Evaluation and Analysis of Comprehensive Benefit of Ground Source Heat Pump in Cold Area

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Abstract: In recent years, with the vigorous implementation of the national measures to promote green building energy conservation, a series of regulations and norms concerning building energy conservation policies have been published. Solar energy, heat pump and other clean energy has also been widely used. According to summarize the influencing factors of the operation of the ground source heat pump system, the evaluation method of comprehensive benefit of the ground source heat pump system is proposed, and the evaluation system of various types of heat pump system is integrated through using the unified dimension. Analytic hierarchy process is used to study the evaluation method of the ground source heat pump. A scientific, rational and practical comprehensive benefit evaluation system of ground source heat pump is constructed. At the same time, the evaluation standard of 15 evaluation indexes and the grading standard of comprehensive benefit evaluation are established. The typical soil source heat pump project is selected for the evaluation and its comprehensive evaluation benefit grade is two-level. Based on the evaluation results, we can effectively analyze the areas that need to be optimized and improved, so as to improve the comprehensive benefit.

1. Introduction

At present, the concentration of greenhouse gases in the atmosphere continues to rise significantly. The concentration of greenhouse gases, such as CO₂, CH₄ and N₂O, has risen to its highest level in the past 800,000 years. The main reasons of the increased greenhouse gas concentration are the use of fossil fuels of people and the change of land use [1]. For a long time, the proportion of building energy consumption in China's total energy consumption has been between 20% and 25%. The total energy consumption of building operation in 2014 is 819 million tons of standard coal, accounting for about 20% of the total national energy consumption [2]. Building energy consumption, along with industrial energy consumption and transportation energy consumption, has become one of the three largest energy consumption households in China [3]. How to reduce building energy consumption has become an important issue in today's society. How to safely, efficiently and economically apply renewable energy to building heating and cooling technology is our challenge [4-6].

The ground source heat pump (GSHP) system is more complex and the influence factors of its benefit have a great relationship with the regional conditions. After a lot of research and analysis, the evaluation index of the comprehensive benefit of the ground source heat pump includes technical benefit index, construction design index, economic benefit index, environmental benefit index and so on. It analyzes the problems in the application of ground source heat pump in Liaoning area in recent years and sums up the factors that have great influence on the benefit. What's more, combined with the
operation, energy saving, economy and environmental benefits of the ground source heat pump system, the comprehensive benefit evaluation method and suitability evaluation method of the ground source heat pump suitable for Liaoning area are deeply studied, which provides a reference for the future application and development of the ground source heat pump in our province.

2. Evaluation methodology research

2.1 Selection of evaluation methods

In the study of the evaluation of the performance of the ground source heat pump in China, fuzzy analytic hierarchy process is widely used. Based on the logic of fuzzy basic mathematics, the inefficiency of fuzzy evaluation method is analyzed, two commonly used fuzzy methods are further used to analyze the research object and the inefficiency of the result output is found. Because the theory of fuzzy evaluation method does not follow the four basic principles of classical analytic hierarchy process, this paper decided to use classical analytic hierarchy process (AHP) as the basic evaluation method.

2.2 AHP Introduction

AHP is short for the analytic hierarchy process. It is a systematic and hierarchical analysis method combining qualitative and quantitative analysis, which was formally proposed by American operations researcher T. L. Saaty [7] in the mid-1970s. Because of its practicability and effectiveness in dealing with complex decision-making problems, it quickly gained the worldwide attention. The basic principle of AHP is to decompose a problem into different groups of factors according to the overall achieved goals and the nature of the problems. And according to the affiliation relationship and correlation influence among different factors, the factors are combined at different levels to form a multi-level analysis structure model. Finally, the problem summarizes the determination of the relative importance weight of the lowest level relative to the highest level (the general goal) and the arrangement of the relative advantages and disadvantages. The steps are as follows:

1) Establishment of hierarchical models

The practical problems such as decision-making objectives, index elements and decision-making objects are divided into the highest, middle and lowest levels according to their interrelation. Then the hierarchy structure is drawn. The highest level of the structural model is the target layer, an element for the ultimately evaluated goal. The criterion layer is the intermediate link to achieve the ultimate goal, dominating the elements at the next level and being dominated by the elements at the upper level at the same time. The lowest level is the scheme layer.

