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Research Article

A Decision Support System for Optimal Building Cold Source Selection

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Building energy consumption is increasingly becoming a matter of global concern. A key aspect of this is the nature of building cold source systems and their effectiveness. However, choosing the cold source for a building is a complex decision-making process. The traditional evaluation method is relatively simple, and it is difficult to comprehensively consider multiple factors and their mutual influences, and it is even more difficult to increase the consideration of the whole life-cycle cost on this basis. Especially in China, the cost of extra-large public projects invested and constructed by the government plays a significant role in the decision-making process, and it should not be affected by other factors to change the decision-making. Therefore, this paper proposes a new decision-making system, which is based on value engineering (VE) and combined with analytic network process (ANP) to conduct a comprehensive study of project decision-making. Based on existing approaches to construction project evaluation and the selection of cold source systems, we establish an evaluation index for building cold source system functional models and network structures. This approach can take into account the impact of cost on decisions. We then present the results of a simulation-based case study of potential central air-conditioning cold source system solutions for the new Xiang'an New Airport in Xiamen, China. The corresponding value coefficients for conventional electric refrigeration, ice storage, and water storage were found to be 0.8262, 1.0049, and 1.2442, respectively. This suggests that water storage-based cooling offers the best technical and economic benefits for this project. It also confirms that the proposed decision support system can identify the modes with the highest value coefficients, which is one of the most effective methods for selecting a building cold source system scheme. Therefore, the system has the potential to support the effective selection of other building cold source schemes.

1. Introduction

As urbanization had continued to advance apace in countries around the world, accompanied by increasing levels in energy demand, building energy consumption has become a critical consideration for strategic decision-makers who are concerned with energy conservation and emission reduction [1, 2]. Air-conditioning systems, especially the central air-conditioning systems in public buildings, have always been significant sources of energy consumption and emissions. They, therefore, present a huge opportunity for energy saving. Central air-conditioning systems are currently the principal source of heating and cooling in major public buildings throughout the world [3]. They are increasingly important energy consumers and a serious cause of environmental pollution [4]. Taking large public building facilities in Beijing as an example, the annual total power consumption of shopping malls, hotels, and office buildings in the city can be as high as 350 kWh/m^2 [5]. The power consumption of air-conditioning systems accounts for between 40% and 60% of the total power consumption of these buildings and the power consumption of the fans and pumps used for cooling transmission and distribution can account for more than 70% of an air-conditioning system's overall power consumption [6]. There is a particular demand for cooling provision in southern China, especially in Guangdong, Fujian, and Hainan, with the annual average duration of this demand being notably longer [7]. Comparative studies show that the development and application of improved technology, optimized project design, and enhanced operational management can achieve an energy-saving of between 30% and 50%, making research in this area of potentially enormous significance [8]. In recent years, we have developed a range of refrigeration technologies, including improved conventional electric refrigeration, ice storage, water storage, gas direct-fired engines, gas-fired combined cooling and heating systems, ground source heat pumps, and seawater source heat pumps, which together constitute the major part of the new possibilities for the cooling of air-conditioning systems [9].

However, careful scientific evaluation of these different cooling technologies and schemes, together with decision-making methods for ascertaining which ones are most appropriate, has not kept pace with their development. Typically, most evaluations focus upon comparing schemes from the viewpoint of initial investment and operating costs, though some also consider factors such as energy consumption, pollutant emission, and full life-cycle cost [5, 10, 11]. As refrigeration technology continues to develop and cooling schemes become more and more abundant, the factors to be considered also continue to increase. Green energy has become an essential focus when evaluating cold source system schemes. At the same time, as these are often large-scale projects, economic considerations regarding construction and operation costs continue to play an important part in decision-making [12–14]. As a result, the selection of cold source system schemes typically involves assessing multiple objectives and criteria [15–17].

This paper is addressed to this multi-faceted decision-making problem. Established theories and tools are drawn upon to develop a decision support system for selecting the best cold source system for buildings that is based on VE and ANP. The objective of this research is to satisfy the various functional requirements of the central air-conditioning system at the lowest cost possible. In this way, the best cooling source system can be selected for large public buildings to meet the global strategic needs of energy conservation and emission reduction.

In the next section, we discuss the relevant literature. In Section 3, we present our methodology, including the background to VE and the evaluation process. In Section 4, we examine a case study where the proposed method is applied and this is discussed in Section 5. Our concluding remarks are given in Section 6.

2. Literature Review

Solving the multi-attribute character of the decision-making associated with cold source selection now, more than ever, demands the adoption of an appropriate decision support system. This has made the technical and economic assessment of cold source systems a topic of growing concern in recent years. To this end, Liu and Cai [18] developed a fuzzy comprehensive evaluation method to quantify the qualitative and fuzzy factors associated with the choice of energy schemes. By contrast, Yin et al. [19] used an analytic hierarchy process (AHP) to determine the subjective weight of each factor from the five perspectives of economy, technical conditions, environmental impact, energy-saving, and social benefits. By pairing various factors, they obtained evaluation scores for different schemes. Yan et al. [20] also used an AHP to construct a matrix with an optimal degree of membership function. This reduced the time taken to construct a judgment matrix and made the evaluation results more objective. Cao and Tu [21] adopted a grey theory approach to generate a dimensionless evaluation index, based on which they were able to determine the pros and cons of different schemes according to the maximum degree of correlation. Meanwhile, Fang et al. [22] used the principles derived from VE to conduct an economic evaluation of various schemes. This was a relatively simple and viable approach, but it ignored other possible attributes, so the evaluation results lacked comprehensive objectivity. Liu et al. [3] also employed VE and combined it with an AHP. In this case, it was able to comprehensively evaluate factors relating to investment, function, resource consumption, and economy.

