Research on centralized cooling system of coal mine based on fuzzy hierarchical method

Juan Zhao¹, Yuanzhen Li⁴, *

¹College of Safety and Environmental Engineering, Shandong University of Science and Technology, Qingdao 266590, China;
²College of Civil Engineering and Architecture, Shandong University of Science and Technology, Qingdao 266590, China.

*Corresponding author e-mail: lxming_2021@sdust.edu.cn

Abstract. The problem of heat damage in coal mines is becoming more and more serious, and the implementation effect of cooling system has become a matter of concern. In order to objectively evaluate the implementation effect of the mine cooling system, a comprehensive evaluation index system of the mine cooling system is established, and each index is quantified by expert scoring. Applying the combination of AHP and fuzzy comprehensive evaluation to comprehensively evaluate the cooling effect of the specific working face of coal mine, and propose management suggestions based on the evaluation results. The results of calculation and analysis show that the evaluation result of a coal mine cooling system is "good", which meets the requirements of mine safety in production.

Key words: Coal mine; Cooling system; Index system; Evaluation; Fuzzy analytic hierarchy process.

1. Preface:
At present, scholars at home and abroad have done a lot of research on the safety evaluation of mine cooling system. The commonly used evaluation methods are multi-objective decision-making method and grey analytic hierarchy process. But it is mainly aimed at the cooling scheme design and optimization process of the whole mine thermal hazard[1]. The research of fuzzy analytic hierarchy process in centralized cooling system uses quantitative analysis method to deal with qualitative problems, and evaluates the cooling effect of each working face in the mine respectively, which can achieve the purpose of analyzing and solving specific problems, and is beneficial to the management and development of the mine.

2. Establishment of the cooling and evaluation system

2.1. Analysis on the Influence Factors of the Thermal Damage System of the Mine
With the increase of coal mine depth and the improvement of mine mechanization, the thermal damage of high temperature mine is becoming more and more serious. This paper analyzes from three aspects of "man-machine-ring" [2]: the physical, psychological quality and management system of the staff
under the mine are the influencing factors that affect the safety production of the cooling system, and the energy consumed by the mechanical and electrical equipment is converted into heat energy and distributed into the surrounding media except for some of the useful work consumed by the mechanical and electrical equipment. The thermal radiation of surrounding rock is the main heating source of air flow in the mine, accounting for about 50% ≤ 60%; the treatment of coal gangue and minerals is the main heat source of oxidation heat in the mine; the heat produced by air compression, and the flow of air flow from the surface to the bottom of the well is a changeable process of heating and compression [3].

2.2. selection of indicators
In the process of drawing up the scheme of mine cooling system, the index is usually divided into three categories: technical feasibility, economy and reasonableness, safety and reliability. This paper does not consider the optimal selection of the scheme, mainly studies the evaluation of the cooling effect of the working face in each area of the mine, selects the qualitative and quantitative indexes from the "man-machine-ring" three aspects of the influencing factors of heat damage, and quantitatively analyzes the qualitative problems by fuzzy analytic hierarchy process (AHP). The main results are as follows:

(1) High temperature and heat damage has a great influence on human beings. When the air temperature is above 35 ℃, especially when the air temperature is above 38 ℃, the proportion of abnormal body temperature will increase obviously. People will accumulate heat due to the disorder of thermoregulation function, destroy the heat balance, and directly endanger the health of miners. The link of "people" can feel the cooling effect most directly and effectively. The degree of comfort of underground workers, the labor intensity of different types of work at different downhole temperatures, and the degree of operation completion can qualitatively analyze the cooling effect in thermal environment.

(2) All mining activities are carried out in a certain environment, and different environmental factors have different effects on the people and equipment operating in the environment. The Coal Mine Safety Code clearly stipulates that the air temperature of the mining face shall not exceed 26 ℃, the air temperature of the electromechanical chamber shall not exceed 30 ℃, and when the air temperature of the above two working places exceeds 30 ℃ and 34 ℃, the operation must be stopped. The parameters of the original temperature measurement of surrounding rock are the important basic parameters for the analysis of mine heat source and the prediction and calculation of downhole air flow temperature; the relative humidity of mine mining face is generally above 95%; the total air pressure air volume supplied to local ventilator must be larger than the suction air volume of the fan should not exceed 2.5 m / s. As an empirical index, WBGT, which combines the above factors of temperature, humidity, wind speed and radiation heat, is widely used in the evaluation of mine thermal hazard, that is, dry ball thermometer, wet ball thermometer and ball temperature to human body. Because the underground workplaces are different and the thermal environment is different, the WBGT index can not reflect the thermal hazard degree of the whole mine. The improved synthetic reduction temperature (SRT) can comprehensively represent the thermal hazard degree [4].