2) Construction of judgment matrix(Paired comparison)

A judgment matrix is a comparison of the relative importance of all the factors in a certain layer to the indicators that dominate these factors in the previous layer. The element of the judgment matrix was obtained by using expert scoring method and Saaty’s 9-scale method. The scaling implications of 9-scale method are shown in Table 1.

| Table 1 1~9 Scaling implications |
|-------------------------------|
| scale | implication |
| 1     | I element is as important as j element |
| 3     | I element is slightly more important than j element |
| 5     | I element is significantly more important than j element |
| 7     | I element is strongly more important than j element |
| 9     | I element is extremely more important than j element |
| 2, 4, 6, 8 | The median of the two adjacent judgments |
| count backwards | Judgment of comparison between elements I and j is a_{ij}, then the judgment of comparison between j and I is a_{ij}=1/a_{ij} |
Due to the differences in each expert's professional level, understanding of decision-making objectives and main research directions, we need to use the expert weighting method to assign reasonable weights to each expert for the recovered expert scoring table, so as to ensure the objectivity of the weight of evaluation indicators [7].

The judgment matrix Ai and the consistency ratio CR corresponding to the judgment matrix are constructed by the scoring of the expert i. The weight of each expert is figured out by Eq.(1).

\[
P_i = \frac{1}{1 + aCR_i}, \quad a > 0, \quad i = 1, 2, \cdots, n
\]

(1)

where \(P_i\) is the weight of the expert i; \(CR_i\) is the consistency ratio of judgement matrices constructed by the expert i; a is a regulating parameter, 10 is usually taken as a constant in actual calculation.

Eq.(2) is used to normalize \(P_i\) to get the normalized weight \(P_i^*\) of each expert.

\[
P_i^* = \frac{P_i}{\sum_{i=1}^{n} P_i}
\]

(2)

(3) Calculation of the single ranking weight vectors and the consistency test

There are generally three methods for determining relative weight vectors, including square root method, sum (product) method, eigenvalue method and least square method. In this paper, the eigenvalue method is chosen to obtain the weight.

The consistency test was performed using the consistency index CI, random consistency index RI and consistency ratio CR. If the test passes, it is the weight vector. If not, the judgment matrix should be reconstructed.

(4) Calculation of the total ranking weight vectors and the consistency test

The weight vector of the total ranking of the lowest level against the highest level is calculated and it is checked by using total ranking consistency ratio CR. If passed, the decision can be made according to the result represented by the total ranking weight vector. Otherwise, it is necessary to reconsider the model or reconstruct the judgment matrix with the larger consistency ratio CR.

3 Evaluation Model of Integrated Benefit of GSHP

3.1 Establishment of hierarchical structure of GSHP

Based on the principles of science, comparability, integrity and operability, the evaluation model of comprehensive benefit of GSHP is established. The concept of evaluation indicators should be clear and the indicators should be comparable, where is the possibility of calculating weights. The selected index should cover the whole process of the GSHP system and reflect the comprehensive benefit of the GSHP completely.
3.2 Construction of judgment matrix (Paired comparison)
In order to make the evaluation results more objective and real, 20 questionnaires were sent to the experts of the ground source heat pump industry, university researchers and engineers of the design institute in Liaoning Province. And 15 valid questionnaires were recovered. The experts mark the comparison of relative importance of indicators at all levels based on 9-scale method. According to the scoring results of the questionnaire completed by each expert, the consistency ratio of the judgment matrix constructed by each expert was calculated. Using Eq.(1) and Eq.(2), the weight of each expert in the evaluation system of comprehensive benefit of ground source heat pump was calculated.

