A Study on Comprehensive Evaluation Model of Multi-level Green Building Fuzzy Indexes

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Abstract

The contradiction of high energy consumption, environmental pollution and quality living and working environment that people demand are the main contradiction today, and developing green, energy-saving and environment-friendly buildings has become an important solution to it. The evaluation system of green building is crucial in measuring the development level of green building, and the study on the standards of such system is much stressed in China. Fuzzy mathematics theory is used in combination with green building evaluation index system in this paper to determine the set of evaluation factors and evaluations, the fuzzy evaluation matrix established by expert scoring method, and the evaluation model of first, second and third-level fuzzy sets of green building created. This model can be adopted for intuitive judgment of the depth of an indicator in a green building design, providing a definite target for designers and promoting the development of green building in our country.

Keywords: Green Building, Multi-level Index, Fuzzy Evaluation, Model Structure.

1. RESEARCH BACKGROUND

1.1 Literature review

Green buildings emerge in a time when the energy becomes increasingly scarce and environmental pollution aggravating. Green buildings mainly refers to buildings of the maximum saving of resources, comprehensive protection of the environment, energy conservation and pollution reduction, that contribute to a healthy, comfortable and efficient living and use environment, and that exist in harmony with ecological environment in their entire life cycles. With the development of the society, people put forward higher demand for comfortable living and work environment, and the consumption of energy in the building is also increasing (Li, 2014). China’s energy consumption in building occupies one third of the total energy consumption in society, and the proportion still grows in the process of urbanization. China sets as its goal that by 2020, green building will account for 35% of the total newly-built projects, and the carbon dioxide in the GDP be reduced to 45% -50%. In view of this, vigorous promotion of green buildings can effectively control the proportion of energy consumption in building in China and is of practical significance for energy conservation and emission reduction in our country (Qian and Wang, 2014). The green building evaluation system, the standards of which vary with country and region, is an important indicator of the national green level. Given its vast territory, diverse climate, and different economic levels, China has to develop an evaluation system consistent to its basic national conditions, regional differences, and building types, which also fully indicates that it’s an urgent need for China to set up comprehensive evaluation model of multi-level green building fuzzy indexes.

1.2 Purpose of research

Green building adopts green concepts across its entire life cycle, including the planning, design, construction and operation, with the management and certification completed by a third party according to unified index evaluation standards. The goal of green building is to pass green building certification, promote the use of advanced green building science and technology achievements in buildings, make full use of special local resources to establish a
virtuous cycle of harmonious coexistence between man and environment, and realize a new type of building that integrates construction benefits, economy and ecology (Wang and Hu, 2014). With the fuzzy evaluation theory, this paper will calculate the star membership vector of green building, draw the score of the project according to the star vector, and finally judge star certification scope with the project’s score, and then determine the limitations of the green building star certification. It can provide some guidance in practical use.

2. OVERVIEW OF GREEN BUILDING EVALUATION SYSTEM

2.1 Evaluation index

The green evaluation system mainly includes six categories of indicators, namely, land saving, water saving, material saving, energy saving, indoor environmental quality and operation management. Each indicator is further divided into several sub-items.

2.2 Star levels of evaluation

The evaluation is divided into three star levels: one star, two stars, three stars. In the star evaluation, it is required that the control items satisfy the requirements, and the star level is judged according to the number of the general items and that of preferred items. When the total number of the general items is A, and the general number of items required for a star level is B, then the ratio is B / A. When the number of the general items is to be changed to different situations, the number required is the actual number * B / A and the calculation results are rounded off (Li and Qi, 2012). For public buildings and residential buildings, the number of items required is show in Table 1.

Table 1 The Number of Division of the Green Building Rating Requirements

<table>
<thead>
<tr>
<th>Certification of green building</th>
<th>Total goal</th>
<th>Evaluation project</th>
<th>Subproject</th>
</tr>
</thead>
</table>
| 1.Ground and outdoor environment | 1.1 Building site  
1.2 Section  
1.3 green |
| 2.Energy saving and energy utilization | 2.1 Reducing energy pressure  
2.2 Improving the utilization of the system  
2.3 Use renewable energy |
| 3.Water saving and water resources utilization | 3.1 Improving water use efficiency  
3.2 Water-saving Facilities  
3.3 Non traditional water use |
| 4 QUALITY UTILIZATION OF INDOOR ENVIRONMENT | 4.1 Lighting and vision  
4.2 lighting  
4.3 Indoor Air Quality |
| 5. Mustard and utilization of materials | 5.1 The use of green building materials  
5.2 Building materials saving |
| 6. Operation management | 6.1 Intelligent system  
6.2 Estate management  
6.3 Environmental management |

