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Research on Comprehensive Evaluation Method for Heating Project Based on Analytic Hierarchy Processing

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Abstract. It is effective to reduce haze in winter by changing the distributed heat supply system. Thus, the studies on comprehensive index system and scientific evaluation method of distributed heat supply project are essential. Firstly, research the influence factors of heating modes, and an index system with multiple dimension including economic, environmental, risk and flexibility was built and all indexes were quantified. Secondly, a comprehensive evaluation method based on AHP was put forward to analyze the proposed multiple and comprehensive index system. Lastly, the case study suggested that supplying heat with electricity has great advantage and promotional value. The comprehensive index system of distributed heating supply project and evaluation method in this paper can evaluate distributed heat supply project effectively and provide scientific support for choosing the distributed heating project.

1. Introduction

In recent years, the environmental situation in China is grim and especially the PM 2.5 is serious. Heating supply with coal in North China is considered as the important sources of the smog. Distributed heat supply systems with gas or electricity are effective in reducing the pollution. While, the evaluation of the distributed heat supply project should be comprehensive, including economic, environmental, risk and other aspects [1]. Therefore, the evaluation index system for distributed heat supply project is essential and also a decision-making method for the index system is necessary.

For the study on evaluation of heating project, reference [2] compared the economic efficiency of three types of heat and cooling supply. Aimed at the average annual cost, the replacement of coal with electricity in the future was put forward in the aspect of economy in reference [3]. A research on electricity price for replacing coal with electricity was conduct in reference [4]. Reference [5] studied the effect on cogeneration economic of thermal and electric load distribution and put forward the guiding measures. In reference [6], a comprehensive evaluation on all heating modes based on multiple attribute decision making method was conduct to decide the optimal heating modes. Reference [7] introduced the definitions and calculation methods of main economic indicator for cooling system by gas. Reference [8] built the index evaluation expectations system of heating pipe network. Reference [9] built the economic value and environmental value models for the abandoning wind energy and storing heating in winter

On one hand, the current researches on heating project evaluation focus on only single index or simple factors and are lack of the comprehensive index system, so they cannot evaluate heating project fully. On the other hand, they are lack of evaluating method and cannot provide effectively basis for evaluating the heating plan. Therefore, a comprehensive evaluation method, considering all indexes including economy, environment, economy, risk, and flexibility index, was proposed in this paper, by which the weights of all indexes and the total weights could be obtained and also the optimal heating plan could be obtained.

2. Comprehensive index system and quantitative method

Comprehensive evaluation for heating project depends on a comprehensive index system. Therefore a comprehensive index system that reflects most characteristics in the whole stage of heating project was built in this paper, which is shown as figure 1.

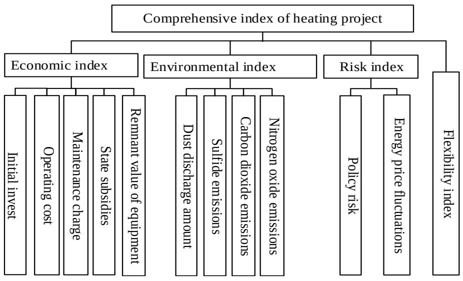

Figure 1. Indicator system with multiple dimensions of heating project

(1) Economic index

Economic index E contains construction and operation stages, including initial invest I, operating cost O, maintenance charge F, allowance W for energy saving and environment friendly equipment and remnant value of equipment Y. The formula is shown as below

$$E = I + O + F - W - Y \tag{1}$$

Where O is energy cost in the whole stage of the project. The formula is shown as below.

$$O = P \times Q / \eta \tag{2}$$

Where P is the price of energy that the heating equipment using, η is efficiencies of heating modes, Q is the total heat load during whole project period.