The feature vector corresponding to the maximum eigenvalue of the judgment matrix $\lambda_{\text{max}}$ was noted as $W$ after normalizing (the sum of the elements in the vector is equal to 1). $W$ is the weight of the relative importance of the same level factor to the previous level factor. The constructed judgment matrix and $W_i$ were as follows:

| Evaluation System of Integrated Benefit Index of GSHP (A) | Technical benefit evaluation | Economic benefit evaluation | Energy-saving benefit evaluation | Environmental benefit evaluation | $W_i$ |
|---------------------------------------------------------|------------------------------|-----------------------------|---------------------------------|---------------------------------|------|
| Technical benefit evaluation B1                         | 1                            | 6                           | 6                               | 6                               | 0.658|
| Economic benefit evaluation                              | 0.1667                       | 1                           | 2                               | 3                               | 0.1711|

![Fig.1 Hierarchical Structure for Comprehensive Benefit Evaluation of GSHP System](image)
(2) Technical benefit evaluation B1

| Technical benefit evaluation B1 | Performance Coefficient C1 | Indoor temperature guarantee rate C2 | Distribution system C3 | Design and construction C4 | Operation management and maintenance C5 | Wi |
|-------------------------------|-----------------------------|------------------------------------|------------------------|---------------------------|-----------------------------------------|-----|
| Performance Coefficient C1   | 1                           | 3                                  | 3                      | 3                         | 3                                       | 0.405 |
| Indoor temperature guarantee rate C2 | 0.3333                     | 1                                  | 2                      | 3                         | 3                                       | 0.2349 |
| Distribution system C3       | 0.3333                      | 0.5                                | 1                      | 3                         | 3                                       | 0.1799 |
| Design and construction C4   | 0.3333                      | 0.3333                             | 0.3333                 | 1                         | 3                                       | 0.1099 |
| Operation management and maintenance C5 | 0.3333                     | 0.3333                             | 0.3333                 | 0.3333                    | 1                                       | 0.0703 |

(3) Economic benefit evaluation B2
Economic benefit evaluation has only one index element, namely C6 indoor temperature guarantee rate.

(4) Energy-saving benefit evaluation B3

| Energy-saving benefit evaluation B3 | Energy utilization coefficient C7 | Energy-saving ratio C8 | Wi |
|------------------------------------|----------------------------------|------------------------|-----|
| Energy utilization coefficient C7  | 1                                | 3                      | 0.75 |
| Energy-saving ratio C8             | 0.3333                           | 1                      | 0.25 |

(5) Environmental benefit evaluation B4

| Environmental benefit evaluation B4 | Emission reduction C9 | Impact of underground thermal environment C10 | Noise C11 | Wi |
|-------------------------------------|-----------------------|----------------------------------------------|-----------|-----|
| Emission reduction C9              | 1                     | 0.3333                                       | 6         | 0.2926 |
| Impact of underground thermal environment C10 | 3                   | 1                                             | 7         | 0.6406 |
| Noise C11                           | 0.1667                | 0.1429                                       | 1         | 0.0668 |

(6) Performance coefficient C1

| Performance coefficient C1 | Unit performance coefficient D1 | System performance coefficient D2 | Wi |
|----------------------------|---------------------------------|----------------------------------|-----|
| Unit performance coefficient D1 | 1                               | 2                                | 0.6667 |
| System performance coefficient D2 | 0.5                             | 1                                | 0.3333 |

(7) Distribution system C3

| Distribution system C3 | Energy efficiency ratio of ground source side transport D3 | Energy efficiency ratio of user side transport D4 | Pump efficiency D5 | Wi |
|------------------------|-------------------------------------------------------------|---------------------------------------------------|-------------------|-----|
|                        |                                                             |                                                   |                   |     |
Energy efficiency ratio of ground source side transport D3 1 1 4 0.4444
Energy efficiency ratio of user side transport D4 1 1 4 0.4444
Pump efficiency D5 0.25 0.25 1 0.1111

(8) Design and construction C4

| Design and construction C4 | Construction quality D6 | Design of ground source side system D7 | Wi  |
|----------------------------|-------------------------|----------------------------------------|-----|
| Construction quality D6    | 1                       | 2                                      | 0.6667 |
| Design of ground source side system D7 | 0.5 | 1 | 0.3333 |

3.3 Calculation of the single ranking weight vectors and the consistency test
Hierarchical single sorting means that the relative importance of W in each judgment matrix is sorted. Whether it confirms the single hierarchical ordering should be carried out by the consistency test. The consistency test refers to the process of using the numerical table of consistency index CI, consistency ratio CR and random consistency index RI to test matrix A.