2.3 Deficiencies

We can sum up the following deficiencies of China’s green building evaluation system: (1) “China Ecological Housing Technology Assessment Handbook” is used in residential buildings. Given its vast territory, great differences in climate, local resources, and policies, it is not scientific to adopt a unified weighting system for the evaluation of all buildings in China. (2) Green Olympics evaluation system is designed to fulfill the promise of a green Olympics and only applicable to Olympic-related buildings and large-scale sports buildings (Li and Hou, 2014). Therefore, the application scope of the evaluation system is small, with the index system and standards for the Olympic Games, and not suitable for promotion in China. (3) The evaluation system of green building is a more widely used evaluation method, which clearly divides the design and operation phases of the building, and the evaluation indexes of public buildings and residential buildings are also slightly different (An and Yang, 2015).
It is suitable for the development of green building in China. However, its evaluation index only includes provisions, rather than qualitative and quantitative analysis. Besides the control items, the general items and preferred items have the same right of veto, so the evaluation method is not flexible and can not effectively stimulate the enthusiasm of developers on star certification.

3. ESTABLISHING COMPREHENSIVE EVALUATION MODEL OF MULTI-LEVEL GREEN BUILDING FUZZY INDEXES

3.1 Establishing index weight coefficient

3.1.1 Definition of AHP

Analytic Hierarchy Process (AHP) is a decision-making method that classifies the target lay, criterion layer, index layer and solution layer on decision-making related factors, and makes qualitative and quantitative analysis of the indicator (Ma, 2015). It establishes a multi-layer analysis model, compares the significance of each factor on the same layer, and then establishes the matrix to obtain the weight coefficient of the index to the upper layer through matrix solution.

3.1.2 AHP

Figure 1 shows the detailed process of weighting with AHP.

![Figure 1. Calculation of Weight Flow Chart by Analytic Hierarchy Process](image)

Step One: Clarify the problem and establish the hierarchy. Target layer (top), expected target of the problem; criterion layer (middle), upper layer criterion that influences the realization of the goal; sub-criterion layer (middle), lower layer criterion that influences the realization of the goal; solution layer (bottom), important measures taken for the overall goal. Step Two: Construct the judgment matrix, compare the importance of each factor of the same layer with the factor of the previous laye (Liu, 2017). For example, the relative importance of factors at a certain layer to the specific factor A in the previous layer, the judgment matrix \( A = (a_{ij})_{n \times n} \) can be obtained, where the common values of \( a_{ij} \) are shown in Table 2.

<table>
<thead>
<tr>
<th>Importance scale</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The two element is of equal importance</td>
</tr>
<tr>
<td>3</td>
<td>The two element is a little more important than the latter</td>
</tr>
<tr>
<td>5</td>
<td>The two element is significantly more important than the latter</td>
</tr>
<tr>
<td>7</td>
<td>The two element is significantly more important than the latter</td>
</tr>
<tr>
<td>9</td>
<td>The two element is significantly more important than the latter</td>
</tr>
<tr>
<td>2.4.6.8</td>
<td>The representation is between the two</td>
</tr>
<tr>
<td>Reciprocal</td>
<td>The ratio of the importance of the element I to the element J is ( a_{ij} )</td>
</tr>
<tr>
<td></td>
<td>The ratio of the importance of the element J to the element I is</td>
</tr>
</tbody>
</table>

Table 2 Significance Scale
This paper will use questionnaire to determine the importance of factors on a layer to factors of the previous layer.

Step Three: hierarchy order and consistency test. After constructing the judgment matrix, the paper uses Matlab calculation tool to write the code of the maximum eigenvalue numerical calculation, and finally obtains the weight coefficient of each factor of the matrix through \( AW = \lambda_{\text{max}} W \).

