Construction and applied research of low-carbon building evaluation index system

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Abstract. Energy conservation in building is a key link on alleviating energy-deficient contradiction, improving the quality of human life environment, and realizing sustainable development in our country. In this paper, we construct low-carbon building evaluation index system and evaluation method from five aspects—low-carbon structure, low-carbon materials, low-carbon energy, low-carbon technology and low-carbon management. Finally, taking “Solar Valley” in Dezhou as an example, we make the evaluation to its situation of low-carbon building.

1. Introduction

At present, our country is in the period of rapid advance of urbanization. Obviously, urban construction promotes the rapid development of building industry. The increase of energy consumption of building and rise continuously of consumption ratio rise continuously bring great pressure to energy saving and emission reduction in our country. Hence, the low-carbon transformation in building industry is imperative.

China is a building giant. Building industry is not only large energy consumption, but also the pillar industry of national economy. Energy conservation in building is a key link on alleviating energy-deficient contradiction, improving the quality of human life environment, and realizing sustainable development in our country. The development of low-carbon building is an indispensable and important part in low-carbon urban construction. Building industry is one of the three major energy consumption industries. Low-carbon transformation is the urgent requirement and strategic choice to speed up the transformation of economic development patterns and adjustment of economic structure, having great significance for the development of low-carbon economy and energy conservation and emissions reduction.

2. Construction of low-carbon building evaluation index system

According to the evaluation index system of green building at home and abroad, the method of AHP fuzzy comprehensive evaluation was used to analyze the construction of low-carbon building evaluation index system comprehensively. Finally, a set of evaluation index system that is suitable to China's low-carbon buildings is put forward.

2.1. Low-carbon building Evaluation index system

In this paper, the evaluation index system on low-carbon building could be divided three levels: object level, criterion level and index level. In addition, we establish 5 first class indexes—low-carbon structure, low-carbon materials, low-carbon energy, low-carbon...
technology, low-carbon management, and 20 second class indexes—energy measurement and monitoring, collective heating, utilization ratio of renewable energy and so on, constructing hierarchical structure model based on low-carbon building evaluation index system, as shown in Table 1. “Low-carbon building evaluation index system” belongs to object level, 5 first class indexes belong to criterion level and 20 second class indexes belong to index level.

### Table 1. Low-carbon building evaluation index system

| Object level | Criterion level                                    | Index level                                      |
|--------------|----------------------------------------------------|--------------------------------------------------|
| U            | Lighting system U11                                | U1                                               |
|              | Heating system U12                                 | U12                                              |
|              | Flooring system U13                                | U13                                              |
|              | Wall system U14                                    | U14                                              |
| U            | Using local materials U21                          | U2                                               |
|              | Building materials production U22                  | U22                                              |
|              | Reuse of materials and waste disposal U23          | U23                                              |
| U            | Energy measurement and monitoring U31              | U31                                              |
|              | Collective heating U32                             | U32                                              |
|              | Utilization ratio of renewable energy U33          | U33                                              |
|              | Utilization ratio of clean energy U34              | U34                                              |
| U            | Utilization of low-carbon and novel materials U41  | U41                                              |
|              | Introduction of novel construction technique U42   | U42                                              |
|              | Utilization of energy conservation and emissions reduction technique U43 | U43 |
|              | Investment of intelligent electronic equipment U44 | U44                                              |
|              | Specialization ratio of building construction team U45 | U45 |
| U            | Greening rate U51                                   | U51                                              |
|              | Talent team construction of real estate U52        | U52                                              |
|              | Waste disposal U53                                  | U53                                              |
|              | Operations management U54                          | U54                                              |

#### 2.1.1 Low-carbon structure index. This index mainly refers to the integrated planning and structural system of building in the process of construction. It is mainly to make evaluation from 4 indexes—lighting system, heating system, floors and wall system. The low-carbon structure index evaluation criterion is shown in Table 2.

### Table 2. Low-carbon structure index evaluation criterion

| Evaluation index | Excellent       | Good            | Fair            | Poor                 |
|------------------|-----------------|-----------------|-----------------|----------------------|
| Lighting system  | Fully coincident| Basically coincident | Partial coincident | Not coincident       |
| Heating system   | 4 items are qualified. | 3 items are qualified. | 2 items are qualified. | One or no item is qualified. |
| Flooring system  | 4 items are qualified. | 3 items are qualified. | 2 items are qualified. | One or no item is qualified. |
| Wall system      | 3 items are qualified. | 2 items are qualified. | 1 item is qualified. | No item is qualified. |

#### 2.1.2 Low-carbon materials index. This index refers to whether the used building materials are low-carbon and recycled in the process of construction. It is mainly to make evaluation from 3 indexes—using local materials, building materials production, material recycling and waste management. The low-carbon materials index evaluation criterion is shown in Table 3.