(2) Economic index

Economic index contains all pollutant discharges, including discharges of dust, sulfur dioxide, carbon dioxide and oxynitride, which can be represented by M. The formula is shown as below.

$$M = (\gamma_C + \gamma_N + \gamma_S + \gamma) \times \lambda \times Q / \eta \tag{3}$$

Where λ is the conversion coefficient of primary energy and the standard coal equivalent, whose value refer to reference [10]. γ_C, γ_N, γ_S and γ are the coefficients of carbon dioxide, oxynitride, sulfur dioxide, and dust respectively that per kilogram standard coal combustion produces, whose values refer to reference [11].

(3)Risk index

Risk index mainly includes environment friendly and energy saving equipment subsidies risks and fluctuations of energy prices, which is shown as below.

$$R=\left(W-E\left(W\right)\right)-\left(P-E\left(P\right)\right)\times Q/\eta \tag{4}$$

Where *E(P)* is the expectation of the energy price in future. *E(W)* is the expectation of the subsidies for energy saving and environmental protection equipment, which contains the equipment purchasing subsidies and energy price subsidies.

$$E\left(W\right)=W\times\left(1-r_W\right)+W_r\times r_W \tag{5}$$

$$E\left(P\right)=P\times\left(1-r_P\right)+P_r\times r_P \tag{6}$$

(4) Flexibility index

Flexibility index *C* refers to the ability to adjust the temperature of the heating equipment. It can be represented by time caused to rise unit temperature as below.

$$C=Q_0/P_0 \tag{7}$$

Where P_0 is the power of heating equipment, and Q_0 is heat load for rising the unit temperature in heating areas. The formula is shown as follows.

$$Q_0=c_0\rho_0V_0 \tag{8}$$

Where c_0, ρ_0 and v_0 are specific heat, density and volume of air respectively.

For some central heating supply, the distance from heat supply center to heating areas should also be considered. Thus, the flexibility index is also related to distance S and the velocity *v* in pipeline, which can be calculated using the following formula.

$$C^*=C+\frac{S}{v} \tag{9}$$

3. Evaluation method based on AHP

The comprehensive evaluation issue is a multiple level model with multiple indexes. The common evaluation methods contain fuzzy comprehensive evaluation, fuzzy analytical method and analytic hierarchy process (AHP). AHP is just the proper method for evaluating the proposed multiple and comprehensive index system. The flowchart of AHP is shown in figure 2.

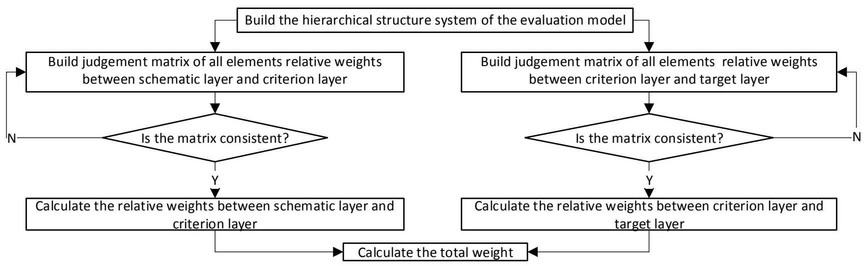

Fig. 2 Flow chart of AHP

(1) The evaluation model of AHP contains three layers, including the target layer, the criterion layer and the option layer. The criterion layer contains the economic criterion, environment criterion, the risk criterion and the flexibility criterion.

(2) The elements of judgement matrix that between schematic layer and criterion layer are the relative weight, which are determined by the ratios of the indexes of the criterion of all projects. Considering the relative weights are inversely proportional to the index, the elements of matrix is set to the reciprocal of the ratios. The criterion was represented by s_k(k=1,2,⋯,K) and the corresponding judgement matrix is A_k(k=1,2,⋯,K), which can be calculated by the following formula.

$$A_k=\begin{bmatrix}\frac{1}{F_{k,1}/F_{k,1}} & \frac{1}{F_{k,1}/F_{k,2}} & \cdots & \frac{1}{F_{k,1}/F_{k,j}}\\ \frac{1}{F_{k,2}/F_{k,1}} & \frac{1}{F_{k,2}/F_{k,2}} & \cdots & \frac{1}{F_{k,2}/F_{k,j}}\\ \vdots & \vdots & \ddots & \vdots\\ \frac{1}{F_{k,i}/F_{k,1}} & \frac{1}{F_{k,i}/F_{k,2}} & \cdots & \frac{1}{F_{k,i}/F_{k,j}}\end{bmatrix}=\left(\frac{1}{F_{k,i}/F_{k,j}}\right)_{N\times N} \tag{10}$$

Where F_k is the k^{th} criteria of the i^{th} project.

