Green Building Energy Efficiency Evaluation and Optimization

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Abstract. This paper analyzes the influencing factors of energy saving benefits of green buildings, and summarizes six types of influencing factors of energy saving benefits, including lighting performance and ventilation performance. Through Bayesian network machine learning, the Bayesian network evaluation model of green building energy efficiency is constructed, and the comprehensive evaluation index system of green building energy efficiency is established. Combined with practical case analysis, the core influencing factors with high degree of influence are obtained by Bayesian network reasoning.

1. Introduction
With the sustainable development of the construction industry and the continuous expansion of the construction market, the resulting resource and environmental problems are becoming more and more prominent. In 2018, Energy consumption during building operation in China was 1 billion tons of standard coal equivalent, and the carbon emissions were 2.11 billion tons of carbon dioxide, accounting for 21.7% and 21.9% of the total energy consumption and national carbon emissions, respectively [1]. Obviously, the current extensive development model of China’s construction industry is no longer in line with China’s sustainable development strategy. Therefore, the government departments issued green building evaluation standards and related management measures to comprehensively promote the development of green buildings. Green building needs to invest a lot of resources and technology in the construction process, which leads to excessive investment in the early stage of green building. However, the energy-saving benefits of green buildings can only be reflected in the stage of operation, which makes developers and relevant participants lack objective understanding and evaluation of the energy-saving benefits of green buildings, which to some extent affects the development and promotion of green buildings.

Based on this, in recent years, domestic and foreign scholars have carried out extensive and in-depth research on the evaluation of green building energy efficiency, and have made a series of achievements. Han Y and Chen H [2] used analytic hierarchy process to analyze green building energy-saving technologies from five aspects, including building envelope energy-saving technologies and HVAC energy-saving technologies. Based on the theory of value engineering, Zhu Z et al. [3] analyzed the incremental cost and incremental benefit of the whole life cycle of green buildings, combined specific cases to verify the practicability and effectiveness of the evaluation method. Based on the perspective of building energy consumption, Dwaikat [4] studied the impact of different energy prices and actual building performance on the energy cost of green buildings during operation, and evaluated the economic benefits.
Therefore, this paper attempts to find a new way to evaluate and optimize the energy efficiency of green building based on Bayesian network theory. Through collecting data and consulting experts, the paper makes a further scientific and objective analysis on the influencing factors and interaction relationship of green building energy efficiency. Building energy efficiency evaluation model of green building based on Bayesian network and building energy efficiency evaluation index system by structure learning and parameter learning. Combined with practical cases, this paper evaluates and optimizes the indicators that affect the energy efficiency evaluation of green building. It is expected to provide some theoretical reference for relevant groups to evaluate the energy efficiency of green building, so as to promote the sustainable development of green building industry.

2. Identification of Influencing Factors

2.1. Preliminary Identification of Influencing Factors

Due to the numerous factors affecting the efficiency of green building energy conservation, this paper refers to the national GB / T50378-2019《Green building evaluation standard》[5]. It is concluded that the factors affecting the efficiency of green building energy conservation can generally be analyzed from the aspects of light environment, sound environment and so on [6]. Taking the light environment as an example, it can be divided into outdoor light environment and indoor light environment. The indoor light environment involves many influencing factors such as the ratio of outer window to wall, the direction of building, and the shading components. In order to comprehensively analyze the influencing factors of green building energy efficiency, 46 influencing factors are preliminarily selected in this paper.

2.2. Determine the Influencing Factors

By sorting out relevant literature and consulting experts’ opinions, the influencing factors with similar connotations such as sunshine spacing and building spacing, building layers and building height are combined, and the factors with less influence such as road organization and building layout are eliminated [7]. Finally, 28 influencing factors of green building energy efficiency are screened out, and they are divided into six dimensions, as shown in table 1.

| Classification              | Influencing factor                                                                 |
|----------------------------|-------------------------------------------------------------------------------------|
| Lighting performance       | Window-wall ratio of external window, Window-wall ratio of inside window, Daylighting skylight and lighting well, Building orientation, Building height |
| Ventilation performance    | Natural ventilation, Equipment ventilation, Window opening ventilation frequency, Wall vents |
| Noise reduction performance| Percentage of green coverage, Hollow glass, Sound absorption and sound insulation materials, Building interval, Building site selection |
| Water-saving performance   | Valve and piping structure design, Water-saving appliances, Reclaimed wastewater, Collection and Utilization of Natural Precipitation |
| Thermal insulation performance | Window material, Curtain wall material, External wall thermal insulation, Ventilated wall, Greening rate |
| Solar energy utilization   | Number of solar photovoltaic panels, Distribution of solar panels, Number of shading components, Distribution of shading components, Number of solar water heaters |

