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# The Research on Energy-saving Reconstruction of Ceramic Kiln Based on Engineering System Theory

Bin Song

Pingdingshan University, Henan 467000, China
binsong59304@21cn.com

In order to optimize the energy-saving benefit of ceramic kiln, the paper discussed energy-saving reconstruction of ceramic kiln based on the method of Engineering System Theory and made a corresponding evaluation. Delphi method and Analytic Hierarchy Process are adopted to determine the weight of each index. Finally, the comprehensive result of the evaluation system is approached by Multi-index Comprehensive Evaluation Method. The benefit of energy-saving reconstruction of ceramic kiln is revealed and its reliability is confirmed; Engineering System Theory is qualified for the evaluation of energy-saving reconstruction of ceramic kiln.

## 1. Introduction

Since ancient time, ceramics has always been one of the most important cultural features of China. Ceramics production is deemed as a traditional artistry in our country. The traditional production of ceramic must adopt kiln whereas problems including high-energy consumption and high pollution exists for a long time in the process of using primitive kiln, which causes huge economic losses. Therefore, in order to improve the situation, energy-saving reconstruction of ceramic kiln has been actively advocated by modern society. Theoretically, the thought of energy-saving reconstruction of ceramic kiln could lead to tangible results with respect to environment. As far as the status quo is concerned, there exist a number of ways regarding energy-saving reconstruction of ceramic kiln without a common technical system. Thus, in order to push the energy-saving reconstruction of ceramic kiln to a more unified, efficient and standardized way, researches should be conducted based on Engineering System Theory.

Based on the Engineering System Theory, the interrelations among energy-saving, economy, environment, management and policy in the energy-saving reconstruction program of ceramic kiln are analyzed. During the process, the appraisal requirement of applying for national fiscal incentives regarding energy-saving technical reconstruction is well-considered. Delphi method, Analytic Hierarchy Process and Multi-index Comprehensive Evaluation Method are adopted to establish a comprehensive evaluation system of energy-saving reconstruction of ceramic kiln.

## 2. Literature review

Since ancient times, China has a superb construction technology and exquisite ceramic firing skills. Until eighteenth Century, Europe began to produce some ceramics imitating Chinese style, and Japan did not master the technology of coal firing until sixteenth Century. However, in the past two centuries, the pace of development in China has been slow, and the ceramic production technology in western countries has developed rapidly and comes from behind. Especially in Japan, Italy, Germany and other countries, the ceramic industry has made rapid progress and is ahead of China with its advanced kiln and firing technology. The modern ceramic kiln has experienced the development process from the flag kiln to the shuttle kiln, the tunnel kiln and the roller kiln, gradually moving towards the "energy saving, light, automation and cleaning" direction. At present, the development of ceramic kilns in the world has entered the era of full automation control of roller kiln and shuttle kiln. With the gradual improvement of technical equipment, great improvement has been made in firing rate, energy consumption and production efficiency of ceramic products.

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At present, there are some studies on the comprehensive evaluation of the system both at home and abroad. These studies are mainly concentrated in the construction and industrial enterprises, and there is not a unified standard or system in the comprehensive evaluation of the ceramic industry energy-saving technology transformation. In China's ceramic industry, energy-saving ideas have been gradually deeply rooted in the hearts of the people. Energy-saving measures are emerging, but the evaluation of energy conservation reform has no clear and unified standard. For the ceramic industry, energy consumption is mainly evaluated by energy audit. The three parts of energy saving, economy and environmental protection are the main criteria to evaluate the feasibility of the project, and the evaluation index is not comprehensive. The evaluation of the scheme is a single independent evaluation, and there is no multi-system and comprehensive evaluation system. However, the research methods and research ideas of the comprehensive evaluation of the system have a certain reference value for the research and application of the comprehensive evaluation system of ceramic kiln technical transformation. The research on system energy-saving evaluation is relatively early in foreign countries. Although China's system energy-saving evaluation research started late, it has also made some progress.