3.1.3 Consistency test

Due to the complexity of objective things, we tend to be subjective and one-sided when constructing the judgment matrix for each comparison. Therefore, after constructing the judgment matrix \( A \), we must carry out consistency test (Yang and Jiang, 2017), where consistency indicator CI: \( CI = \frac{\lambda_{\text{max}}-n}{n-1} \). Then, based on Table 3, determine the average random consistency index RI.

Table 3 Average Random Consistency Index RI

<table>
<thead>
<tr>
<th>n</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>0</td>
<td>0</td>
<td>0.52</td>
<td>0.089</td>
<td>1.12</td>
<td>1.26</td>
<td>1.36</td>
<td>1.41</td>
<td>1.45</td>
<td>1.49</td>
</tr>
</tbody>
</table>

Finally, calculate the ratio of random consistency CR as \( CR = \frac{CI}{RI} \). When \( CR \leq 0.10 \), that the consistency of the judgment matrix is within the accepted range; otherwise, the judgment matrix is to be further adjusted.

3.2 Overview of fuzzy evaluation

In 1965, US professor founded fuzzy mathematics that, with its unique fuzzy theory and method of dealing with fuzzy problems, has been widely used in many fields. Being fuzzy, it means the state of objective things with no clear definition and boundaries, which is an objective property of things (Bao and Wang, 2013). Fuzzy comprehensive evaluation is an evaluation method based on fuzzy mathematics theory. It can quantify the qualitative description through membership theory and can be used to deal with difficult-to-quantify fuzzy problems. The evaluation index system thus established takes into full account China’s basic national conditions and proposes requirements of multi-level indicators for water, land, energy, material saving and environmental protection. Some indicators in the system lack specific quantification, so it is feasible to use the fuzzy comprehensive evaluation method to calculate the evaluation results of the index system (Man, 2013).

3.3 Fuzzy evaluation theory

The general process of fuzzy theory evaluation is as follows:

3.3.1 Establish feature set

\[
U = (u_1, u_2, \ldots, u_m)
\]

The above formula indicates that the set \( U \) contains \( m \) elements that have an impact on its objective evaluation, and \( U \) is also called the first feature set, where \( u_i=(u_{i1}, u_{i2}, \ldots, u_{im}) \) represents the second feature set, or a sub-target feature set of \( u_i \) (Li, 2015).

3.3.2 Establish evaluation set

Evaluation set: \( X = (x_1, x_2, \ldots, x_n) \)

\( x_j (j=1, 2, \ldots, n) \) refers to level \( j \) in the evaluation.

3.3.3 Establish weight set
Given the different severity of the impact on the target and to accurately reflect the impact of various factors on its evaluation objectives, this paper uses AHP to determine the weight of the evaluation index.

\[ W = (w_1, w_2, ..., w_m), \ 0 \leq w_i \leq 1, \sum_{i=1}^{m} w_i = 1 \]  

Among them, \( w_i \) represents the weight coefficient of \( u_i \) on the goal object.

3.3.4 Establish membership matrix

The degree of membership indicates the degree to which each factor conforms to the target. When the index is evaluated by the evaluation criteria, the evaluation results vary with evaluators. The membership evaluation matrix is established to avoid forcing comprehensive opinions of the evaluators (Liu and Wang, 2016). It stipulates that the degree of possibility of making evaluation results of \( u_i \) as \( x_j \), recorded as membership degree \( r_{ij} \). Therefore, the membership vector of evaluating \( i \) factors in \( m \) evaluation scales is:

\[ R_i = (r_{i1}, r_{i2}, ..., r_{im}), \ (i=1, 2, ..., m) \]

Therefore, the membership matrix is constructed as:

\[ R = (R_1, R_2, ..., R_n)^T = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \]

In matrix \( R \), \( r_{ij} = \) (number of people making some evaluation of the indicator) / total number of people participating in the evaluation.

3.3.5 Single-layer fuzzy comprehensive evaluation vector \( B \)

Assuming that the evaluation membership matrix is \( R = [r_{ij}] n \times m \), the corresponding weight vector is \( W = (w_1, w_2, ..., w_m) \), the fuzzy comprehensive evaluation vector \( B \) is

\[ B = W \ast R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_m \end{bmatrix} = (b_1, b_2, ..., b_n) \]

The vector \( B \) in the above formula is the fuzzy comprehensive evaluation of the index. When dealing with multi-layer and multiple-index problems, the single-layer fuzzy comprehensive evaluation is hard to get the correct evaluation results. Classification should be made to the different nature of the evaluation factors before multi-layer comprehensive evaluation is conducted to the evaluation results, with principle similar to single-layer fuzzy comprehensive evaluation (Zhang and Zhou, 2013).