The consistency index CI=0, full consistency; CI is close to 0, satisfactory consistency; CI is the more consistent, the less serious. The formula is as follows:

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}
\]

Where n is the order of the matrix; \(\lambda_{\text{max}}\) is the maximum eigenvalue of the matrix. The other random consistency indicator RI, the numerical table obtained by the Saaty [7] Institute of American Operations Research is as follows:

| n  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 |
|----|----|----|----|----|----|----|----|----|----|----|----|
| RI | 0  | 0  | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 |

\[
CR = \frac{CI}{RI}
\]

Normally, when the consistency ratio CR is less than 0.1, it is considered that the inconsistency of matrix A is within the allowable range. And there is satisfactory consistency, passing the consistency test. The normalized feature vector can be used as the weight vector, or the paired comparison matrix A should be reconstructed to adjust \(a_{ij}\). The results of consistency test and hierarchical single ranking of the index judgment matrix of the comprehensive evaluation system are as follows:

(1) Rank weights of B1, B2, B3 and B4 elements to decision target A

| Interlayer element                                  | Weight |
|-----------------------------------------------------|--------|
| Technical benefit evaluation B1                     | 0.658  |
| Economic benefit evaluation B2                       | 0.1711 |
| Energy-saving benefit evaluation B3                  | 0.0889 |
| Environmental benefit evaluation B4                  | 0.082  |

CR=0.0442; \(\lambda_{\text{max}}=4.1179\).
(3) Rank weights of C1, C2, C3, C4 and C5 elements to B1

| Interlayer element                                          | Weight |
|------------------------------------------------------------|--------|
| Performance coefficient C1                                 | 0.405  |
| Indoor temperature guarantee rate C2                        | 0.2349 |
| Distribution system C3                                      | 0.1799 |
| Design and construction C4                                  | 0.1099 |
| Operation management and maintenance C5                     | 0.0703 |

CR=0.0909; $\lambda_{\text{max}}=5.4074$.

(4) The weight of C2 elements to B2 is 1.

(5) Rank weights of C7 and C8 elements to B3

| Interlayer element          | Weight |
|-----------------------------|--------|
| Energy utilization coefficient C7 | 0.75   |
| Energy-saving ratio C8       | 0.25   |

CR=0.0000; $\lambda_{\text{max}}=2.0000$.

(6) Rank weights of C9, C10 and C11 elements to B4

| Interlayer element                                    | Weight   |
|-------------------------------------------------------|----------|
| Impact of underground thermal environment C10         | 0.6406   |
| Emission reduction C9                                 | 0.2926   |
| Noise C11                                             | 0.0668   |

CR=0.0961; $\lambda_{\text{max}}=3.0999$.

(8) Rank weights of D1 and D2 elements to C1

| Interlayer element            | Weight |
|------------------------------|--------|
| Unit performance coefficient D1 | 0.6667 |
| System performance coefficient D2 | 0.3333 |

CR=0.0000; $\lambda_{\text{max}}=2.0000$.

(9) Rank weights of D3, D4 and D5 elements to C3

| Interlayer element                                      | Weight |
|--------------------------------------------------------|--------|
| Energy efficiency ratio of ground source side transport D3 | 0.4444 |
| Energy efficiency ratio of user side transport D4       | 0.4444 |
| Pump efficiency D5                                      | 0.1111 |

CR=0.0000; $\lambda_{\text{max}}=3.0000$.