(3)The weights of schematic layer and criterion layer can build a weight vector, ω_{sk}(k=1,2,..,K), which is shown as below.

$$\omega_{s_k}=\begin{bmatrix}\dfrac{\frac{F_{k,1}/F_{k,1}}{\sum_{i=1}^{N}F_{k,1}/F_{k,i}}+\frac{F_{k,2}/F_{k,1}}{\sum_{i=1}^{N}F_{k,2}/F_{k,i}}+\cdots+\frac{F_{k,N}/F_{k,1}}{\sum_{i=1}^{N}F_{k,N}/F_{k,i}}}{N}\\ \dfrac{\frac{F_{k,1}/F_{k,2}}{\sum_{i=1}^{N}F_{k,1}/F_{k,i}}+\frac{F_{k,2}/F_{k,2}}{\sum_{i=1}^{N}F_{k,2}/F_{k,i}}+\cdots+\frac{F_{k,N}/F_{k,2}}{\sum_{i=1}^{N}F_{k,N}/F_{k,i}}}{N}\\ \vdots\\ \dfrac{\frac{F_{k,1}/F_{k,N}}{\sum_{i=1}^{N}F_{k,1}/F_{k,i}}+\frac{F_{k,2}/F_{k,N}}{\sum_{i=1}^{N}F_{k,2}/F_{k,i}}+\cdots+\frac{F_{k,N}/F_{k,N}}{\sum_{i=1}^{N}F_{k,N}/F_{k,i}}}{N}\end{bmatrix}=\begin{bmatrix}a_{k,1}\\ a_{k,2}\\ \vdots\\ a_{k,i}\end{bmatrix} \tag{11}$$

(4) The elements of judgement matrix that between criterion layer and target layer are determined by the ratios of weights between the two criterions. The judgement matrix is shown as below.

$$\begin{bmatrix}s_1/s_1 & s_1/s_2 & \cdots & s_1/s_j\\ s_2/s_1 & s_2/s_2 & \cdots & s_2/s_j\\ \vdots & \vdots & \ddots & \vdots\\ s_i/s_1 & s_i/s_1 & \cdots & s_i/s_j\end{bmatrix}=\left(s_i/s_j\right)_{K\times K} \tag{12}$$

Where s_i/s_j is the integer between 1 and 9 and their bottoms. The higher value corresponds to more significant.

(5) Check the consistency of the judgement matrix by consistency ratio (*C.R.*). If *C.R.*<0.1, the matrix is consistent. *C.R.* can be calculated as (13).

$$C.R.=\frac{C.I.}{R.I.} \tag{13}$$

Where *C.I.* is the consistency index, which can be calculated as (14). *R.I.* is the mean consistency index, which is related to the order of the matrix.

$$C.I.=\frac{\lambda_{\max}-1}{k-1} \tag{14}$$

Where λmax is the biggest eigenvalue of the judgement matrix and k is the matrix order.

