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Comprehensive Evaluation of Energy-saving Effect of Green Buildings in Chemical Plants

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The energy-saving effect of chemical plants is influenced by many factors, it is a complicated and systematic project to evaluate it scientifically and objectively. On the basis of the evaluation criteria of green energy-saving effects of public buildings and factories at home and abroad, this paper combines with the development status of China's chemical industry, formulates the principle for the selection of evaluation indicators for the energy-saving evaluation system of chemical plant green buildings, selects relevant contents including land resources, energy, water resources, and materials as evaluation indicators; this paper uses Analytic Hierarchy Process (AHP) to calculate the weights of the evaluation indicators in the evaluation system, the results show that, energy, water, and materials account for the largest proportion of the entire evaluation system, and it’s the focus of the energy-saving effect of the chemical plants buildings; at last, this paper constructs energy consumption indicators of chemical plant green buildings to evaluate the comprehensive effect of building energy conservation.

1. Introduction

With the rapid economic development, China's industrialization (Raftery et al., 1998) is also in a critical period of rapid expansion. Industrial buildings (San, 2010), as industrial development infrastructures, accounted for more than 50% in the entire construction industry (Song, 2018).

As the pillar industry of the national economy, the plant construction of the chemical industry also occupies a large proportion. Traditional chemical factories (Kaming et al., 1994) cover large areas, they are simple in design, and have no consideration of the impact on the environment (Ghandour et al., 1983), which left nothing but a dirty impression in people’s heart.

With the development of the economy and people’s increasing demands on the environment, applying green building technologies such as solar energy (Kabalci, 2013), natural lighting, new processes, and new equipment to chemical plants, building industrial parks (Fox and Skitmore, 2002) that have complete ecosystems (Korhonen, 2001) and integrate science, efficiency, tidy and environment, is the goal of the business development and the direction of the development of energy-saving buildings.

At present, China's green building energy-saving evaluation system (Suh et al., 2014) is mainly targeted at residential and public buildings (Asdrubali et al., 2015), while for factories, especially chemical plants, which have a large impact on the environment (Krarti, 2015), there is no complete and systematic evaluation criteria yet.

Therefore, it is necessary to build a green building evaluation system for industrial plants, and it is also important for the sustainable development of society and the environment. The effect of energy-saving in chemical plants is influenced by many factors, and its scientific, objective, and accurate evaluation is a complex and systematic project.

Based on the evaluation criteria of green energy-saving of public buildings and factories at home and abroad, this paper constructs an evaluation indicator system for the green building energy-saving effect of chemical plants, and uses mathematical models to comprehensively evaluate and study the green building energy-saving effect of chemical plants.

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2. Green energy-saving buildings

2.1 Green energy-saving buildings

The construction industry is an industry that consumes a lot of resources and energy. At the same time, it also causes a lot of pollution to the environment during the use of raw materials, construction of buildings, and use of the buildings. For the sustainable development of mankind, for the harmony between construction and nature, for maximizing conservation of resources and protecting the environment, and for providing people with a comfortable and healthy space, the construction of green energy-saving buildings is the goal and direction of development. The most important features of green energy-saving buildings are low consumption, high efficiency, and environmental-friendly.

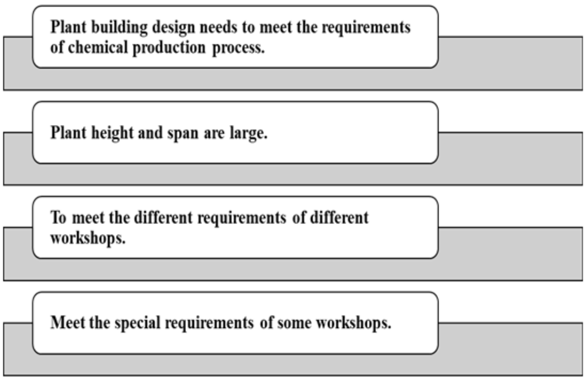

Figure 1: Features of green energy-saving buildings   *Figure 2: Features of chemical factor buildings*

2.2 Evaluation systems of green building energy-saving at home and abroad

The green energy-saving building is a complex and large-scale system engineering that requires cooperation of a variety of technologies, which is of great significance to the sustainable development. Therefore, countries around the world are actively exploring and researching it, and it needs to depend on the green ecological building evaluation system in the actual promotion and application process. Table (1) shows green building evaluation systems established by countries based on their geographical characteristics. The current internationally widely used standards include the US LEED evaluation system, the British BREEAM evaluation system, and the German GNBB evaluation system.