(10) Rank weights of D6 and D7 elements to C4
### Table 9 Rank weights of D6 and D7 elements to C4

| Interlayer element                  | Weight  |
|-------------------------------------|---------|
| Construction quality D6             | 0.6667  |
| Design of ground source side system D7 | 0.3333  |

CR=0.0000; \( \lambda_{\text{max}} = 2.0000 \).

### 3.4 Calculation of the total ranking weight vectors and the consistency test

Hierarchical total sorting refers to the process of calculating the absolute weight of each layer element to the target. The total ranking of weight of all index elements of the scheme layer for decision goal A of the comprehensive evaluation system of ground source heat pump is shown in the following table:

### Table 10 Hierarchical total ranking weights

| Schema layer indicator                                      | Weight |
|------------------------------------------------------------|--------|
| Unit performance coefficient D1                            | 0.1777 |
| Investment payback period C6                               | 0.1711 |
| Indoor temperature guarantee rate C2                        | 0.1546 |
| System performance coefficient D2                           | 0.0888 |
| Energy utilization coefficient C7                           | 0.0667 |
| Energy efficiency ratio of ground source side transport D3 | 0.0526 |
| Energy efficiency ratio of user side transport D4           | 0.0526 |
| Impact of underground thermal environment C10              | 0.0525 |
| Construction quality D6                                    | 0.0482 |
| Operation management and maintenance C5                     | 0.0463 |
| Design of ground source side system D7                      | 0.0241 |
| Emission reduction C9                                       | 0.024  |
| Energy-saving ratio C8                                      | 0.0222 |
| Pump efficiency D5                                          | 0.0132 |
| Noise C11                                                   | 0.0054 |

CR=0.0323; \( \lambda_{\text{max}} = 15.6828 \).

### 4 Grading standard of comprehensive benefit evaluation of GSHP

#### 4.1 Standardized assignment of evaluation indicators

Referred to the relevant national standards, industry standards [8-15] and research conditions of the ground source heat pump, this paper formulates the evaluation value of each index grade of the comprehensive benefit evaluation system of the ground source heat pump. And according to the merits and disadvantages of the degree, it will be divided into four evaluation levels: very good, good, general and poor.

### Table 11 Standardized assignment of evaluation indicators

| Indicator item                  | Very good | Good | General | Poor |
|--------------------------------|-----------|------|---------|------|
| D1Unit performance coefficient |            |      |         |      |
| Measured value based on standard |          |      |         |      |
| COPsys                         | [3.5, +\( \infty \)) | [3, 3.5) | (2.6, 3) | (-\( \infty \), 2.6) |
| EERsys                         | [3.9, +\( \infty \)) | [3.4, 3.9) | [3, 3.4) | (-\( \infty \), 3) |
| C2Indoor                       | Up to 100% | Greater than | Greater than | Less than |
|                                |           | or         | or      |      |
temperature guarantee rate equal to 95% equal to 90% 90%

Winter D3≤0.05 0.05<D3≤0.067 0.067<D3≤0.1 D3≥0.1

Summer D3≤0.04 0.04<D3≤0.059 0.059<D3≤0.083 D3≥0.083

D4<0.05 0.05≤D4<0.067 0.067≤D4<0.1 D4≤0.1

D5Pump 5<Q≤30 70% 60% 50% 40%

30<Q≤150 80% 70% 60% 50%

Q>150 85% 75% 65% 55%

D6 Construction quality Very good Good General Poor

D7 Design of ground source system Complete satisfaction Basic satisfaction Basic dissatisfaction Dissatisfaction

C5 Operation management and maintenance Very good Good General Poor

C6 Investment payback period 4 6 8 10

C7 Energy utilization coefficient 1.5 1.2 1.0 0.8

C8 Energy-saving ratio 30% 25% 15% 10%

C9 Emission reduction Meet the standard Failure to meet the standard

C10 Impact of underground thermal environment minimum small less more

C11 Noise Less than express value 10% Less than express value 5% Equal to express value Greater than express value 10%

Notes: 1. D2 index is the standardized assignment corresponding to one of the lower scores in COPsys and EERsys.
2. D3 index is the standardized assignment corresponding to one of the lower scores in Winter and Summer.