(3) Any mechanical and electrical equipment and cables in the mine emit the heat generated by themselves through the convection with the environment. When the temperature and humidity of the working environment exceed the prescribed limit or are near the limit value for a long time, it will lead to the difficulty of heat dissipation of the equipment, resulting in equipment failure. According to the relevant data, the accident rate of mechanical and electrical equipment is 3.6 times higher than that of the place below 30 ℃ when the relative humidity is more than 90% and the temperature is 30 ℃ 34 ℃. The downhole air temperature is 30 ℃, and the failure rate of downhole mechanical and electrical equipment increases by more than 1 ℃ with the increase of 1 ℃. Mine heat damage has a great influence on equipment, so it is of great significance to study the influence of mine equipment and management on cooling effect.
According to the actual characteristics of modern mine and the factors affecting the cooling system, the index system of cooling system composed of man-machine-ring is established. As shown in figure 1.

![Fig. 1 Evaluation index system of mine cooling](image)

**3. Summary of high temperature heat damage in a coal mine.**

The underground depth of a coal mine is between -650 m and -1200 m, and the average ground temperature gradient is 2.42 °C/ 100m. The temperature of the surrounding rock is up to 44 °C, and the temperature of the working face at the depth of -680 m is over 26 °C in the summer. The air humidity is high, and the humidity of the underground mining face in summer is up to 90%. The temperature of the air return air in the working face of the deep high-temperature area can reach 32-35 °C, and the workers in the field experience heat stroke, and the high-temperature heat damage seriously endangers the health of the staff and the production of the on-site safety.

In June, 2016, a coal mine underground centralized cooling and cooling system started to run, and the -900 concentrated refrigeration system adopted the German WAT cooling technology. After the centralized refrigeration system was put into operation, the heat stroke of the workers had not occurred, the head-to-head cooling effect was more obvious, and the temperature was reduced by 4-5 °C. There are no phenomena that affect the production due to high temperature weather.
4. The comprehensive evaluation of cooling control system based on AHP and fuzzy comprehensive evaluation

4.1. The importance degree of the index is determined by the AHP method

In order to reflect the importance of each evaluation index to the mine cooling system, the weight is determined by AHP AHP[5]. The expert consultation method is used to assign value to construct the judgment matrix of the target layer and each index category layer. The expert assignment is to send the questionnaire of indicator opinion solicitation to 6 senior engineers, 6 engineers and 4 technicians of enterprises, including 6 professors and production units in colleges and universities. Ask experts to score according to the actual situation, withdraw and remove invalid questionnaires according to the high and low of the experts, determining a judgment matrix, calculating a feature vector of each judgment matrix, obtaining a single-order weight of each layer after the normalization processing, and carrying out the consistency check on the result of the hierarchical single-ordering by the maximum characteristic root of each judgment matrix, And then the level general order and the consistency check are carried out. The target weight and the index layer weight of the person, the environment, the equipment and the management are obtained according to the AHP (AHP) level analysis and calculation method[6]. See Table 1 for details.

| Target layer | Criterion layer | Index layer | Weights | Weights | Sort |
|--------------|-----------------|-------------|---------|---------|------|
| people       | Stratification  | Labor intensity | 0.4551  | 0.2438  | 1    |
|              |                 | Human comfort | 0.1411  | 0.0760  | 6    |
|              |                 | Achievement of work goals in hot environment | 0.2627  | 0.1440  | 2    |
| Mine cooling | environment     | Sound personnel management system and implementation | 0.1411  | 0.0760  | 7    |
| management   |                 | Original rock temperature | 0.0217  | 0.0064  | 15   |
|              |                 | Air supply | 0.4133  | 0.1229  | 3    |
|              |                 | Wet bulb black bulb temperature index | 0.0585  | 0.0174  | 11   |
|              |                 | Relative humidity | 0.3182  | 0.0946  | 4    |
|              |                 | wind velocity | 0.1095  | 0.0323  | 9    |
|              |                 | Reasonable layout of cooling equipment | 0.0788  | 0.0234  | 10   |
|              |                 | Ratio of refrigeration capacity to heat dissipation of excavated surrounding rock | 0.0780  | 0.0127  | 12   |
|              |                 | System operation stability | 0.3386  | 0.0553  | 8    |
|              |                 | Good rate of equipment operation and maintenance | 0.4862  | 0.0794  | 5    |
|              |                 | Impact on extractive activities | 0.0486  | 0.0079  | 13   |
|              |                 | Economic rationality of operating costs | 0.0486  | 0.0079  | 14   |

It is found from the table that the importance of the indexes that affect the treatment of mine heat damage is unequal, some of which play a decisive role in the treatment of mine heat damage, while others have little influence on the treatment of mine heat damage. Among them, the environment and equipment play a major role in people, especially the labor intensity of the type of work, the degree of achievement of the working goal in the thermal environment, and the air supply occupies the dominant position, which is in accordance with the actual situation, which proves the qualification of the index.
4.2. Application of Fuzzy Evaluation Method

According to the results of expert consultation, the relative importance of each index s(i) is determined, and then the fuzzy judgment matrix is established from the relative importance of each factor in each level to a certain factor in the upper layer. The evaluation grades were excellent (90 points), good (80 points), medium (70 points 80 points), average (60 points 70 points), poor (0 points 60 points), and the scores were excellent (90 points), 80 points (80 points), 70 points (70 points), 60 points (60 points) and 60 points (0 points).