In the field of traffic, Azizi put forward the method of integrating the system, that is to consider the relationship between each subsystem, analyze all the factors that affect the evaluation of the energy consumption of the rail traffic, and thus achieve the purpose of evaluating and optimizing the energy consumption of the whole rail traffic (Azizi et al., 2017). In the field of architectural evaluation, the British Architecture Institute proposed the first green building assessment method in the world. The BREEAM-Building Research Establishment Environmental Assessment Method established a best practice for the design of green buildings and widely used it in Canada and New Jersey, Norway and other places. On the basis of BREEAM, the United States Green Building Commission developed a green building classification evaluation system named LEED (Leadership in Energy and Environmental Design). Aslanoglu established the evaluation index system for the design of rural residential energy conservation. The system comprehensively considered the climate characteristics of the region, the living habits of the residents, the utilization of resources in the rural areas and the supply of resources and so on. At the same time, the information entropy and the unknown measure theory were integrated into the evaluation system. The results indicate that the evaluation system is of a certain degree of adaptability and operability (Aslanoglu et al., 2017). Lei analysed the unreasonable of the economic evaluation method and the energy evaluation method of building energy saving, and pointed out that the evaluation of the efficiency of building energy saving needs to be considered from the whole system and link the system theory with the building energy conservation, and he put forward the system energy-saving evaluation method according to the viewpoint of the system theory (Lei et al., 2017).

In terms of energy-saving evaluation of power plant, Liu constructed a set of more perfect energy-saving evaluation index system for thermal power plant in view of the current energy consumption status and characteristics of domestic thermal power plants. The design of this system conforms to the design principle of the index system, and finally determines the evaluation standard of the index, which has practical value in the comprehensive evaluation of energy conservation in thermal power plants (Liu et al., 2018). Padhi used the theory of matter element analysis when constructing the energy-saving comprehensive evaluation index system of thermal power plants. Combined with the energy-saving status, utilization and characteristics of thermal power plants, they used this system to make a comprehensive evaluation of thermal power plants (Padhi et al., 2017).

In the energy-saving evaluation of automobile industry, Quaglione thought that the energy saving evaluation of automobile industry needs to be measured from two aspects of "technology" and "management". And based on the whole life cycle theory, they considered "technology" and "management", and put forward the idea of automobile energy saving evaluation system (Quaglione et al., 2017).

In the energy-saving evaluation of oil field enterprises, Rozik pointed out entropy weight analysis method to determine the index weight ratio objective. The analytic hierarchy process can consider the subjective experience of experts. The two methods of empowerment can be combined to establish the comprehensive energy saving evaluation model of oil field enterprises. In addition, an effective method for solving the problem of multi index energy saving evaluation is put forward, and the reliability of the method is proved (Rozik et al., 2017).

In addition, Wu put forward that there are some limitations in the current enterprise energy-saving evaluation, without considering the integration of the whole system. Therefore, all factors affecting the energy saving of enterprises are analyzed and studied comprehensively. Based on the system theory, the effect of reducing the pollutant emission reduction is analyzed, and the method of the enterprise energy-saving evaluation is optimized (Wu et al., 2017).

To sum up, in the evaluation process of energy-saving renovation projects of the kiln, there are some problems such as whether the energy-saving transformation of the kiln is feasible, whether the project is economically significant, whether it can meet the requirements of environmental protection, and whether it

meets the national energy-saving policy. The research of comprehensive evaluation index system of kiln renovation is proposed. The purpose is to carry out an exploratory research and practice on the overall evaluation of the transformation effect of the ceramic kiln according to the situation of the energy-saving transformation of the kiln and the comprehensive analysis of the evaluation system. The evaluation system of kiln renovation can provide a unified standard and basis for the comprehensive evaluation of relevant industries.

## 3. Methodology

### 3.1 Overview of comprehensive evaluation system

Evaluation, as a cognitive activity, is widely used in human activities. The Index is often applied as the basis for evaluation. The index that exerts influences on evaluation could be complex. Adopting single index as the only measure of the evaluation could lead to lack of legitimacy. Thus, when carrying out solid evaluation, multiple indexes or contributory factors reflecting evaluation object should be gathered together to form a comprehensive index system, so as to evaluate the overall situation of the object more comprehensively. Such evaluation method is called Multi-index Comprehensive Evaluation Method.

The two main features of Multi-index Comprehensive Evaluation are as follows: Evaluation method includes a number of indexes, describing the different attributes of the evaluation object; The final evaluation should be able to make a holistic evaluation of the object by adopting a aggregate index to describe the general level of the object As the scale of the evaluation object becomes larger, more contributory factors needed to be considered, leading to higher requirements for the evaluation work. The evaluation should not be affected by one-sideness, subjectivity and it should be normative and scientific. Moreover, only quantitative and structural factors fails to met the current high requirement of evaluation work. A large number of unstructured, semi-structured, gray and fuzzy factors should also be included in the process with corresponding solutions. Researchers have already proposed many well-focused comprehensive evaluation methods with various features.

There are many specific methods of comprehensive evaluation, but the overall line of thought is identical. Generally, steps from getting familiar with the evaluation object, establishing the evaluation index system, to determining the weight of each index, to establishing the mathematical model of evaluation, analyzing the evaluation results are all involved. Among them, index system establishment, weight-determination of index and mathematical model building are the key points of the comprehensive evaluation.