#### Table 3. Low-carbon materials index evaluation criterion

| Evaluation index | Excellent       | Good            | Fair            | Poor                 |
|------------------|-----------------|-----------------|-----------------|----------------------|
| Using local materials | Fully coincident | Basically coincident | Partial coincident | Not coincident       |
| Building materials production | 4 items are qualified. | 3 items are qualified. | 2 items are qualified. | One or no item is qualified. |
| Material recycling and waste management | 4 items are qualified. | 3 items are qualified. | 2 items are qualified. | One or no item is qualified. |
| Waste disposal | 3 items are qualified. | 2 items are qualified. | 1 item is qualified. | No item is qualified. |
| Operations management | 3 items are qualified. | 2 items are qualified. | 1 item is qualified. | No item is qualified. |
Table 3. Low-carbon materials index evaluation criterion

| Evaluation index                        | Excellent                  | Good                       | Fair                       | Poor                      |
|----------------------------------------|----------------------------|----------------------------|----------------------------|---------------------------|
| Using local materials                  | 3 items are qualified.     | 2 items are qualified.     | 1 item is qualified.       | No item is qualified.     |
| Building materials production          | 3 items are qualified.     | 2 items are qualified.     | 1 item is qualified.       | No item is qualified.     |
| Reuse of materials and waste disposal   | 4 items are qualified.     | 3 items are qualified.     | 2 items are qualified.     | One or no item is qualified. |

2.1.3. Low-carbon energy index. This index refers to the effective and sufficient utilization of energy in the process of building construction and operations management. It is mainly to make evaluation from 4 indexes—energy measurement and monitoring, collective heating, utilization ratio of renewable energy and utilization ratio of clean energy. The low-carbon energy index evaluation criterion is shown in Table 4.

Table 4. Low-carbon energy index evaluation criterion

| Evaluation index                        | Excellent                  | Good                       | Fair                       | Poor                      |
|----------------------------------------|----------------------------|----------------------------|----------------------------|---------------------------|
| Energy measurement and monitoring       | 3 items are qualified.     | 2 items are qualified.     | 1 item is qualified.       | No item is qualified.     |
| Collective heating                      | 3 items are qualified.     | 2 items are qualified.     | 1 item is qualified.       | No item is qualified.     |

2.1.4. Low-carbon technology index. This index refers to a series of adopted energy conservation and emissions reduction techniques, the enhancement of energy utilization efficiency and reduction of waste emission in the process of building construction. It is mainly to make evaluation from 5 indexes—utilization of low-carbon and novel materials, introduction of novel construction technique, utilization of energy conservation and emissions reduction technique, investment of intelligent electronic equipment, specialization ratio of building construction team. The low-carbon technology index evaluation criterion is shown in Table 5.

Table 5. Low-carbon technology index evaluation criterion

| Evaluation index                        | Excellent                  | Good                       | Fair                       | Poor                      |
|----------------------------------------|----------------------------|----------------------------|----------------------------|---------------------------|
| Utilization of low-carbon and novel materials | 3 items are qualified. | 2 items are qualified.     | 1 item is qualified.       | No item is qualified.     |
| Introduction of novel construction technique | 3 items are qualified. | 2 items are qualified.     | 1 item is qualified.       | No item is qualified.     |
| Utilization of energy conservation and emissions reduction technique | 4 items are qualified | 3 items are qualified.     | 2 items are qualified.     | One or no item is qualified. |

2.1.5. Low-carbon management index. This index refers to the implemented low-carbon management in the process of construction completion, putting into normal use and operations maintenance. It is mainly to make evaluation from 4 indexes—greening rate, talent team construction of real estate, waste disposal and operations management. The low-carbon management index evaluation criterion is shown in Table 6.