Table 1: Green building evaluation system of some countries

Country	Assessment System	Country	Assessment System
England	BREEAM	USA	LEED
Denmark	BEAT	France	ESCALE
Finland	Promise E	Germany	LNB
Netherlands	Eco-Quantum	Canada	BEPAC
Australia	NABERS	Sweden	Eco-effect
Italy	Protocollo	Japan	CASBEE

2.3 Status and characteristics of the evaluation of chemical plant green buildings

Industrial plant refers to various buildings engaged in industrial production, including various production supporting facilities. The chemical industry has its own production process, so they have some features as shown in Figure 2 above, compared to general residential and civil buildings.

Most of the green building evaluation systems at home and abroad are residential and commercial buildings. The systems that can be used currently to evaluate industrial buildings only are US LEED, UK BREEAM, and Japan CASBEE. The characteristics of the evaluation systems for the energy-saving effect of chemical plant green buildings are shown in Figure (3) below, it is a system of expert cooperation involving multiple disciplines and fields.

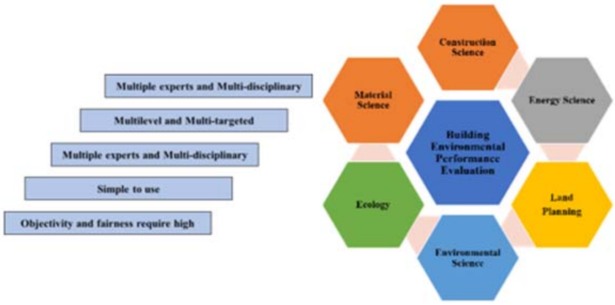

Figure 3: Features of the evaluation of chemical plants green buildings

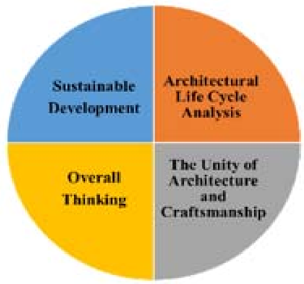

Figure 4: Principle for selection of evaluation indicators

3. Construction of the comprehensive evaluation indicator system

3.1 Principles for the selection of evaluation indicators

When constructing a system for evaluating the energy-saving effect of chemical plant buildings, following principles (4) as shown in the figure are mainly applied for the referring of standards and systems of various evaluation systems at home and abroad. The entire life cycle of a building means the entire period from the design, raw material mining, processing and transportation, construction, to the operation and maintenance of the building, and the disposal of the waste materials, during which, we need to consume least resources and energy, minimize the pollution to the environment, and make the buildings harmonious with the surrounding environment.

