectively. The range of grey matter is extended to the left and right to the right to $a_0 = -2, a_5 = 13$. The green building design rating of the index “j” is constructed, and the trigonometric whitening function is constructed as follows:

$$f_j^1(x) = \begin{cases} 0, x \in [-2, 7] \\ \frac{x - (-2)}{2.5 - (-2)}, x \in [-2, 2.5] \\ \frac{7 - x}{7 - 2.5}, x \in [2.5, 7] \end{cases} \quad (3)$$

$$f_j^2(x) = \begin{cases} 0, x \in [1, 10] \\ \frac{x - 1}{5.5 - 1}, x \in [1, 5.5] \\ \frac{10 - x}{10 - 5.5}, x \in [5.5, 10] \end{cases} \quad (4)$$

$$f_j^3(x) = \begin{cases} 0, x \in [4, 13] \\ \frac{x - 4}{8.5 - 4}, x \in [4, 8.5] \\ \frac{13 - x}{13 - 8.5}, x \in [8.5, 13] \end{cases} \quad (5)$$

Therefore, according to the formula, the value of triangular whitening weight function of each index is calculated as shown in Table 6.
Table 6. Evaluation index of trigonometric whitening weight function

| Green building design | Measured value | $f_1^j (v)$ | $f_2^j (v)$ | $f_3^j (v)$ |
|-----------------------|----------------|-------------|-------------|-------------|
| X_{11}                | 8.1            | 0           | 0.42        | 0.91        |
| X_{12}                | 7.0            | 0           | 0.67        | 0.67        |
| X_{13}                | 6.9            | 0.02        | 0.69        | 0.64        |
| X_{21}                | 8.0            | 0           | 0.44        | 0.89        |
| X_{22}                | 8.5            | 0           | 0.33        | 1           |
| X_{23}                | 8.2            | 0           | 0.40        | 0.93        |
| X_{31}                | 9.2            | 0           | 0.18        | 0.84        |
| X_{32}                | 6.9            | 0.02        | 0.69        | 0.64        |
| X_{33}                | 7.9            | 0           | 0.47        | 0.87        |
| X_{34}                | 7.9            | 0           | 0.47        | 0.87        |
| X_{41}                | 7.0            | 0           | 0.60        | 0.73        |
| X_{42}                | 7.1            | 0           | 0.58        | 0.76        |
| X_{43}                | 6.6            | 0.04        | 0.71        | 0.62        |
| X_{44}                | 8.0            | 0           | 0.47        | 0.87        |
| X_{51}                | 8.9            | 0           | 0.24        | 0.91        |
| X_{52}                | 8.8            | 0           | 0.27        | 0.93        |
| X_{53}                | 8.0            | 0           | 0.44        | 0.89        |

3.5. Calculation of comprehensive clustering coefficient

Combined with the weight of each index calculated above, the comprehensive clustering coefficient $\sigma_i^k$ corresponding to the three grey classes $k (k = 1, 2, 3)$ can be obtained, as shown in Table 7.

Table 7. Evaluation index of comprehensive clustering coefficient

| Green building design | Weight   | $f_1^j (x_j)\eta_j$ | $f_2^j (x_j)\eta_j$ | $f_3^j (x_j)\eta_j$ |
|-----------------------|----------|---------------------|---------------------|---------------------|
| X_{11}                | 0.0812   | 0.0000              | 0.0341              | 0.0739              |
| X_{12}                | 0.0486   | 0.0000              | 0.0326              | 0.0326              |
| X_{13}                | 0.0802   | 0.0016              | 0.0553              | 0.0513              |
| X_{21}                | 0.0834   | 0.0000              | 0.0367              | 0.0742              |
| X_{22}                | 0.0880   | 0.0000              | 0.0290              | 0.0880              |
| X_{31}                | 0.0786   | 0.0000              | 0.0314              | 0.0731              |
| X_{32}                | 0.0197   | 0.0004              | 0.0136              | 0.0126              |
| X_{33}                | 0.0197   | 0.0000              | 0.0093              | 0.0171              |
| X_{34}                | 0.0693   | 0.0000              | 0.0326              | 0.0603              |
| X_{41}                | 0.0648   | 0.0000              | 0.0389              | 0.0473              |
| X_{42}                | 0.0317   | 0.0000              | 0.0184              | 0.0241              |
| X_{43}                | 0.0606   | 0.0024              | 0.0430              | 0.0376              |
| X_{44}                | 0.0129   | 0.0000              | 0.0061              | 0.0112              |
| X_{51}                | 0.0737   | 0.0000              | 0.0177              | 0.0671              |
| X_{52}                | 0.0593   | 0.0000              | 0.0160              | 0.0551              |
| X_{53}                | 0.0570   | 0.0000              | 0.0251              | 0.0507              |

$$\sum_{j=1}^{12} f_j (x_j)\eta_j = 0.0044$$

The following results can be obtained:
\[
\sigma_i^3 = \sum_{j=1}^{19} f_j^i(x_j) \cdot \eta_j = 0.0044 \quad \sigma_i^2 = \sum_{j=1}^{19} f_j^i(x_j) \cdot \eta_j = 0.4526 \quad \sigma_i^1 = \sum_{j=1}^{19} f_j^i(x_j) \cdot \eta_j = 0.8362
\]

3.6 Evaluation results
According to the principle of maximum membership degree of green building design evaluation, it comes to \(\max_{1 \leq i \leq 3} \{\sigma_i^i\} = \sigma^3\). The evaluation grade of the green building project is "three-star", which can be certified by the three-star marking of green building, and the performance of green building belongs to a good level.

4. Conclusion
In this paper, according to the local evaluation standard of green building in Qinghai Province, according to the theory of analytic hierarchy process, we calculate the weight of the evaluation index of green building, establish the grey clustering evaluation model, and consider the regional characteristics, establish the green building evaluation system which conforms to the case location. In the future green building evaluation project of Qinghai Province, the index factors of various locals should be selected to establish a scientific and reasonable evaluation index system in order to take reasonable and effective measures in the design of green building projects in Qinghai Province, so as to promote the development of green buildings in this area.

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