4.2 Calculation and Evaluation of Comprehensive Benefit Score
In order to reflect the evaluation result reasonably, this paper evaluates the evaluation grade and the comment to make it quantified. The evaluation method refers to the classification standard of each index listed in the relevant standard and sums up according to the weights in this paper, as well as the opinions of industry experts. In this paper, the evaluation grade of comprehensive benefit of ground source heat pump was divided into one-grade, two-grade, three-grade and four-grade, which are evaluated as follows: S≥85, 70≤S<85, 55≤S<70, S<55. The four grades of GSHP system must have met the design requirements in the standard [11].

| Comprehensive project score | Grade | Comment |
|-----------------------------|-------|---------|
| S≥85                        | One-grade | Very good |
| 70≤S<85                     | Two-grade | Good |
| 55≤S<70                     | Three-grade | General |
| S<55                        | Four-grade | Poor |

The measured values or calculated results of the indicators of the ground source heat pump project to be evaluated were compared with Table 11 to obtain the standardized assignment value. Multiply
the standardized assignment value of each indicator with the weight value of the indicator in the Table 10 to get the score of each indicator and add the scores of all indicators to get the comprehensive score S of the comprehensive performance evaluation of the project. Finally, S based on the comprehensive score of the project evaluation was matched with the grade of the comprehensive benefit evaluation of the GSHP.

The comprehensive benefit evaluation method of ground source heat pump provided in this chapter can not only evaluate the comprehensive benefit of the project, but also enable users to realize which indicator is low through the evaluation results, so as to improve the comprehensive benefit of the system optimization and improvement.

5 Analysis of typical GSHP project in Liaoning region

Sino-German Energy Conservation Demonstration Center Project of Shenyang Jianzhu University is located on the southwest side of Shenyang Jianzhu University Campus of Hunnan East Road, Hunnan New District. With a total construction area of 1600m², it is a teaching and exhibition office building, with the exhibition hall, conference room, reception room, guest room, public toilet and equipment room. The building makes full use of renewable energy such as solar energy and geothermal energy, which greatly reduces the consumption of fossil energy.

According to the load characteristics and system configuration of the building, two air-source, ground-source and dual-source heat pump units were selected. And the unit types are KS180S and KS400S respectively. When the soil source heat pump was in single operation, the rated power was 4.5 KW, rated refrigerating capacity/heating capacity was 30 KW/38 KW. As the main cold and heat source of the building, it provides heating in winter and cooling in summer. At the same time, combining with PVT system, soil buried heat exchange system and phase change heat storage system, it improves the utilization efficiency of energy in all aspects and achieves the purpose of energy saving.

5.1 System operating performance analysis

The operation records of the heating period from November 1, 2017 to March 31, 2018 and the cooling period from July 1, 2018 to August 31, 2018 were obtained through investigation and testing. The index elements of the project are calculated and analyzed according to the operation data. According to Shenyang historical meteorological records, the highest temperature was 31°C and the lowest temperature was 17°C on August 15, 2018. The weather was fine and the north wind was less than or equal to grade 3. The summer refrigeration unit runs only during working hours. The average temperature difference between air conditioning supply and return water was 7.41 ℃. According to the analysis of Fig.3 below, the indoor temperature basically fluctuates little within 24 h, with the
maximum temperature difference of 1 °C, the highest point at 15:40 and the lowest point at 22:50. The system starts one unit, and the average cooling capacity was 12 kWh, the average input power of the heat pump unit was 3.1 kW, the input power of ground source side well pump was 2.28 kW, the input power of the air conditioning circulating water pump was 0.55 kW. The average EER of the unit was 3.87 and the EERsys of the system was 2.02 under this working condition.

In the cooling period, the cooling capacity of the whole cooling period was 17,350 kWh through the calculation of the operating records, the power consumption of the unit was 4,448.72 kWh, the power consumption of the ground source side equipment was 1,201.7 kWh, the power consumption of the air conditioning circulating pump was 289.9 kWh. The EER of refrigeration energy efficiency ratio of the heat pump unit was 3.9 and the EERsys was 2.92.