4. GREEN BUILDING FUZZY EVALUATION MODEL

Construct green building fuzzy multi-layer index comprehensive evaluation model according to fuzzy evaluation theory and supervision evaluation index system.

4.1 Multi-layer evaluation element set

Level-1 indicator evaluation element set: \( U = (u_1, u_2, u_3, u_4, u_5) = (\text{energy saving, water saving, materials saving, indoor environmental quality}) \)
Level-2 indicator evaluation element set: \( U_1 = (u_{11}, u_{12}, u_{13}, u_{14}) = (\text{land use, outdoor environment, traffic design, site design and greening}) \). \( U_2 = (u_{21}, u_{22}, u_{23}, u_{24}) = (\text{Architectural design of retaining structure, HVAC, electrical and lighting, energy use}) \). \( U_3 = (u_{31}, u_{32}, u_{33}) = (\text{Building water system, water use efficiency, use of non-traditional water sources}) \).

Level-3 indicator evaluation element set: \( U_{11} = (u_{111}, u_{112}, u_{113}) = (\text{land saving, green space, underground space utilization}) \). \( U_{12} = (u_{121}, u_{122}, u_{123}, u_{124}) = (\text{outdoor light environment, outdoor sound environment, outdoor wind environment, outdoor heat island}) \). \( U_{13} = (u_{131}, u_{132}) = (\text{Public transport, supporting public buildings}) \). \( U_{14} = (u_{141}, u_{142}, u_{143}) = (\text{Ecological design and layout, rainwater recovery and utilization, greening methods}) \). \( U_{21} = (u_{211}, u_{212}, u_{213}) = (\text{Building design, containment thermal performance}) \). \( U_{22} = (u_{221}, u_{222}, u_{223}, u_{224}) = (\text{Energy efficiency, system optimization, energy saving control measures}) \). \( U_{31} = (u_{311}, u_{312}) = (\text{Water system design, public water saving measures}) \). \( U_{32} = (u_{321}, u_{322}) = (\text{Building form design, building materials measures}) \). \( U_{33} = (u_{331}, u_{332}) = (\text{Sound insulation performance, noise reduction measures}) \).

4.2 Evaluation elements weight set

Corresponding weight vector to Level-1 indicators:
\[ W = (\text{Land saving, energy saving, water saving, material saving, indoor environmental quality}) = (w_1, w_2, w_3, w_4, w_5) \]

Corresponding weight vector to Level-2 indicators:
\[ w^1 = (\text{Land use, outdoor environment, traffic design, site design and greening}) = (w_{11}, w_{12}, w_{13}, w_{14}) \]
\[ w^2 = (\text{Architectural design of retaining structure, HVAC, electrical and lighting, energy use}) \]
\[ w^3 = (\text{Building water system, water use efficiency, use of non-traditional water sources}) \]

Corresponding weight vector to Level-3 indicators:
\[ w^{11} = (\text{Land saving, site greening rate, underground space utilization}) = (w_{111}, w_{112}, w_{113}) \]
\[ w^{12} = (\text{Outdoor light environment, outdoor sound environment, outdoor wind environment, outdoor heat island}) = (w_{121}, w_{122}, w_{123}, w_{124}) \]
\[ w^{13} = (\text{Public transport, supporting public buildings}) = (w_{131}, w_{132}) \]
\[ w^{14} = (\text{Ecological design and layout, rainwater recovery and utilization, greening methods}) \]
\[ w^{15} = (\text{Building parameter design, containment thermal performance}) \]
\[ w^{16} = (\text{Energy utilization, system optimization, energy saving measures}) \]
$w^{41} =$ (Water system design, public water saving measures)

$w^{42} =$ (Building form design, building materials measures)

$w^{43} =$ (Sound insulation performance, noise reduction measures)

### 4.3 Star levels

Green building star certification includes three stars, two stars, one star, failure, and evaluation vector therefore determined as: $X=(x_1, x_2, x_3, x_4)=$ (three stars, two stars, one star, failure), and the corresponding score vector is: $Y=(y_1, y_2, y_3, y_4)$.