Close examination of the extant literature reveals that there are many methods of technical and economic evaluation in cold source systems, including fuzzy comprehensive evaluation, AHP, grey theory, and VE; however, there are many problems in the use of these decision-making methods. First of all, the evaluation systems developed for the selection of building cooling source systems typically ignore the user's functional experience, and the selection of cooling source system function evaluation indicators is not comprehensive enough to demonstrate the actual applicability of different projects. Second, some of the principal approaches, such as AHP, disregard the interrelation of multiple factors when using their relative weights to develop an evaluation index. More importantly, in the evaluation process, only the functional parameters are considered and the cost is ignored. Thus, there is an important gap in how to conduct evaluations currently. In order to avoid the above problems, this paper attempts to use a more complete and comprehensive method than AHP—ANP, and integrates the VE theory into it and then establishes a decision support system to solve the problem of building cooling source selection.

After inspecting many regions in China, we found that Xiamen, as a subtropical zone, has a high demand for cooling over an extended part of the year. This therefore offers the ideal mix of resources, climate, and demand to be able to assess the viability of our research. Having identified a suitable region, we decided to use the development of the central air-conditioning refrigeration system at Xiang'an New Airport in Xiamen, China, as an example through which to explore the applicability of various currently commonly-used cooling technologies. As with some of the approaches mentioned above, our approach is based on VE principles but is combined with a network analytic hierarchy (a kind of ANP). We used these combined perspectives to develop a decision support system, which we evaluated by simulating its application to the cooling scheme for the central air-conditioning system of Xiang'an Airport. The goal was to identify the most effective cold source system. This was done by establishing a comprehensive functional evaluation index system to obtain the most appropriate functional coefficients for an ANP, together with an expert scoring method. On this basis, we incorporate the theory of VE into it. By obtaining data such as the full life-cycle cost of the project, the value coefficient of each cooling source system is finally determined. This method overcomes the limitations and one-sidedness of previous decision support systems and can comprehensively consider the impact of functions and costs on decision-making. The system is able to meet the needs of an airport terminal construction project. More broadly, it can be applied to the design of cold source supplies for other large public buildings, thus contributing to both national and global concerns regarding energy conservation and emission reduction.

3. Methodology

As refrigeration technology has developed, different cooling schemes have become more and more abundant. As a result, the range of factors that need to be considered when evaluating cooling technology and its economic viability has also increased. Although there is a general interest in identifying the lowest cost options, it is also essential to meet the functional requirements involved in deploying a cooling system in a particular building. We therefore sought to establish a comprehensive system that could incorporate functional evaluation indicators, while using ANP and expert scoring methods to obtain the functional coefficients. By combining this with the actual cost and using the principle of VE, we can determine the value coefficients for the program. As an increasing number of factors need to be considered in the technical and economic evaluation of refrigeration solutions, it is also becoming increasingly important to examine how different factors are interrelated and influence each other. Overall, we want the decision support system we develop to meet the functional requirements of the cold source aspects of a central air-conditioning system at the lowest possible cost. Doing this involves identifying suitable theories and methods that will best enable the decision support system to promote the most optimal choices.

3.1. Value Engineering. VE is an approach to thinking about and managing technology that analyzes both the cost and function of different objects in a project to arrive at the lowest cost solution that will preserve the necessary functionality. It also seeks to improve the value of objects through research and innovation and it is applicable across a wide variety of fields, for example, biomedical field [23], biomaterials [24], game [25], computer network [26], construction engineering [27], etc. Functional analysis is at the core of VE. Its primary goal is uncovering the optimal total benefit that will realize the required functionality of an object by finding the lowest life-cycle cost associated with it [28]. To meet the principles of VE, the selection of an architectural plan for a cold source system must take into account the full range of the system's functionality and its economic grounds. The specific process has three stages: functional analysis, cost analysis, and value analysis. Functional analysis is the critical stage. In our case, we seek to ensure that assessment of a potential technology also considers its economic rationality; i.e., we are looking for the lowest price that meets the functional requirements of a building's cold source system. This forms the basis of our evaluation of each scheme's viability.

3.2. Evaluation Process. Our approach combines the principles of VE with the ANP, leading to the following steps in evaluation.

3.2.1. Establishing a Functional Evaluation Index. First, we determine the research objects (the things that need evaluation). The purpose of an economic evaluation of a central air-conditioning cooling technology is to choose the optimal cooling scheme. So the research objects are the different potential modes of cooling in a central air-conditioning system. Our goal is to develop a decision support system by sorting and analyzing the various aspects of the cooling functionality of a central air-conditioning system.

3.2.2. Determining the Weight of Each Functional Evaluation Index. The potential cooling modes for the central air-conditioning system in large buildings need to be considered and analyzed from different aspects prior to selection. Some conventional indicators such as the users' functional experience, environmental protection, and economy are fundamental to selection of an appropriate cold source. However, these basic indicators include a variety of factors that should be considered. Furthermore, these factors are mutually dependent and have mutual feedback between them, for instance, functional experience and economy, where the greater the economy, the worse the operational experience, and vice versa. For this reason, we need to find a reliable way of identifying the dependence and feedback between the indicators.

The ANP is a generalization of the analytic hierarchy process (AHP). The AHP combines qualitative and quantitative decision-making methods that are used to calculate the relative importance and weight of multiple selected options [29, 30]. The main difference between the ANP and AHP approaches is that the elements in an ANP are interdependent while they are independent in an AHP. Thus, an ANP considers not only the feedback relationship between the upper and lower levels of the network but also the interdependence between elements at the same level [31]. Based on their dependency and feedback, an ANP calculates the weight of each element in the functional index. More information about the approach can be found in [32].