In the heating period, according to the running record, it is concluded that the whole heating period heating was 56,589.4 kWh, the unit power consumption was 18,026.03 kWh, the ground source side equipment power consumption was 6,307.4 kWh, the power consumption of air conditioning circulating pump was 1,360.4 kWh, the COP of the heating performance coefficient of heat pump unit was 3.208, the COPsys of heating performance coefficient of heat pump system was 2.25, the ACOP of the ground source heat pump units of Sino-German center was 3.6.

In the initial investment of this project, the equipment was about 335,000 yuan, the equipment installation cost was about 1,500 yuan, the underground heat exchange buried pipe cost was about 150,000 yuan, the civil construction cost was about 10,000 yuan, and the total cost was about 496,500 yuan. Among the annual operating costs, the electricity cost was 0.5 yuan per kilowatt-hour, and the equipment electricity cost was about 15,817 yuan. The staff in the computer room was students of related subjects, so the labor cost was 0 yuan. The system had not been in use for a long time, so there was no maintenance in the calculation year, and the total cost was 15,817 yuan.

5.2 Comprehensive benefit evaluation of the project
Measured values of all indicators mentioned in Chapter 3 of this project were obtained through testing, investigation and calculation and filled in the following Table 13. Measured values were obtained according to Table 11 for standardized assignment, which was multiplied by the comprehensive weight value to get the index score of each indicator.
Table 13 Calculation of comprehensive benefit of the project

| Indicator                                         | Comprehensive weight value | Measured value | Standardized assignment | Indicator scoring |
|---------------------------------------------------|----------------------------|----------------|-------------------------|-------------------|
| D1 Unit performance coefficient                   | 0.1777                     | 3.6            | 55                      | 9.7735            |
| D2 System performance coefficient                 | 0.0888                     | Winter 2.25/Summer 2.92 | 55 | 4.884 |
| D3 Energy efficiency ratio of ground source side transport | 0.0526                     | Summer 0.05512/Winter 0.16194 | 55 | 2.893 |
| D4 Energy efficiency ratio of user side transport | 0.0526                     | 0.02232        | 100                     | 5.26              |
| D5 Pump efficiency                               | 0.0132                     | 67.5%          | 85                      | 1.122             |
| D6 Construction quality                          | 0.0482                     | Very good      | 100                     | 4.82              |
| D7 Design of ground source side system           | 0.0241                     | Basic satisfaction | 85 | 2.0485 |
| C2 Indoor temperature guarantee rate              | 0.1546                     | 100%           | 100                     | 15.46             |
| C5 Operation management and maintenance           | 0.0463                     | Very good      | 100                     | 4.63              |
| C6 Investment payback period                     | 0.1711                     | 4.362          | 85                      | 14.5435           |
| C7 Energy utilization coefficient                 | 0.0667                     | 1.1            | 70                      | 4.669             |
| C8 Energy-saving ratio                           | 0.0222                     | 23.51%         | 70                      | 1.554             |
| C9 Emission reduction                            | 0.024                      | Meet the standard | 100 | 2.4 |
| C10 Impact of underground thermal environment    | 0.0525                     | small          | 100                     | 5.25              |
| C11 Noise                                        | 0.0054                     | Up to the standard | 100 | 0.54 |
| Total                                            |                            |                |                         | 79.8475           |

According to the calculation, the comprehensive benefit evaluation score of the "Sino-German Energy Conservation Demonstration Center" soil source heat pump project was 79.8475 points. Based on the evaluation grading standard in Table 12, the project was ranked as the second level of comprehensive benefit, with good comprehensive benefit. This result was consistent with the feedback of field research. The performance coefficient of the unit and system in this project was low. Considering that it is related to the design deviation of the ground source side system, the actual operation condition does not operate in accordance with the design operation condition.

5.3 Comparison and analysis with conventional heating and refrigeration systems

The traditional system of networked heating and chiller cooling was compared with the soil-source heat pump system in Sino-German Energy Conservation Demonstration Center. And the comparative economic analysis results are as follows.