### 3.2 Delphi method

Put forward the specific problems of evaluation Identify the members of the expert group Make the first round of the score and send it to the member of the expert group Collect the first round of the score, collect and analyze According to the results of the first round of scoring, the second round of scoring forms will be formulated and sent to the members of the expert group. Collect and analyze the second rounds of the score. According to the conclusion of the second round of scoring, the third round of scoring form is formulated and sent to the members of the expert group. Reclaim the third round of the score and carry out a summary analysis. Prepare the final result

### 3.3 Judgment matrix establishment

Hierarchical structure reflects the relationships among the factors, but each criteria of the criterion layer does not necessarily share the same weight in the measurement of the evaluation object. In the eyes of different decision makers, factors are of different weight.

Assuming to compare the influence of factor $\mathrm{X} = \{x_1, \cdots, x_n\}$ on factor Z, the pairwise comparison of the two factors could be expressed by pairwise comparison matrix. Each time taking out two factors, $x_i$ and $x_j$, and using $a_{ij}$ as the $x_i$ and $x_j$ influence ratio to Z. All the comparison results could be defined in matrix $\mathrm{A} = (a_{ij})_{nxn}$, namely the judgement matrix of A in interval Z-X.It is easy to perceive that the $x_i$ influence ratio to Z is $a_{ji} = \frac{1}{a_{ij}}$, as $a_{ij}$ stands for $x_i$ and $x_j$ influence ratio to Z. Table 1 is scale meaning table.

As for the selection of scale, the paper solicited opinions of experts adopting the Delphi method introduced in Chapter 3.2, the finals of which would be the basis for the judgment matrix. Figure 2 is energy-saving reconstruction model of ceramic kiln and analysis.

*Table 1: scale meaning table*

| Scaling | Definition |
|---|---|
| 1 | The I index is more important than the j index |
| 2 | The I index is slightly more important than the j index |
| 3 | The I index is significantly more important than the j index |
| 4 | The I index is more important than the j index |

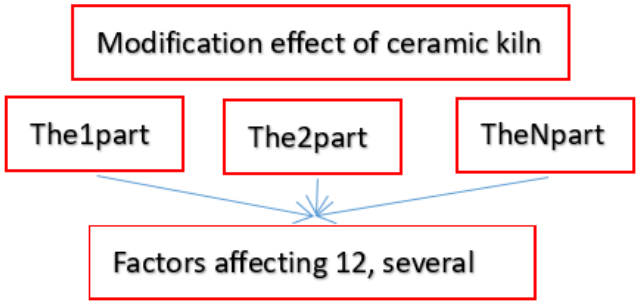


*Figure 2: energy-saving transformation model of ceramic kiln*

### 3.4 composition of the evaluation system

Every part of criterion layer would affect the evaluation of the reconstruction of ceramic kiln window, the factors of which are correlated with each other to various extent. For example, changes on the first part itself could have a positive or negative impact on the evaluation system and on other parts, while the outcome of the first part could also be influenced by one or several inner factors. The premise to conduct a solid comprehensive evaluation is to conduct a detailed assessment of each small part of it. Due to the complexity of the reconstruction system of ceramic kiln window, meticulous analysis of each part of it should be carried out to find out the influence each factor has on other factors and on the whole system. Only in this way could a solid comprehensive evaluation be accomplished. The thinking of whole evaluation system should be comprehensive. The chosen parts or contributory factors should be well-focused. The analyzing process should be feasible and the evaluation criteria should be objective.

### 3.5 Energy-saving evaluation

As shown in Figure 3, the specific evaluation of construction of ceramic kiln with respect to energy-saving is divided into three parts.

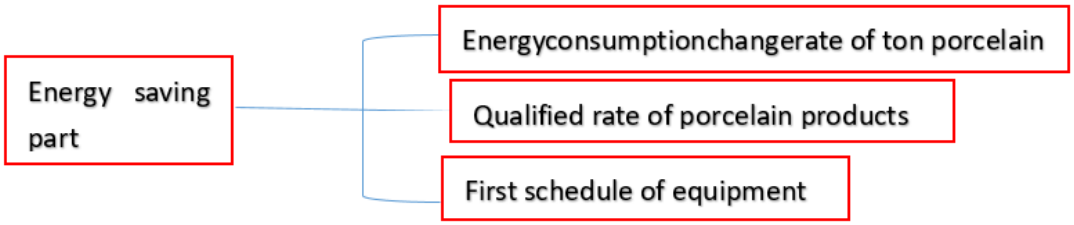


*Figure 3: Energy saving evaluation index*

### 3.6 Feasibility evaluation

Compare the calculated return on investment (hereinafter referred to as ROI) to the average ROI of the industry or standard ROI of the industry. If the calculated ROI is greater than or equal to the average or standard ROI, the project is deemed to be feasible, otherwise is not. Figure 4 is Economic Part Evaluation Index.