3.2.3. Scoring the Functional Index. Experts scored the various functional indicators of each cooling mode. To ensure professional and comprehensive scoring, we interviewed 10 experts, who included academics studying building energy, managers, technicians, and front-line employees involved in environmental protection and construction engineering. Based on the average score of each index, the functional score, f_j, for each scheme can then be calculated as follows:

$$f_j = \sum_{k=1}^{n} f_{jk} l_{jk} \cdot (j = 1, \cdot 2, \ldots, m; k = 1, \cdot 2, \ldots, \cdot n), \tag{1}$$

where f_{jk} is the average score of an index, k, in a scheme, j, and l_{jk} is the weight of the index, k, in scheme j. The functional coefficient is as follows:

$$F_j = \frac{f_j}{\left(\sum_{j=1}^{m} fj\right)}, \tag{2}$$

where F_j is the functional coefficient of scheme j.

3.2.4. Determining the Cost Coefficient for Each Scheme. Technical experts from related units determined the total life-cycle cost of each scheme based on the same cooling system scale and other conditions, including the initial investment, construction cost, operating expenses, maintenance, and depreciation. The operating expenses cover the installed electrical load, energy consumption, energy storage, energy-saving, environmental protection, and emission reduction. The summation of all these costs is the total life-cycle cost for all of the schemes. Finally, the cost coefficient for each scheme is the entire life-cycle cost for every single scheme divided by the total life-cycle cost for all the schemes. This is calculated as follows [33]:

$$C_j = \frac{c_j}{\sum_{j=1}^{m} cj} \cdot (j = 1, \cdot 2, \ldots, m), \tag{3}$$

where C_j is the cost coefficient for scheme j, c_j is the life-cycle cost for scheme j, and m is the total number of schemes.

3.2.5. Calculating the Value Coefficient for Each Scheme. The higher the value coefficient, the better the technical and economic efficiency of the cooling scheme. The calculation of the value coefficient for each scheme can be realized using

$$Vj = \frac{F_j}{C_j}, \tag{4}$$

where V_j is the value coefficient for scheme j.

4. Case Study

To assess the viability of our proposed approach, we used data from a hypothetical example relating to the central air-conditioning cold source system of the Xiang'an New Airport in Xiamen, China. We then employed the proposed decision support system to select a reasonable building cooling source plan.

4.1. Project Overview. Xiamen's Xiang'an New Airport is in Xiang'an District, Xiamen City, Fujian Province, China. The scope of the airport includes Xiaodeng Island,the eastern part of Dadeng Island, the shoal area between Dadeng, Xiaodeng Island, and also involves part of the sea around Dayang Island. The airport uses a central air-conditioning system with the designed cooling load of its energy station being 170.85mw. The terminal is designed around the concept of a "humanistic airport" that can meet the triple goals of meeting "functional priority and being economical and practical," while "considering its image." The terminal thus seeks to reflect fully the characteristics of the times and the region, with not only humanistic features but also green environmental protection, efficient operation, and up-to-date scientific and technological capabilities that will still remain economical and practical.

4.2. Analysis of the Preliminary Refrigeration Scheme. There are various possible modes for building refrigeration. These include conventional electric refrigeration, water storage, ice storage, gas direct-fired engines, gas cooling-heating and triple power supplies, ground source heat pumps, and seawater source heat pumps. There are a number of contextual factors that can affect the applicability of these, such as the scale and use of the building, the natural conditions, energy status, structure and price of the construction site, the current national energy conservation, and emission regulations and environmental protection policies. In this study, we consider three potential refrigeration modes: conventional electric refrigeration, ice storage, and water storage.

Conventional electric refrigeration works on the principle of having a refrigeration compressor that sucks a working medium in the form of a low-pressure and low-temperature gas (such as ammonia or freon) into an evaporator. The transformed high-temperature and high-pressure gas is discharged into a condenser after compression. This method is widely used and easily adjusted and provides stable operation. Ice storage technology uses a cold storage medium to store cold energy during low power consumption periods (e.g., at night). This cold energy is then released during peak power consumption periods (e.g., daytime) to reduce the peak load, having filled drop-offs in consumption, thus saving the operating costs. As with ice storage air-conditioning systems, water storage air-conditioning aims to save energy by exploiting the difference between peak and trough electricity prices in the power grid. Here, water chillers store cold energy in a pool overnight and discharge the cold energy from the pool during the day, with the main engine running off-peak.

The latter two types of cold storage air conditioning reduce the unit capacity and the consumption and leakage of refrigerant to offer more effective environmental protection. However, ice storage systems need substantial investment, require complex debugging, and are challenging to realize. It is therefore much more straightforward to use water-based cold storage. However, the conversion efficiency of water storage is lower than that of ice storage, due to the complex

Table 1: Functional evaluation index system and notes.

Control layer	Network layer	Network layer factors	Notes
Functional evaluation index system for the building's cold source system A	Functional experience B_1	Safety and reliability B_{11} Convenience of use B_{12} Flexible load adaptability B_{13} Difficulty of operation and maintenance management B_{14}	The system functions are safe and efficient; the temperature is stable; and it is easy to maintain.
	Social and environment l benefits B_2	Degree of green environmental protection B_{21} Conservation of energy, reduction of emissions B_{22} Enhancement of architectural landscape B_{23}	Green environmental protection means that the scheme adapts to the local ecological environment, attaches importance to building environmental protection, and makes full use of renewable resources. Energy-saving and emission reduction refers to the CO_2 emission reduction and annual total electricity consumption generated by the same refrigeration capacity. Landscaping refers to the impact of the exposed facilities on the architectural landscape.
	Reliability B3	Energy supply B_{31} Energy-resource structure B_{32} Energy price fluctuation B_{33}	The system offers flexibility of resource allocation and adjustability.
	Demonstrable advances B4	Use of modern techniques B_{41} Application of science and technology B_{42} Policy orientation B_{43}	The project uses globally advanced technology and equipment and can be widely used in other projects. If the technology used is not referential, it actively responds to national policies.
	Project applicability B5	Natural conditions B_{51} Building scale B_{52} Building use B_{53} Installation area B_{54}	Project applicability refers to the fact that different projects have different requirements for their cold and heat sources. The greater the degree of satisfaction, the better the applicability.

structure of the water storage tank, the large area it has to occupy, the complexity of its construction, the high initial investment, the surplus pump power requirements, the difficulties associated with treating the water, and the high labor costs. Having said this, as large buildings typically have a fire pool, this can be used for cold storage, which offsets some of the associated costs.