2.3. Scale Design and Analysis

Cronbach’s α values of lighting performance, ventilation performance, noise reduction performance, water saving performance, heat preservation performance and solar energy utilization in the scale were 0.901, 0.916, 0.921, 0.911, 0.934 and 0.924, respectively, which were all greater than 0.7, indicating that the items of each dimension of the scale had high internal consistency. Principal component analysis
was used to analyze scale data. A total of six common factors with eigenvalues greater than 1 were extracted, and the variance contribution rates were 13.653 %, 13.386 %, 12.491 %, 12.188 %, 11.642 % and 11.386 %, respectively. The cumulative variance contribution rate was 74.746 %, indicating that the six factors explained 74.746 % of the information of the scale, indicating that the extracted factors were acceptable. Based on the above analysis, it is concluded that the data of each index in this study have high reliability and validity.

3. Bayesian Network Evaluation Model

3.1. Construction of Bayesian Network Evaluation Model

Bayesian Network is a directed acyclic graph composed of nodes and directed arcs, which is a theoretical model tool for causal analysis and probability reasoning. Nodes represent each information element, directed arc segment represents the relationship between nodes, conditional probability represents the degree of influence between nodes. A simple Bayesian network model is shown in figure 1. The conditional probabilities between the parent node and the child node are $p(b|a)$ and $p(c|b)$, respectively. Then the probability of the parent node occurrence is $p(a,b,c) = p(a)p(b|a)p(c|a,b)$. In the Bayesian network evaluation model of green building energy efficiency, the conditional probability between each node is $p(x_1, x_2... x_k) = p(x_k|x_1, x_2... x_{k-1})... p(x_2|x_1)p(x_1)$.

![Figure 1. Simple Bayesian network model.](image)

Due to the large amount of data of green building energy efficiency evaluation, this paper uses GeNIe2.3 to build Bayesian network evaluation model. As shown in figure 2, in the Bayesian network evaluation model of green building energy efficiency, six types of indicators such as lighting performance and ventilation performance are the parent nodes of each energy efficiency influencing factor. Similarly, green building energy efficiency evaluation is the parent node of six kinds of indicators such as lighting performance and ventilation performance.
3.2. Establishment of Comprehensive Evaluation Index System

Through literature review and expert consultation, the rating results of each sub-node can be obtained by rating each evaluation index. In this paper, we set the final node joint probability in state 1, 2, 3, 4, 5, respectively, indicating that the evaluation results are 'good, relatively good, medium, relatively poor, poor'. \( P(\text{state}\_i) \) represents the conditional probability value of the end node at level \( i \). By multiplying the scores of each level with the conditional probability value, the comprehensive evaluation index \( G \) of green building energy efficiency is obtained, as shown in equation (1).

\[
G = 100 \times P(\text{state}5) + 80 \times P(\text{state}4) + 60 \times P(\text{state}3) + 40 \times P(\text{state}2) + 20 \times P(\text{state}1)
\]  

When \( G \geq 80 \), the green building energy efficiency evaluation results are 'good', when \( 80 \geq G \geq 60 \), the green building energy efficiency evaluation results are 'relatively good', when \( 60 \geq G \geq 40 \), the green building energy efficiency evaluation results are 'medium', when \( 40 \geq G \geq 20 \), the green building energy efficiency evaluation results are 'relatively poor', when \( 20 \geq G \geq 0 \), the green building energy efficiency evaluation results are 'poor'.