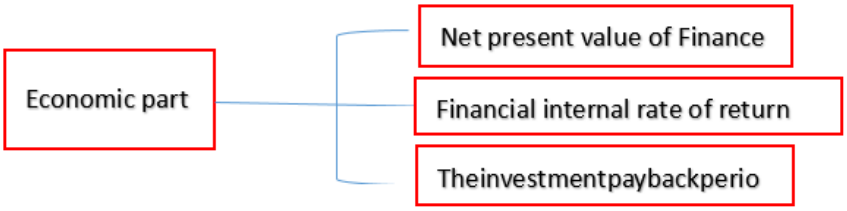


*Figure 4: Economic part evaluation index*

Accordingly, the four above parts should be accounted in evaluating economic benefits of a program. The four concrete economic indexes are: 1. net present value of finance, the performance of the profitability; 2. financial internal rate of return, the utilization of the funds; 3. the investment payback period, the cost-recovery period; 4. return on investment, investment profit level against the industry.

### 3.7 Environmental evaluation index determination

Based on the promulgation of the "Emission Standards for Ceramic Industrial Pollutants" (GB25464-2010) in 2010, the model is analyzed as shown in Table 2.

*Table 2: emission standards for industrial pollutants (GB25464-2010)*

| Contaminants | Company | The secret of the stick, the secret of the road, Suo Shifen |
|---|---|---|
| $SO_2$ | $mg/m^3$ | 500 |
| $NO_X$ ($NO_2$) | $mg/m^3$ | 600 |
| particulate matter | $mg/m^3$ | 100 |

To be specific, exhaust gas emission, dust particles emission and thermal pollution emission are selected as environmental indexes in the evaluation of the reconstruction of ceramic kiln.

## 4. Results analysis

At the beginning, the paper introduced the basic principle and application steps of Delphi method, Analytic Hierarchy Process and Weighted Average Comprehensive Evaluation method, paving the road for case-based calculation of a comprehensive evaluation system in the next step. Evaluation index system was established through Analytic Hierarchy Process. The weight of each index in the evaluation index system was determined based on Delphi method and Analytic Hierarchy Process. The comprehensive evaluation value of the evaluation index system was obtained using Delphi method and Weighted Average Comprehensive Evaluation. Next, comprehensive energy-saving evaluation model was established in combination with the features of energy-saving technical reconstruction of ceramic kiln. It provided ideas and basis of evaluation for the case-based analysis later. Then, the judgment matrix formed by evaluation index system, which gathered experts opinions based on Delphi method, was applied. Finally, the weight of each index was calculated upon the principles and methods of Analytic Hierarchy Process and thus obtain the weight of the comprehensive index the of the model.

## 5. Conclusion

Based on comprehensive evaluation theory, the paper proposed that the comprehensive evaluation of the reconstruction of sealing furnace should include five parts, which are energy-saving, economy, environment, management and policies. The comprehensive evaluation index system of reconstruction of channeling furnace is established. The exploratory assessment of the reconstruction program of S kiln of the ceramic company has been conducted. The concrete work are listed as follows:

Firstly, indexes of the five parts that influence the comprehensive evaluation outcome of the reconstruction of ceramic kiln are analyzed. Energy-saving part has three impact indexes. Economy part has four impact indexes. Environment part has three impact indexes. Management part has three impact indexes and policy part has two impact indexes.

Secondly, based on the impact index of the reconstruction of channeling furnace, a comprehensive evaluation model suitable for the reconstruction of ceramic kiln is primarily built. The analytic hierarchy model is set up adopting the method of Analytic Hierarchy Process. The model has three layers with five criterion layers and 15 index layers below.

Thirdly, the weights of individual part and the weights of index of the evaluation system are calculated with the process of experts scoring and Analytic Hierarchy Process Method. Among them, the weight of each index of the criterion layer, the top index layer of the index system, are 0.43 in energy-saving, 0.26 in economy, 0.15 in environment, 0.11 in management, 0.25 in policy respectively. By calculating, the significance of each index upon comprehensive evaluation system could be revealed.

When expert scoring is involved in the evaluation process, subjectivity, leading to different scores from different judges, is unavoidable. Further improvement of this step is expected, while objective value replacing subjective value with correspondence in between could be suggested. Based on that, objective value could be obtained and translated to subjective value to realize the evaluation outcome.

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