4.3. Evaluation Model. In this study, a functional evaluation index system of the building cold source system was constructed and an ANP network structure diagram was established on this basis. This model can be used to evaluate the weight of various functional indicators of the building cold source system. The specific steps are given in the following sections.

4.3.1. Functional Evaluation Index System. According to the above-mentioned functional requirements for Xiamen's Xiang'an New Airport terminal design, the evaluation index system for the cold source system focused on five considerations: operational experience, social-environmental benefits, reliability, demonstrable advances, and project applicability. To establish the functional evaluation index system, we studied and reviewed the evaluation indexes for cold and heat sources in air-conditioning systems in the relevant literature. This gave us a preliminary refrigeration system scheme for the project. We also referred to the current relevant national and local design codes and standards and followed established principles regarding scientific rigor, objectivity, and comparability.

Table 1 shows the various layers in the functional evaluation index system. The first layer is the control layer for the airport terminal building. The second layer is the network layer, which contains the five evaluation criteria detailed above. The third layer relates to the various factors in the network layer with a total of 20 sub-standards. Here, the functional experience focuses on safety, efficiency, temperature stability, and the ease of maintenance for users. The social and environmental benefits mainly focus on whether the system meets green environmental protection requirements, reduces energy consumption and emissions, and enhances the building landscape. Reliability is concerned with the provision of energy and the structure and cost of operating the system. Demonstrable advances look at the technological and scientific level of the system and whether it meets government policy. The applicability of the project considers where it will be used, such as the natural conditions, the building's size and its use, and the installation area, so as to be able to judge how closely the system meets the project requirements.

4.3.2. Establishing an ANP Network Structure Diagram. In the functional evaluation index system, the factors of each group are interdependent with a feedback relationship. The

Table 2: Factor interactions.

	B_{11}	B_{12}	B_{13}	B_{14}	B_{21}	B_{22}	B_{23}	B_{31}	B_{32}	B_{33}	B_{41}	B_{42}	B_{43}	B_{51}	B_{52}	B_{53}	B_{54}
B_{11}				●									●				
B_{12}				●	●	●						●					●
B_{13}				●		●						●		●	●		
B_{14}												●			●		
B_{21}								●	●	●			●				
B_{22}					●				●	●			●				
B_{23}													●				
B_{31}	●			●					●	●		●	●		●	●	
B_{32}	●			●	●	●		●		●		●	●		●	●	●
B_{33}				●				●									
B_{41}	●	●	●	●	●	●						●	●				●
B_{42}											●		●				
B_{43}					●	●				●	●			●	●	●	●
B_{51}	●		●	●	●	●	●	●	●						●	●	●
B_{52}			●	●	●	●	●										●
B_{53}			●	●	●	●											●
B_{54}				●	●		●										

characteristics of the different groups of factors are also interdependent. As discussed in Section 3.2, expert analysis and discussion provided the reference for identifying the specific relationships among the various factors. Table 2 shows the outcome of this exercise. The indicators in the rows are those effected, and the ones in the columns are the effectors. For example, the intersection of row B_{11} and column B_{14} indicates that the safety and reliability of the building's cold source system has an impact on the difficulty of operation and maintenance management. To put it another way, the degree of difficulty in operating and maintaining the building's cold source system depends on its safety and reliability.

Figure 1 shows a network structure diagram of the evaluation index system, based on the relationships between the indexes. According to Figure 1, the control layer has only one objective, which is evaluation of the cooling functions of the central air-conditioning system, so there is no evaluation criterion. In the network layer, the arrows show the direction of influence of each factor on the other factors. The curved arrows indicate the influence between different internal factors in a factor group. The model reveals the interrelationships between the different indicators, so that subsequent comparison of all the elements in the indicators can be used to construct a judgment matrix.

4.3.3. Constructing the Judgment Matrix.

This step relates to the construction of a judgment matrix based on the method described in Section 2.2, the expert assessments and the literature review. The focus here is upon the relative importance of the specific elements and entails comparison of the importance of all the elements in the functional evaluation index.

As an example, the first column of judgment matrix A in Table 3 represents the importance of B_1, B_2, B_3, B_4, and B_5 with a given B_1. Based on these degrees of importance, the last column shows the weight of each factor. Note that where there is an unaffected evaluation criterion, the corresponding eigenvector is zero.

The normalized values of B_1, B_2, B_3, B_4, and B_5 are $w = (0.545,\ 0{,}0.2329,\ 0.1385,\ 0.0837)$, respectively. After calculation, the maximum eigenvalue is $\lambda_{\max} = 4.0511$ and the consistency ratio is $\mathrm{CR} = 0.0189 < 0.1$, which is an acceptable level of consistency.