### 4.4 Fuzzy evaluation matrix

Use expert scoring method to score each indicator in line with the evaluation levels (Li and Li, 2013). For example, invite ten experts to score land-saving targets, and if three experts score three stars, four experts score two stars, two experts score one star, and one expert score failure, then the final evaluation vector of land saving is (0.3, 0.4, 0.2, 0.1).

Define $R_{ij}$ as the fuzzy evaluation matrix of $U_{ij}$. $r_{ij}^{pq}$ represents the score level of $U_{ij}$ is $q, q \in \{1, 2, 3, 4\}$. Classify the membership matrix according to indicator layers, and the fuzzy matrix model of Level-1 indicators is:

$$R_{ij} = \begin{bmatrix}
    r_{ij}^{11} & \ldots & r_{ij}^{1q} \\
    \ldots & \ldots & \ldots \\
    r_{ij}^{p1} & \ldots & r_{ij}^{pq}
\end{bmatrix} \tag{6}$$

Among them, $0 \leq r_{ij}^{pq} \leq 1, r_{ij}^{p1} + \ldots + r_{ij}^{pq} = 1$. According to the model, we can list the fuzzy evaluation matrix constituted by scores of the experts in the green building evaluation system:

$$R_{11} = \begin{bmatrix}
    r_{11}^{11} & r_{11}^{12} & r_{11}^{13} & r_{11}^{14} \\
    r_{12}^{11} & r_{12}^{12} & r_{12}^{13} & r_{12}^{14} \\
    r_{13}^{11} & r_{13}^{12} & r_{13}^{13} & r_{13}^{14} \\
    r_{14}^{11} & r_{14}^{12} & r_{14}^{13} & r_{14}^{14}
\end{bmatrix}, \quad R_{21} = \begin{bmatrix}
    r_{21}^{11} & r_{21}^{12} & r_{21}^{13} & r_{21}^{14} \\
    r_{22}^{11} & r_{22}^{12} & r_{22}^{13} & r_{22}^{14} \\
    r_{23}^{11} & r_{23}^{12} & r_{23}^{13} & r_{23}^{14} \\
    r_{24}^{11} & r_{24}^{12} & r_{24}^{13} & r_{24}^{14}
\end{bmatrix}, \quad R_{31} = \begin{bmatrix}
    r_{31}^{11} & r_{31}^{12} & r_{31}^{13} & r_{31}^{14} \\
    r_{32}^{11} & r_{32}^{12} & r_{32}^{13} & r_{32}^{14} \\
    r_{33}^{11} & r_{33}^{12} & r_{33}^{13} & r_{33}^{14} \\
    r_{34}^{11} & r_{34}^{12} & r_{34}^{13} & r_{34}^{14}
\end{bmatrix}, \quad R_{41} = \begin{bmatrix}
    r_{41}^{11} & r_{41}^{12} & r_{41}^{13} & r_{41}^{14} \\
    r_{42}^{11} & r_{42}^{12} & r_{42}^{13} & r_{42}^{14} \\
    r_{43}^{11} & r_{43}^{12} & r_{43}^{13} & r_{43}^{14} \\
    r_{44}^{11} & r_{44}^{12} & r_{44}^{13} & r_{44}^{14}
\end{bmatrix}, \quad R_{51} = \begin{bmatrix}
    r_{51}^{11} & r_{51}^{12} & r_{51}^{13} & r_{51}^{14} \\
    r_{52}^{11} & r_{52}^{12} & r_{52}^{13} & r_{52}^{14} \\
    r_{53}^{11} & r_{53}^{12} & r_{53}^{13} & r_{53}^{14} \\
    r_{54}^{11} & r_{54}^{12} & r_{54}^{13} & r_{54}^{14}
\end{bmatrix}$$

### 5. CONCLUSION

Green building evaluation is a complicated and systematic project, and should be developed to the types of buildings and regions. Despite its rapid development in recent years, green building in China still lags behind developed countries. Based on fuzzy mathematics theory, the paper constructs a new multi-level indicator comprehensive evaluation method for green buildings, defines each index according to fuzzy comprehensive
evaluation theory and discusses the specific evaluation method, with a view to better promote the development of green buildings in China.

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