Table 14 Economic analysis

| Project                        | Cost(yuan) |
|--------------------------------|------------|
|                                | Buried pipe heat pump project | Conventional chiller & heat grid |
| Initial cost                   | 335,000    | 220,000                     |
| Equipment cost                 | 150        | 150                         |
| Installation cost              |            |                             |
According to the heating cost of 24 yuan /m² in Shenyang, the heating area of the building is 1537m², the heating cost should be paid is 36,888 yuan. As shown in Table 14, the initial investment of the buried pipe heat pump project is 105,000 yuan more than that of the traditional system, but the annual operating cost is 24,071 yuan less than that of the traditional system. The investment payback period is 4.362 years.

### Table 15 Conventional energy substitution calculation

|                  | Buried pipe heat pump project | Conventional chiller & heat grid |
|------------------|-------------------------------|--------------------------------|
| Heating load /MJ | 203,721.84                    |                                |
| Cooling load /MJ | 62,460                        |                                |
| Annual total heating energy / kgce | 8,094 | 9,930 |
| Annual total cooling energy/ kgce | 1,871 | 2,376 |
| Annual total consumption / kgce | 9,964 | 12,306 |
| Conventional energy substitution / kgce | 2,342 |
| Ratio of energy-saving | 23.51% |

### Table 16 CO₂, NO₂ and dust emission reduction

| Standard coal saving (kgce/year) | Emission reduction of CO₂ (kg/year) | Emission reduction of SO₂ (kg/year) | Emission reduction of dust (kg/year) |
|----------------------------------|------------------------------------|-------------------------------------|--------------------------------------|
| 2,342                            | 5,784.74                           | 46.84                               | 23.42                                |

Through the calculation, the use of soil source heat pump in Sino-German Energy Conservation Demonstration Center can save about 2342 kg of the standard coal every year, 5784.74 kg of the carbon dioxide emission, 46.84 kg of sulfur dioxide emission and 23.42 kg of dust emission. The energy saving rate was reached 23.51%.

### 6. Conclusions

This paper was used by AHP to study the evaluation method of GSHP and constructed a scientific, rational and practical evaluation system of comprehensive benefit of GSHP. The evaluation system was covered the benefit evaluation from four aspects, including technology, economy, energy saving and environment. The specific conclusions were as follows:

1. A scientific evaluation method for the comprehensive benefit of GSHP was established by analytic hierarchy process (AHP). The evaluation system of comprehensive performance of GSHP was constructed, as well as the judgment matrix was constructed by using expert scoring method and expert weighting method. A professional analytic hierarchy process software (Yaahp) was used to calculate the ranking of the weights of various indicators for the decision-making level and carry out the consistency test. The evaluation standard of 15 evaluation indexes and the grading standard of comprehensive benefit evaluation were established by means of literature review, national standard
and expert consultation.

(2) The evaluation results were consistent with the feedback from users and the GSHP operation management company. It was verified that the evaluation method of comprehensive benefit of GSHP can construct a reasonable evaluation and analysis based on the technical, economic, energy saving and environmental benefits of the GSHP project.

(3) This paper was studied the suitability evaluation methods of GSHP and soil source heat pump in Liaoning by means of literature survey, analytic hierarchy process, expert scoring method and expert weighting method. It was determined that the application of ground water source heat pump is closely related to groundwater chemical characteristics, groundwater dynamic field, hydrogeological conditions and environmental protection. The application of soil source heat pump was related to the thermal and physical properties of rock and soil, hydrogeological conditions, environmental conditions and construction conditions.

(4) According to the evaluation method of the comprehensive benefit of GSHP, the selected typical GSHP project was evaluated and the comprehensive evaluation benefit grade was level two. The index data of energy efficiency ratio, indoor temperature guarantee rate and emission reduction were very good. To sum up, according to the evaluation results, we can analyze the areas that need to be optimized and improved in order to fully improve the comprehensive benefit.

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