The final weighted matrix, A, is as follows:

$$A = \begin{bmatrix} 0.545 & 0.3431 & 0 & 0.4277 & 0.4915 \\ 0 & 0.288 & 0.3537 & 0.2543 & 0 \\ 0.2329 & 0.1171 & 0.4402 & 0.0813 & 0.1248 \\ 0.1385 & 0.1925 & 0.1271 & 0.2367 & 0.0778 \\ 0.0837 & 0.0593 & 0.0791 & 0 & 0.3059 \end{bmatrix}. \quad (5)$$

4.3.4. Constructing the Hypermatrix and Calculating the Weights.

Based on the network structure in Figure 1, the initial hypermatrix of the network layer is as follows:

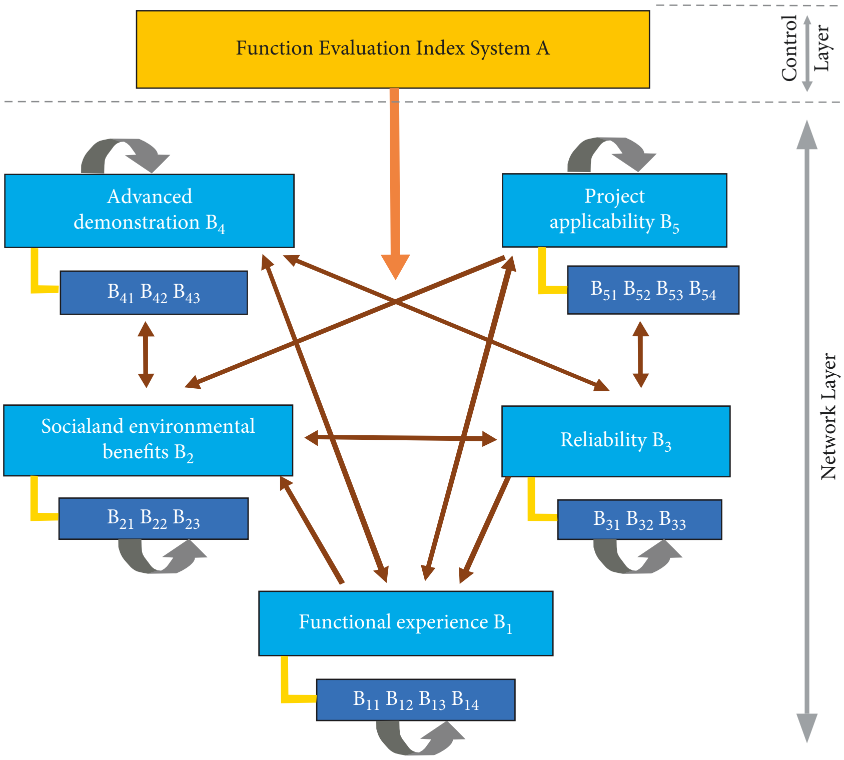

FIGURE 1: Network structure of the functional evaluation index system.

TABLE 3: Judgment matrix *a*

B1	B1	B3	B4	B5	w
B1	1	3	4	5	0.545
B3	1/3	1	2	3	0.2329
B4	1/4	1/2	1	2	0.1385
B5	1/5	1/3	1/2	1	0.0837

$$W = \begin{bmatrix} W11 & W12 & W13 & W14 & W15 \\ W21 & W22 & W23 & W24 & W25 \\ W31 & W32 & W33 & W34 & W35 \\ W41 & W42 & W43 & W44 & W45 \\ W51 & W52 & W53 & W54 & W55 \end{bmatrix}. \tag{6}$$

The fourth column of Table 4 shows the weights for judgment matrix B, which relates to W_{11} for a given B1 when compared with B14.

After calculation, the maximum eigenvalue is λ max = 3.0036 and the consistency ratio is CR = 0.0031 < 0.1, which is again an acceptable level of consistency. According to Table 4, the weight vector, w, of the fourth column of W_{11} is $w = (0.6483, 0.1220, 0.2296)$. Similarly, the weight vector for the first, second and third columns of W_{11} is zero as follows:

$$W_{11} = \begin{bmatrix} 0 & 0 & 0 & 0.6483 \\ 0 & 0 & 0 & 0.1220 \\ 0 & 0 & 0 & 0.2296 \\ 0 & 0 & 0 & 0 \end{bmatrix}. \tag{7}$$

TABLE 4: Judgment matrix B.

B$_{14}$	B$_{11}$	B$_{12}$	B$_{13}$	w
B$_{11}$	1	5	3	0.6483
B$_{12}$	1/5	1	1/2	0.1220
B$_{13}$	1/3	2	1	0.2296

Table 5 shows the other weighted matrices to obtain the initial hypermatrix.

Each submatrix of the initial hypermatrix is multiplied by its corresponding weight (the value given by Matrix A) to obtain the weighted hypermatrix, $\overline{W_{ij}}$. The value of the weighted Matrix A is $\overline{W_{ij}} = a_{ij}W_{ij}$, $i = 1, 2, 3, 4, 5$, $j = 1, 2, 3, 4, 5$, a_{ij}, with W_{ij} being the submatrix in the initial hypermatrix, so

$$\overline{W_{ij}} = \begin{bmatrix} 0.545W11 & 0.3431W12 & 0 & 0.4277W14 & 0.4915W15 \\ 0 & 0.288W22 & 0.3537W23 & 0.2543W24 & 0 \\ 0.2329W31 & 0.1171W32 & 0.4402W33 & 0.0813W34 & 0.1248W35 \\ 0.1385W41 & 0.1925W42 & 0.1271W43 & 0.2367W44 & 0.0778W45 \\ 0.0837W51 & 0.0593W52 & 0.0791W53 & 0 & 0.3059W55 \end{bmatrix}. \tag{8}$$

The weighted hypermatrix is given in Table 6.

The weighted hypermatrix W_{ij} is stabilized by being multiplied by itself 4 times (the column vectors are normalized before each self-multiplication), so that $\overline{W_{ij}}^{\infty} = \lim_{t\longrightarrow\infty}\overline{WW_{ij}}^{t}$.The stabilized hypermatrix is given in Table 7. The weight of each functional evaluation index is then as follows: $w = ($ 0.0486, 0.0187, 0.1574, 0.0372, 0.0539,

Table 5: ANP initial hypermatrix.