Table 6. Low-carbon management index evaluation criterion

| Evaluation index                        | Excellent                  | Good                       | Fair                       | Poor                      |
|----------------------------------------|----------------------------|----------------------------|----------------------------|---------------------------|
| Talent team construction of real estate | 4 items are qualified      | 3 items are qualified.     | 2 items are qualified.     | Two or no item is qualified. |
| Waste disposal                         | 3 items are qualified      | 2 items are qualified.     | 1 item is qualified.       | No item is qualified.     |
2.2. Evaluation method of low-carbon building

2.2.1. Establish evaluation factors set. Generally, evaluation factors gather is expressed as $U = \{u_1, u_2, \cdots, u_n\}$. The evaluation element can be quantitative or qualitative. Evaluation factors in this paper refer to the 20 indexes established above.

2.2.2. Establish level comment set. Comment set refers to the set which is consisted of various evaluations to each sub-factor set made by the estimator according to the actual demand. Generally, it is expressed as $V = \{v_1, v_2, \cdots, v_m\}$, where $v_i$ is evaluation level criterion, and $m$ is number of level comment. In this paper, according to the scores and votes made by experts, the level comment set of low-carbon building evaluation index system is identified as $V = \{\text{excellent, good, fair, poor}\}$.

2.2.3. Fuzzy comprehensive evaluation. The goal of fuzzy comprehensive evaluation is to obtain more reasonable evaluation results, and it is essential to consider all factors comprehensively, not just analyze one factor. According to single factor evaluation known matrix $R$ and weight set $W$, comprehensive evaluation should be made through fuzzy transformation. Fuzzy comprehensive evaluation is expressed as $B$, fuzzy comprehensive evaluation index is expressed as $b_j$, namely evaluation index which could be explained as membership grade of evaluation object to evaluation element $v_i$ when consider all factors.

$$B = W \odot R = \left( w_1, w_2, \cdots, w_n \right) \odot \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} = \left( b_1, b_2, \cdots, b_n \right)$$

3. Applied research of low-carbon building evaluation index system

“Solar Valley” in Dezhou is a joint name, covering solar production manufacturing, technology research, talent cultivation and relative supporting industries; it is a generalization of image of solar industrial cluster, planning to construct a solar “Silicon Valley” that incorporate production, learning and research as a whole. “Solar Valley” in Dezhou is a green “Jerusalem” that reveal human wisdom. Represented by “Solar Valley” in Dezhou, Chinese Sun City—Dezhou introduce an idea of low-carbon ecology starting from tourism project planning, implement energy saving and environmental protection building materials in the process of construction, using new energy products in lighting, landscaping, building in scenic spot whenever possible; guide accommodation and catering industry to implement low-carbon and green management model, insisting on clean production, advocating green consumption, protecting ecological environment and use the resources rationally; osmosis the idea of low-carbon into eating, accommodation, transportation, traveling, shopping, entertainment and other links of every tourist, launched a activity—“Access Chinese Sun City, Experience Low-carbon Trip”, attracting tourists to experience low-carbon tourism. Above all, we should build brand of “Chinese Sun City—low-carbon Dezhou”, and make efforts to become a pioneer of low-carbon green and practitioner of low-carbon tourism.

Through field researching and communicating with staff of “Solar Valley” in Dezhou, we

| Operations management | qualified. | qualified. | qualified. | qualified. |
|-----------------------|------------|------------|------------|------------|
|                       | 4 items are qualified | 3 items are qualified | 2 items are qualified | One or no item is qualified |


manipulate collected data detailedly, and analyze the raw data of quantitative index, as is shown in Table 7.

### Table 7. Raw data of quantitative index evaluation criterion

| Quantitative index                              | Unit | Data | Evaluation rating |
|------------------------------------------------|------|------|-------------------|
| Utilization ratio of renewable energy           | %    | 25   | Excellent         |
| Utilization ratio of clean energy               | %    | 42   | Excellent         |
| Investment ratio of intelligent electronic equipment | %    | 28   | Good              |
| Specialization ratio of building construction team | %    | 95   | Excellent         |
| Greening rate                                   | %    | 40   | Excellent         |

Through experts’ questionnaire, telephone interview and other forms, consulting the leaders and staff of “Solar Valley” in Dezhou, university professors and relative experts of Environmental Protection Agency in Dezhou, 15 qualitative indexes of low-carbon were got.

After calculating the scores of each evaluation index in low-carbon building evaluation system by evaluation panel of experts based on the method of membership grade of quantitative index and qualitative index, fuzzy matrix of low-carbon building evaluation index of “Solar Valley” in Dezhou could be obtained, as is shown in Table 8.