(6) The relative weights of all elements of criterion layer to target layer can constitute weight vector in turn, which is shown as below.

$$\mu_s = \begin{bmatrix} \dfrac{\dfrac{s_1/s_1}{\sum_{i=1}^{K} s_i/s_1} + \dfrac{s_1/s_2}{\sum_{i=1}^{K} s_i/s_2} + \cdots + \dfrac{s_1/s_K}{\sum_{i=1}^{K} s_i/s_K}}{K} \\ \dfrac{\dfrac{s_2/s_1}{\sum_{i=1}^{K} s_i/s_1} + \dfrac{s_2/s_2}{\sum_{i=1}^{K} s_i/s_2} + \cdots + \dfrac{s_2/s_K}{\sum_{i=1}^{K} s_i/s_K}}{K} \\ \vdots \\ \dfrac{\dfrac{s_K/s_1}{\sum_{i=1}^{K} s_i/s_1} + \dfrac{s_K/s_2}{\sum_{i=1}^{K} s_i/s_2} + \cdots + \dfrac{s_K/s_K}{\sum_{i=1}^{K} s_i/s_K}}{K} \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_k \end{bmatrix} \tag{15}$$

(7) Calculate the combined weights of target layer to all options W_i,, which is shown as below.

$$W_i = \sum_{k=1}^{K} a_{k,i} \cdot b_k \tag{16}$$

4. Case study

4.1. Simulation condition

Take a 10-year heating project as an example. The hotel is 400 m^2, and heating days is 120/year and heating load is 420kWh/day. Five alternative heating options are shown as follows:

Options one: Use a full automatic fuel oil boiler. Heat power is about 70kW and fuel consumption is 4.5kg/hour. The fuel price is 5.5 yuan/kg.

Option two: Use electric hot water boiler. The electric power is 35kW. Heating efficiency is 58kW/35kW and electricity price is 0.48 yuan/kWh;

Option three: Use coal-fired district heating, and heating costs is 42 yuan/m^2. Boiler power is 400 kW. Standard coal is used and heating value is 29307kJ/kg, i.e. about 8.14kWh/kg;

Option four: Use gas boiler. The power is 30kW and natural gas calorific value is 3558.8kJ/L, i.e. 13.85 kWh/kg. Natural gas is about 3.36 yuan/L.

4.2. Results and analysis

According the definition of all indexes and the calculation method shown in formula (1)-(9), the indexes of all options are shown in Table 1.

Table 1 Indexes of four options

Option	Initial Invest	Operating Cost	Maintenance Charge	Subsidies	Residual Value	Environment	Risk	Flexibility
One	100	17.6	10	0	10	155	113.4	29.31
Two	150	15.1	15	10	15	0	97.1	35.38
Three	0	16.8	12	0	0	203	10	502.57
Four	140	12.2	8	10	12	0	13.3	68.4

Based on the index system and evaluation method proposed in this paper, the four heating projects are evaluated and the results are shown in Table 2.

Table 2 Evaluation results of all options

Criterion	Economy	Environment	Risk	Flexibility	Total Ranking
Weight	0.367	0.391	0.096	0.146	
Option One	0.15	0.12	0.05	0.43	0.165
Option Two	0.11	0.66	0.05	0.36	0.394
Option Three	0.61	0.09	0.51	0.03	0.278
Option Four	0.13	0.13	0.39	0.18	0.163

The flexibility of Option 1, 2 and 4 have absolute predominance and Option 1 is the best. Option 3 takes absolute advantage in economic index. Option 3 and 4 have absolute predominance in risk index and option 3 is better, however, option 2 is the best one in total rank. Above all, the proposed method could not only obtain the total weights/rank of the optional heating plans but also the weights/rank of optional plans under each criterion. The results can be used to choose heating projects under the comprehensive evaluation and also under the evaluation of one certain criterion. Therefore, the proposed method can effectively guide the selection of heating projects.

5. Conclusion

A comprehensive evaluation method for heating project based on AHP was proposed. Firstly, a comprehensive index system including economic, environmental, risk and flexibility, was built and all indexes were quantified, which enriched the evaluation index of distributed heat supply projects. Secondly, a comprehensive evaluation method based on AHP was put forward to analyze the proposed multiple and comprehensive index system. Lastly, taking typical heating modes including heat supply with electricity, diesel oil, coal and natural gas as the case study, it suggested that supplying heat with electricity has great advantage and promotional value. The comprehensive index system of distributed heating supply project and evaluation method in this paper can evaluate distributed heat supply project effectively and provide scientific support for choosing the distributed heating project.

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