	B_{11}	B_{12}	B_{13}	B_{14}	B_{21}	B_{22}	B_{23}	B_{31}	B_{32}	B_{33}	B_{41}	B_{42}	B_{43}	B_{51}	B_{52}	B_{53}	B_{54}
B11	0	0	0	0.6483	0	0	0	0	0	0	0	0	1	0	0	0	0
B12	0	0	0	0.1220	0	0	0	0	0	0	0.1634	0.1634	0	0	0	0	1
B13	0	0	0	0.2297	1	0.6667	0	0	0	0	0.5396	0.5396	0	1	0.5	0	0
B14	0	0	0	0	0	0.3333	0	0	0	0	0.2970	0.2970	0	0	0.5	0	0
B21	0	0	0	0	0	0	0	1	0.5	0.5	0	0	0.4000	0	0	0	0
B22	0	0	0	0	1	0	0	0	0.5	0.5	0	0	0.4000	0	0	0	0
B23	0	0	0	0	0	0	0	0	0	0	0	0	0.2000	0	0	0	0
B31	0.75	0	0	0.1219	0	0	0	0	1	0.5	0	0.6667	0.6667	0	0.75	0.75	0
B32	0.25	0	0	0.3196	1	1	0	0.75	0	0.5	0	0.3333	0.3333	0	0.25	0.25	1
B33	0	0	0	0.5584	0	0	0	0.25	0	0	0	0	0	0	0	0	0
B41	1	1	1	1	0.2	0.25	0	0	0	0	0	1	0.5	0	0	0	0.8
B42	0	0	0	0	0	0	0	0	0	0	0.75	0	0.5	0	0	0	0
B43	0	0	0	0	0.8	0.75	0	0	0	1	0.25	0	0	1	1	1	0.2
B51	1	0	0.5396	0.1277	0.4550	0.1429	0.3330	1	1	0	0	0	0	0	1	1	0.1634
B52	0	0	0.1634	0.3128	0.1411	0.4286	0.5695	0	0	0	0	0	0	0	0	0	0.5396
B53	0	0	0.2970	0.0840	0.1411	0.4286	0	0	0	0	0	0	0	0	0	0	0.2969
B54	0	0	0	0.4754	0.2627	0	0.0973	0	0	0	0	0	0	0	0	0	0

0.0394, 0.0042, 0.0741, 0.0626, 0.0142, 0.1740,0.1358, 0.0738, 0.0680, 0.0154, 0.0200, 0.0027). At this point, the most critical step in the VE based functional analysis is complete because the functional evaluation index weights have been obtained. The functional coefficients are a combination of these results with the expert scores.

4.4. Calculating the Value Engineering Correlation Coefficient. The experts used a 10-point system to score the 17 functional evaluation indexes corresponding to the three potential cooling schemes (conventional electric refrigeration, ice storage, and water storage), which was based on analysis of the preliminary refrigeration system scheme in accordance with the process described in Section 3.2. Figure 2 shows the average scores.

The system lifespan was taken to be 20 years. On the basis of the project feasibility study report, the cost of each scheme was calculated and used as its life-cycle cost. In Section 3.2, equations (1) to (4) were used to calculate the functional score, functional coefficient, cost coefficient, and value coefficient. Table 8 shows the results.

5. Discussion

First of all, it should be noted that when only the function is considered without considering the cost, the ice storage function coefficient (0.3377) and the water storage function coefficient (0.3385) are relatively close, but higher than the traditional electric refrigeration function coefficient (0.3288). However, if the final value coefficient considers the cost of the entire life cycle, the traditional electric refrigeration has high cost and poor economic benefits. Finally, the value coefficients of traditional electric refrigeration, ice storage, and water storage are 0.8262, 1.0049, and 1.2442, respectively, which is different from the simple use of ANP. The function coefficients obtained are different, the gap is obviously widened this time, and the traditional electric refrigeration shows obvious disadvantages. To sum up, if the factors of VE are not considered, ice storage, water storage, and electric refrigeration, there is no difference between the three, and it is difficult to distinguish the advantages and disadvantages. However, after the introduction of VE theory, the value coefficients of ice storage and water storage both exceed 1, which is significantly more than electrical refrigeration. Therefore, the theory and cost control factors of proving VE are crucial to the selection of cooling source systems in large public buildings.

According to the calculation results, the final value coefficient of electric refrigeration is the lowest and less than 1. It can be seen that its function and cost cannot be well matched, and the cost input is too high, but more functions cannot be realized. The reasons for its low function score mainly come from issues such as energy, technology, and policy orientation. As it stands, the energy supply in China is still unable to cope with the increasing demand generated by the rapid development of China's national economy and the rapid growth in people's living standards. The national power shortage situation has yet to change fundamentally and there is a particularly pronounced gap between production and demand in the Eastern coastal areas. In view of the evaluation and this current situation, a conventional electric refrigeration scheme should not be pursued for this project. Solving the current issues involves paying equal attention to development and saving. On the one hand, it is necessary to increase investment in electric power and speed up the pace of power plant construction. On the other hand, it is essential to soften the peaks and fill the troughs in demand by saving electricity and making full use of existing power resources. This entails adjustments to the national power policy. Given this situation, if part or even all of the power consumption for refrigeration systems can be transferred to off-peak periods during the night, this will have a very positive effect on balancing the power grid's load and improving the efficiency of its load utilization. This has made "air-conditioning cold storage" of common concern in the power sector and the air-conditioning and refrigeration industry.

Table 6: Weighted hypermatrix.