### Table 8. Fuzzy matrix of low-carbon building evaluation index of “Solar Valley” in Dezhou

| Evaluation index                                      | Excellent | Good | Fair | Poor |
|------------------------------------------------------|-----------|------|------|------|
| Lighting system                                      | 0.533     | 0.267| 0.200| 0    |
| Heating system                                       | 0.400     | 0.467| 0.133| 0    |
| Flooring system                                      | 0         | 0.600| 0.400| 0    |
| Wall system                                           | 0.400     | 0.400| 0.200| 0    |
| Using local materials                                | 0.200     | 0.400| 0.400| 0    |
| Building materials production                        | 0.800     | 0.200| 0    | 0    |
| Reuse of materials and waste disposal                | 0.133     | 0.600| 0.267| 0    |
| Energy measurement and monitoring                    | 0.544     | 0.456| 0    | 0    |
| Collective heating                                   | 0         | 0.942| 0.058| 0    |
| Utilization ratio of renewable energy                | 1         | 0    | 0    | 0    |
| Utilization ratio of clean energy                    | 1         | 0    | 0    | 0    |
| Utilization of low-carbon and novel materials        | 0.667     | 0.200| 0.133| 0    |
| Introduction of novel construction technique         | 0.333     | 0.667| 0    | 0    |
| Utilization of energy conservation and emissions reduction technique | 0.733     | 0.267| 0    | 0    |
| Investment of intelligent electronic equipment       | 0         | 1    | 0    | 0    |
| Specialization ratio of building construction team   | 1         | 0    | 0    | 0    |
| Greening rate                                        | 1         | 0    | 0    | 0    |
| Talent team construction of real estate              | 0.200     | 0.667| 0.133| 0    |
| Waste disposal                                       | 0.267     | 0.533| 0.133| 0.067|
| Operations management                                | 0.133     | 0.600| 0.267| 0    |

Bring fuzzy evaluation matrix and weight to the model, the result can be obtained:

\[
B = W \circ R = \begin{pmatrix} w_1 r_{11} & \cdots & w_n r_{1m} \\ w_1 r_{21} & \cdots & w_n r_{2m} \\ \vdots & \ddots & \vdots \\ w_1 r_{m1} & \cdots & w_n r_{mm} \end{pmatrix}
\]

\[
= \begin{pmatrix} 0.632 & 0.217 & 0.103 & 0.048 \end{pmatrix}
\]
0.632+0.217+0.103+0.048=1, so the result of evaluation has been normalized.

According to the principle of maximum membership grade, evaluation result of building of “Solar Valley” in Dezhou that the relative performance being “excellent” is 0.632. 63.2 % of the total votes think the result of low-carbon building evaluation is “excellent”, 21.7 % of the total votes think that is “good”, 10.3 % of the total votes think that is “fair”, and only 1.8 % of the total votes think that is “poor”. Order scores set \( F = (f_1, f_2, f_3, f_4)^T = (90, 80, 70, 60)^T \), namely 80-90 scores is excellent, 70-80 scores is good, 60-70 scores is fair, below 60 scores is poor. Therefore, the calculated result of comprehensive evaluation value is:

\[
Z = B \times F = (0.632, 0.217, 0.103, 0.048) \times (90, 80, 70, 60)^T = 84.33
\]

84.33 is between 80 and 90, so low-carbon building evaluation result of “Solar Valley” in Dezhou is “excellent”.

The evaluation result corresponds to the actual situation, and the comprehensive evaluation of low-carbon building of “Solar Valley” in Dezhou is 84.33. It is mainly ascribed the efforts that “Solar Valley” in Dezhou made in utilization of energy conservation and emissions reduction technology, clean and renewable energy, adoption of modern management means, vigorously development new solar products and technique, and “Solar Valley” in Dezhou has acquired good benefits.

4. Conclusion

Investigating and evaluating carbon emission in the construction project, analyzing various influencing factors in the process of implementing low-carbon building, constructing low-carbon building evaluation index system and evaluation method are conductive to understanding the current situation of their own carbon emission for construction corporation, and accordingly improve the links and activities that have great impact on carbon emission in the process of construction effectively, as well as provide decision and gist in understanding the situation of low-carbon building development and taking specific carbon reduction measures for relative government departments.

Low-carbon building is in the early stage of development in our country, and the difficulties and challenges that we are faced with is huge. Therefore, it is necessary to give full play to the role of three main body—government, enterprise and society, strengthening the consciousness of developing low-carbon economy in the whole society, forming a national low-carbon green life style and consumption patterns, and jointly promoting the healthy development of low-carbon building.

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