According to the effect of cooling system in a coal mine, five experts are selected to rate the cooling effect of each working face, calculate the evaluation score and grade of each working face, and finally judge the degree of cooling effect of each working face. The assignment system is shown in Table 2:

| Table 2. Evaluation Results Assignment System |
| working face            | Criterion layer                          | Score  | Total score | grade  |
|-------------------------|------------------------------------------|--------|-------------|--------|
| 27304 working face      | people (B1)                              | 78.2   | 250.2       | general |
|                         | environment (B2)                         | 82.4   |             | good   |
|                         | Equipment and management (B3)            | 89.6   |             | good   |
| 27304 working face      | people (B1)                              | 78.4   | 249.4       | general |
|                         | environment (B2)                         | 81.5   |             | good   |
|                         | Equipment and management (B3)            | 89.5   |             | good   |
| 27307 heading along the slot | people (B1)                     | 82.8   | 248.2       | good   |
|                         | environment (B2)                         | 80.9   |             | good   |
|                         | Equipment and management (B3)            | 84.5   |             | good   |
| Seven mining electromechanical chambe | people (B1)                     | 79.8   | 245         | general |
|                         | environment (B2)                         | 76.3   |             | good   |
|                         | Equipment and management (B3)            | 88.9   |             |        |

4.3. Analysis of comprehensive evaluation results.

As can be seen from Table 3, the comprehensive indexes of the 27307 tunneling, 27304 and 27305 working face are 248.2, 250.2 and 249.4, respectively, indicating that the comprehensive management and evaluation scores of the three working face cooling systems are close and best; however, for both working surfaces, the parameters of the working face indexes are all B3. And the cooling effect of the working surface is good. The lowest of the total rating index of the seven-mining and mechanical working chamber, among which, because the high-temperature heat-damage environment of the working face is higher than that of other working surfaces, the B2 evaluation value is the worst, and the management should be strengthened in the cooling management of the working face.

5. Application of Evaluation results to cooling system of a Coal Mine

5.1. Cooling Measures in Mining face

According to the results of fuzzy comprehensive evaluation, the evaluation scores of 27304 working face and 27305 working face are 250.2, 249.4, which are higher than those of other working faces. The cooling effect of mining face in a coal mine is the best from the "man-machine-ring" system. As the first production site of coal, coal mining face has the characteristics of narrow working space, many machinery and equipment, poor visual environment and high temperature. It is the heat dissipation concentration area. Coal and rock temperature and mechanical and electrical equipment heat dissipation are the main reasons that affect the wind temperature of working face. The centralized refrigeration...
technology can be used to cool down the mining face by means of bottom hole refrigeration and surface heat discharge.

5.2. Cooling measures for heading face
The evaluation score of tunneling face is 248.2, and the cooling effect of man-machine-ring is in good condition. The heading face is a single single-headed roadway, which is mainly driven by excavation and supplemented by other geological conditions. There is no independent ventilation system and no direct access to the ground. The environmental (B2) cooling effect evaluation is the lowest, and measures should be taken for its ventilation by regulating wind speed and air supply. Increase air volume, adopt centralized refrigeration mode to each mining face in seven mining areas, use local mechanical refrigeration to cool down in three mining areas, increase head-on air volume and reduce moisture, increase air supply, and reduce air moisture content (less than 70%).

5.3. Measures for Chamber Cooling
The evaluation score of the chamber is 245, and the overall cooling effect is in a general state, which is caused by the characteristics of the electromechanical chamber itself. Many large mechanical and electrical equipment are often arranged in the chamber, and their continuous operation emits a lot of heat, coupled with the narrow space, once the ventilation is poor, the climate condition will inevitably deteriorate. For mechanical and electrical equipment, high temperature certainly has an impact on its operation quality and service life, but it belongs to the "machine" factor in "man-machine environment", and its influence is still weak compared with "human". Therefore, the cooling measures are mainly from the point of view of protecting workers, and the harm to equipment cannot be considered for the time being. Pay close attention to the individual protective measures of operators in high temperature places.

6. Conclusion
In this paper, the evaluation index system of the mine cooling system is set up from the "man-machine-ring" analysis, and the weight between the evaluation indexes is determined by the analytic hierarchy process. Combined with the actual cooling of a mine, the fuzzy comprehensive evaluation method is used to analyze the expert score, and the cooling effect of the working face in different areas of the mine is evaluated. The corresponding preventive measures are taken according to the rating grade of different working faces, so that the result is more accurate and practical. And has the guiding significance to the effective cooling of the coal mine.

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