3.2 Content and standards of the evaluation systems

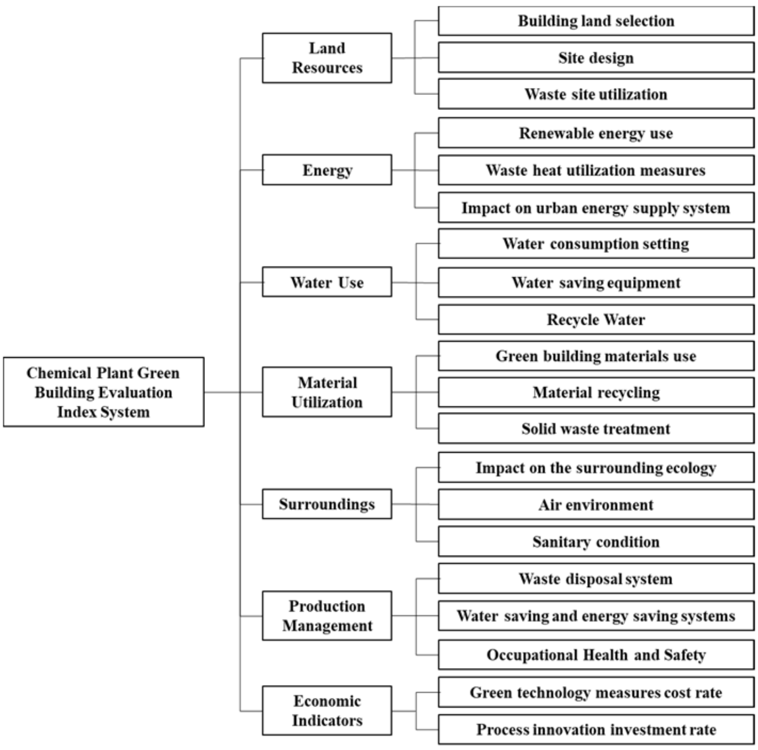

Figure 5: Industrial plant green building evaluation indicators

According to the evaluation systems of green and energy-saving buildings at home and abroad, taking into account the characteristics of chemical plants as industrial buildings, construct a green building energy-saving indicator system as shown in the following figure (5), including 7 level-2 indicators of energy, material utilization and surroundings, etc., and 21 level-3 indicators.

When evaluating the level of indicators, we take the method of combining qualitative indicators with quantitative indicators, as for the environment function characteristics of buildings that can be evaluated using quantitative indicators, we use four grades of excellent, good, medium, and poor, to score 4 points, 3 points, 2 points, and 1 point respectively for evaluation; for qualitative indicators that can not be measured by data, we use descriptive language to judge and evaluate.

4. Comprehensive evaluation of energy-saving effect of chemical buildings

4.1 AHP

The method of evaluation should be as simple as possible in order to facilitate the calculation of the evaluation. In this paper, a method of combining qualitative with quantitative analysis is used to construct a comprehensive evaluation system for the energy-saving effect of chemical plant green buildings. As the evaluation of green building energy-saving involves many aspects and levels, we adopt the AHP, which decomposes the factors related to final decision-making into several levels and then compares the importance, so as to determine the weight of each indicator for the modelling of the final evaluation model. The following figure (6) is the solution process of AHP.

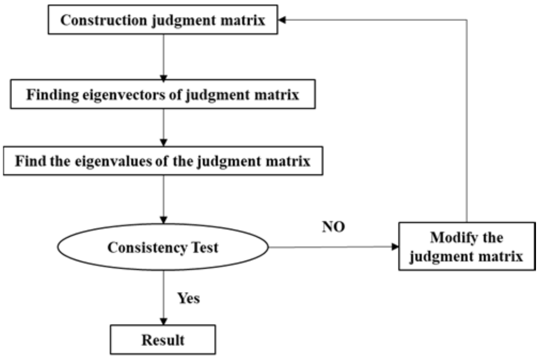

Figure 6: Solving process of AHP

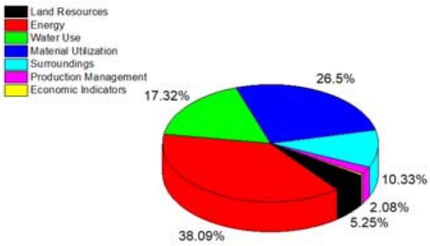

Figure 7: Evaluation results of the criteria level indicators

4.2 Determination of the weight of evaluation indicators

Weight represents the relative importance of a certain indicator in the entire evaluation system. We generally use the weighted coefficient to represent it. In the evaluation system for the energy-saving effect of chemical plant green buildings, this paper will adopt an open system based on the actual conditions of the factory to negotiate and formulate by consulting experts, scholars, and raw material suppliers in various industries.

4.2.1 Method of determining the weight

When determining the weight of the evaluation indicator, the judgment matrix A is obtained by comparing the importance of the indicators in pairs, Table (2) is the judgment of importance level and its corresponding assignment.

Table 2: Scale and its description of AHP

X_i and X_j	Extremely Important	More Important	Obviously important	Slightly Important	Equally Important
Value	9	7	5	3	1

After constructing the judgment matrix, in order to ensure the rationality of the obtained weight values, consistency of the judgement matrix should be tested until the consistency is reached, otherwise, the judgment matrix should be constantly readjusted. The formula for calculating the consistency is as follows:

$$CI=\frac{\sigma_{max}-n}{n-1} \tag{1}$$

$$CR=\frac{CI}{RI} \tag{2}$$

where, CR represents the random consistency ratio, RI represents the random consistency indicator as shown in Table (2), σ_{max} is the maximum eigenvalue of the judgment matrix, and n is the order of the judgment matrix. When CR<0.1, the judgement matrix conforms to the consistency, otherwise it will be adjusted properly until the consistency is satisfied.