4. Case Analysis

4.1. Project Overview

Wuhan Construction Building is located at the junction of Changqing Road and Zhenxing Road in Wuhan City. It covers an area of 6360 m\(^2\) and the total building area is 25318 m\(^2\). As shown in figure 3, there are five floors above ground, one floor below ground, and the basement area is 3934.90 m\(^2\). It is a typical case of green energy-saving renovation of old buildings to improve green energy-saving benefits, which has strong practical significance and can provide some reference for the evaluation of green energy-saving benefits.
4.2. Analysis of Evaluation Results

Based on the Bayesian network evaluation model and comprehensive evaluation index system established above, combined with the key indicators of the project, the comprehensive evaluation of energy efficiency benefits of green building for the transformation project is carried out. The comprehensive evaluation indexes of energy-saving benefits of the project are respectively expressed as “good”, “relatively good”, “medium”, “relatively poor” and “poor”. The partial specific case evaluation is shown in Table 2.

| Wuhan Construction Building | Architectural design indicators | Comprehensive evaluation |
|-----------------------------|---------------------------------|--------------------------|
| building orientation        | Southward                      | medium                   |
| building height             | Five floors above, one floor below | medium                  |
| hollow glass                | Shading coefficient 0.16 ~ 0.93 | relatively poor          |
| reclaimed wastewater        | Water supply system hydrostatic pressure not exceeding 0.35 mpa | relatively good          |
| Number of solar water heaters | Fulfilled rate of solar water heater to domestic hot water is 86.7 % | medium                 |
| Window material              | OTK aluminum alloy insulating glass with built-in shutters | relatively poor          |

Similarly, the joint probability value of the final node can be deduced according to the conditional probability value of the nodes that affect the energy efficiency of green building. According to equation (1), the evaluation value of green building energy efficiency (final node) can be calculated. \[ G = 100 \times P(\text{state}5) + 80 \times P(\text{state}4) + 60 \times P(\text{state}3) + 40 \times P(\text{state}2) + 20 \times P(\text{state}1) = 63.2. \] Therefore, the green energy-saving benefit evaluation result of the building is ‘relatively good’.
4.3. Evaluation Indicators Reasoning Optimization

4.3.1. Positive Reasoning Analysis. Changing the probability value of the sub-node of the window-wall ratio, the state5 probability value is updated from 22 % to 100 %, so that it is completely in the state5 state. According to Bayesian network reasoning, the probability value of the state5 of the window ventilation frequency is updated from 12 % to 31 %, the probability value of the state5 of the lighting performance is updated from 21 % to 28 %, the probability value of the state5 of the ventilation performance is updated from 23 % to 26 %, and the probability value of the state5 of the green building energy efficiency evaluation of the final node is updated from 20 % to 27 %. It can be seen that the higher the window-wall ratio is, the greater the window ventilation frequency is, the better the lighting performance is, the better the ventilation performance is, the higher the green building energy efficiency evaluation is, and there is a positive correlation between the factors.

4.3.2. Reverse Reasoning Analysis. Set the final node to the highest level, inverting the changes to the child nodes. If the probability value of green building energy efficiency evaluation state5 is set to 100 %, the change of lighting performance and ventilation performance state5 reaches or exceeds 10 %, and the change is significant. The three-level indicators of state5 changes more than 8 % include the distribution of shading components, the ventilation performance of equipment, the setting of lighting skylights, the material of external windows, the ratio of external windows to wall, the number of solar panels, building spacing, natural ventilation performance, and building orientation. The energy-saving benefits of green buildings can be improved by changing the above factors.

5. Conclusion

This paper takes the green building as the research object, and evaluates the energy saving benefits generated in the operation stage. By analyzing the possible influencing factors of green building energy efficiency, the Bayesian network evaluation model of green building energy efficiency is constructed and the comprehensive evaluation index system of green building energy efficiency is established. Summarizing the full text, the following conclusions can be drawn.

- This paper sorts out the influencing factors of green building energy efficiency, through the collation of data and consulting relevant staff, experts and scholars engaged in green building energy efficiency transformation, and finally screens out 28 influencing factors of green building energy efficiency including lighting performance and ventilation performance.
- Through Bayesian network learning, taking the influencing factors of green building energy efficiency as child nodes, six kinds of indicators such as lighting performance and ventilation performance as parent nodes, and green building energy efficiency evaluation as final node, a visual Bayesian network evaluation model and a comprehensive evaluation index system are constructed to provide an effective evaluation and optimization tool for green building energy efficiency evaluation.
- Combined with specific cases, the energy efficiency of green building is evaluated. Through forward reasoning, reverse reasoning, the key influencing factors such as the distribution of sunshade purchases, natural ventilation performance, and the ratio of window to wall are identified as a certain theoretical reference.

References

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