	B_{11}	B_{12}	B_{13}	B_{14}	B_{21}	B_{22}	B_{23}	B_{31}	B_{32}	B_{33}	B_{41}	B_{42}	B_{43}	B_{51}	B_{52}	B_{53}	B_{54}
$\mathbf{B_{11}}$	0	0	0	0.3533	0	0	0	0	0	0	0	0	0.4277	0	0	0	0
$\mathbf{B_{12}}$	0	0	0	0.0665	0	0	0	0	0	0	0	0.0699	0	0	0	0	0.4915
$\mathbf{B_{13}}$	0	0	0	0.1252	0.3431	0.2287	0	0	0	0	0	0.2308	0	0.4915	0.2458	0.4915	0
$\mathbf{B_{14}}$	0	0	0	0	0	0.1144	0	0	0	0	0	0.1270	0	0	0.2458	0	0
$\mathbf{B_{21}}$	0	0	0	0	0	0	0	0.3537	0.1769	0.1769	0	0	0.1017	0	0	0	0
$\mathbf{B_{22}}$	0	0	0	0	0.288	0	0	0	0.1769	0.1769	0	0	0.1017	0	0	0	0
$\mathbf{B_{23}}$	0	0	0	0	0	0	0	0	0	0	0	0	0.0509	0	0	0	0
$\mathbf{B_{31}}$	0.1747	0	0	0.0284	0	0	0	0	0.4402	0.2201	0	0.0542	0.0542	0	0.0937	0.0937	0
$\mathbf{B_{32}}$	0.0582	0	0	0.0744	0.1171	0.1171	0	0.3302	0	0.2201	0	0.0271	0.0271	0	0.0312	0.0312	0.1249
$\mathbf{B_{33}}$	0	0	0	0.1301	0	0	0	0.1101	0	0	0	0	0	0	0	0	0
$\mathbf{B_{41}}$	0.1385	0.1385	0.1385	0.1385	0.0385	0.0481	0	0	0	0	0	0.1271	0.0636	0	0	0	0.0622
$\mathbf{B_{42}}$	0	0	0	0	0	0	0	0	0	0	0.1775	0	0.0636	0	0	0	0
$\mathbf{B_{43}}$	0	0	0	0	0.1540	0.1444	0	0	0	0.1271	0.0592	0	0	0.0778	0.0778	0.0778	0.0156
$\mathbf{B_{51}}$	0.0837	0	0.0452	0.0107	0.0270	0.0085	0.0197	0.0791	0.0791	0	0	0	0	0	0.3059	0.3059	0.0500
$\mathbf{B_{52}}$	0	0	0.0137	0.0262	0.0084	0.0254	0.0338	0	0	0	0	0	0	0	0	0	0.1651
$\mathbf{B_{53}}$	0	0	0.0249	0.0070	0.0084	0.0254	0	0	0	0	0	0	0	0	0	0	0.0908
$\mathbf{B_{54}}$	0	0	0	0.0398	0.0156	0	0.0058	0	0	0	0	0	0	0	0	0	0

Table 7: Stabilized hypermatrix.

	B11	B12	...	B54
B11	0.0486	0.0486	...	0.0486
B12	0.0187	0.0187	...	0.0187
B13	0.1574	0.1574	...	0.1574
B14	0.0372	0.0372	...	0.0372
B21	0.0539	0.0539	...	0.0539
B22	0.0394	0.0394	...	0.0394
B23	0.0042	0.0042	...	0.0042
B31	0.0741	0.0741	...	0.0741
B32	0.0626	0.0626	...	0.0626
B33	0.0142	0.0142	...	0.0142
B41	0.1740	0.1740	...	0.1740
B42	0.1358	0.1358	...	0.1358
B43	0.0738	0.0738	...	0.0738
B51	0.0680	0.0680	...	0.0680
B52	0.0154	0.0154	...	0.0154
B53	0.0200	0.0200	...	0.0200
B54	0.0027	0.0027	...	0.0027

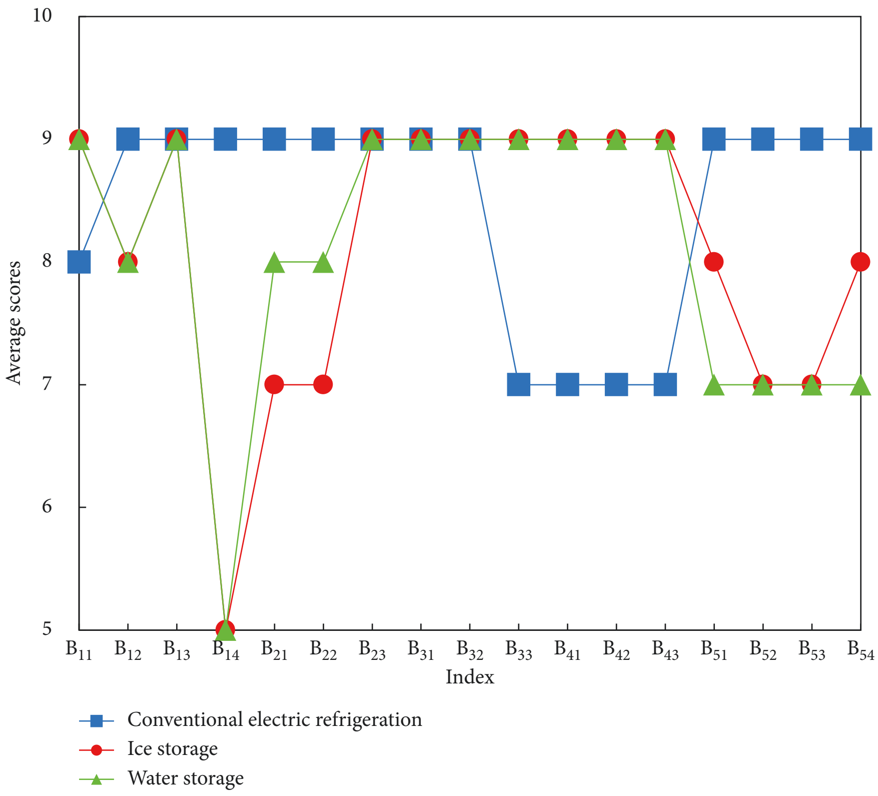

Figure 2: Expert-based scoring results.