Table 3: Specified value of random consistency indicator RI

Order	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

4.2.2 Weight analysis of energy-saving evaluation system of chemical plant green buildings

After expert scoring we can get the comparison matrix, then analyze the matrix for consistency test, and finally the weights of energy-saving evaluation system of chemical plant green buildings are obtained as shown in table (4).

Table 4: Weights of the evaluation indicator system of chemical plant green buildings

Target Layer	Criteria layer	Indicator layer	Weights
Chemical Plant Green Building Evaluation	Land Resources (F_1) 0.0525	Building land selection	0.6473
		Site design	0.0908
		Waste site utilization	0.2619
	Energy (F_2) 0.3809	Renewable energy use	0.5100
		Waste heat utilization measures	0.3461
		Impact on urban energy supply system	0.1439
	Water Use (F_3) 0.1732	Water consumption setting	0.1633
		Water saving equipment	0.4200
		Recycle Water	0.4167
	Material Utilization (F_4) 0.2650	Green building materials use	0.4530
		Material recycling	0.1834
		Solid waste treatment	0.3636
	Surroundings (F_5) 0.1033	Impact on the surrounding ecology	0.5656
		Air environment	0.2876
		Sanitary condition	0.1468
	Production Management (F_6) 0.0208	Waste disposal system	0.3879
		Water saving and energy saving systems	0.4720
		Occupational Health and Safety	0.1401
	Economic Indicators (F_7) 0.0043	Green technology measures cost rate	0.6888
		Process innovation investment rate	0.3112

The pie chart (7) shows the weights of the evaluation indicators shown in the above table, the results show that energy accounts for the largest proportion; followed by the utilization of material, and then the use of water resources and the influence of the surrounding environment. The analysis shows that the green energy-saving effect of chemical plants depends on the utilization of energy, materials, and water resources to a large extent, while other indicators such as land resources and economic indicators have little impact on the green energy-saving effect. Therefore, the top priority of green energy-saving buildings in chemical plants is the utilization of energy and the energy conservation.

4.3 Construction of the indicator of building energy consumption

After determining the distribution of weights of indicators in each level, we can establish a chemical plant energy consumption model. The formula is as follows:

$$\mathrm{M} = \sum_1^n w_i M_i \tag{3}$$

where n represents the total number of evaluation indicators; M represents the indicator value of the building's energy consumption; w_i represents the weight value of each indicator; M_i represents the score of each indicator. The energy-saving effect of chemical plant green buildings is evaluated by the value of M, the larger the M-value, the better the energy-saving effect of the project. According to M's score, we can divide it into several intervals (0, 1], (1, 2], (2, 3], (3, 4], (4, 5], these intervals correspond to the five levels of unqualified, poor, average, good and excellent. The following points should be noted in the process of implementing the evaluation model: (1) The process of evaluation must be transparent and reliable, and base on the principles of openness, fairness and justice; (2) The purpose of the evaluation system is to guide the process of building construction and to achieve energy-saving results, rather than for the final evaluation; (3) The evaluation experts need to have a good professional background.

5. Conclusion

Basing on the evaluation standards of green building energy-saving effect of public buildings and factories at home and abroad, this paper constructs an evaluation indicator system for the energy-saving effect of chemical plant green buildings, and uses mathematical models to comprehensively evaluate and study the green building energy-saving effect of the chemical plants. The specific findings are as follows:

(1) According to the existing green building evaluation systems at home and abroad, this paper combined with the development status of China's chemical industry and formulated the principle of selection of evaluation indicators for the evaluation system of green building energy-saving effect, it selected land resources, energy, water resources, materials and other related content as the evaluation indicators.

(2) This paper uses AHP which combines qualitative analysis with quantitative analysis to calculate the weights of the evaluation indicators in the evaluation system, the results showed that, energy, water, and materials accounted for the largest proportion of the entire evaluation system and should be focused on in the energy-saving buildings.

(3) Finally, this paper constructed energy consumption indicators of chemical plant green buildings which can evaluate the comprehensive effect of energy-saving of the buildings.

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