Table 8: Summary of the value engineering correlation coefficients.

	Functional score	Functional coefficient	Cost (10000)	Cost coefficient	Value coefficient
Electric refrigeration	8.1557	0.3238	139489	0.3919	0.8262
Ice storage	8.5045	0.3377	119586	0.3360	1.0049
Water storage	8.5270	0.3385	96858	0.2721	1.2442

If we look at the ice storage and water storage results, we can see that their value coefficients are 1.2442 and 1.0049, respectively, and exceed 1 in both cases. They are both also better schemes. Although the difference between their functional coefficients is minimal, the cost coefficient for water storage is lower, indicating that it can realize the necessary functions at a lower cost. From the perspective of energy utilization, the conversion efficiency of water storage technology is 90%, while that of ice storage technology is 80%. So the energy conversion efficiency for water storage is slightly higher. It is worth mentioning that the airport occupies a vast area and the land price is relatively low, so there is enough space for water storage. Water storage also brings advantages in requiring a lower investment, offering reliable operation, providing a good refrigeration effect, and delivering obvious economic benefits. Altogether, this suggests that it has broad application potential and universal applicability. To sum up, it is objectively reasonable to choose a water storage-based cooling scheme when undertaking the energy supply implementation at Xiamen's Xiang'an New Airport. Through the simulation study of Xiamen Xiang'an New Airport, it can be seen that the decision support system established in this paper based on the VE theory and ANP method can select the appropriate cold source system for my country's civil aviation airports and even large-scale public construction projects, so that it can be realized with the least cost. Therefore, it can effectively promote the strategic goal of energy conservation and emission reduction in our country and even in the world.

6. Conclusion

The selection of a building's cold source system is a crucially important decision and it is a decision that has to be made frequently and recurrently. This makes it imperative to choose a method with a sound scientific basis for the technical and economic evaluation of such projects. We have developed a decision support system for the functional evaluation of building cold source systems that incorporates aspects such as functional experience, social and environmental benefits, reliability, demonstrable advances, and project applicability. It avoids the problem of neglecting costs and social and environmental benefits as a result of focusing upon functionality. By considering interdependencies and feedback relationships, our proposed method can objectively analyze the technical economy of typical cooling modes in central air-conditioning systems. The system relies on the use of ANP and introduces the theory of VE. The quantitative data of the actual life-cycle cost of the project is added, so that the decision-making takes into account both the function and cost of the cooling system of large public buildings, and the combination of qualitative and quantitative improves the rationality of decision-making results. Overall, by following the precepts of "function first, economy and practicality, but taking the image into account," it has demonstrable potential for the reasonable selection and application of a range of cold source systems. The case study has also confirmed the feasibility of using the method by identifying the best option for the energy-saving operation of the air-conditioning system in the airport terminal at Xiamen's new Xiang'an Airport. This suggests that it could play an important role in the energy-efficient construction of civil aviation structures and other large buildings in China, or even globally, thereby helping to meet the needs of energy conservation and emission reduction around the world. we sum up as follows:

(1) In recognition of the increasing importance of energy-savings and emissions reduction, this paper has presented a functional evaluation index system that contributes to the planning and construction of more effective cold source systems. The key novelty of the approach is, first of all, this paper considers the user's functional experience and establishes the system function evaluation index more comprehensively than before. Secondly, this paper considers the mutual influence relationship between factors, so it uses a more advanced method than AHP-ANP. More importantly, we integrate VE into it, truly consider for the enterprise, reduce costs, and maximize value. Data relating to Xiamen's new Xiang'an Airport was used as a resource for testing the viability of the approach, leading to the examination of three potential cooling modes, namely, conventional electric cooling, ice storage, and water storage. The proposed decision support system conducted empirical calculations and established value coefficients corresponding to the above three cooling modes of 0.8262, 1.0049, and 1.2442, respectively. This indicates that a final choice of water storage would be the most scientifically reasonable. The case study served to verify the effectiveness of the proposed model. This research provides a way of improving upon existing functional evaluation index systems for building cold source systems, thus offering a solid basis for the technical and economic evaluation of similar future schemes.

(2) The selected water storage cooling mode offers good technical and economic performance as a cold source supply for the air-conditioning system in the new airport terminal. In particular, its adoption would ensure significant energy savings. Thus, the proposed decision support system has the prospect of playing an exemplary role in the design and construction of energy systems in other large structures and buildings, thereby helping to meet the ongoing need for more effective energy conservation and emissions reduction.

Despite the effectiveness of our proposed method, the key to its success is the application of VE. The ANP model established in the functional analysis described here does not consider all possible factors and unpredictable changes. Moreover, the data in the judgment matrix is at least partly determined by subjective factors. This means that the final result that combines all of the relevant information may deviate from reality. In view of these shortcomings, a feedback loop could be added to the model, so that unsatisfactory evaluation factors can be fed back into the evaluation and revised, making the ANP model a more effective evaluation tool.

Furthermore, this study is largely based on the energy supply for a single airport and considers only the cooling system, not the heating system. As it lacks an overall consideration of the airport's cold and heat sources, the approach is not yet sufficiently comprehensive. Future research needs to cover the heating mode as well, so that it is further adapted to meeting the needs of green energy supply, energy conservation, and emissions reduction [34, 35].

Data Availability

The data used to support the findings of the study are included within the article.

Conflicts of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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