Analysis of the Influence of Green Building Fresh Air System on Indoor Environment Based on Improved Analytic Hierarchy Process

Liu Hua¹, Chen Xiaoyi², Niu Runping*² and Su Yuhai¹

¹ State Key Laboratory of Air-conditioning Equipment and System Energy Conservation, Guangdong Key Laboratory of Refrigeration Equipment and Energy Conservation Technology, Zhuhai, Guangdong, 519070, China.
² Beijing University of Civil Engineering and Architecture, Beijing, 100044, China
Corresponding author’s e-mail: niurunping@bucea.edu.cn

Abstract: With the increasing pollution of outdoor environment, it is urgent for people to improve indoor air quality and create a good living and working environment. Using fresh air system to regulate indoor air quality is one of the commonly used technologies in green building design. The fresh air system energy consumption accounts for about 30% of the total energy consumption of air conditioning system, which has an important impact on the overall evaluation of green buildings. Based on the improved Analytic hierarchy process (AHP), an objective and accurate evaluation of the indoor environment of the fresh air system is carried out by questionnaire. The main purpose of this article is to find out the main factors that the fresh air system affects the indoor environment in the green building, while reducing the energy consumption of the fresh air system and creating a good indoor environment.

1. Introduction
With the progress of science and technology and the rapid growth of the global economy, the global Greenhouse Effect is expanding, the ozone layer hole, desertification and other environmental problems are becoming more and more serious, and the ecological environment on which human beings depend becomes more and more fragile. More people began to pay attention to the protection of the ecological environment. In recent years, green buildings in China have been developing vigorously. Up to the end of 2017, there are 4314 green building evaluation and marking projects in China[1], with a cumulative building area of nearly 50 billion m². Electricity consumption for large new public buildings is expected to reach 200 billion kWh/a by 2020. In such buildings, 50%~60% of the electricity used for air conditioning refrigeration and heating is used, and about 30% - 40% of the energy consumption of this part is used for fresh air treatment[3]. With the air tightness of the building becoming higher and higher, the application of fresh air system in the green building is widely concerned by scholars all over the world. Therefore, this paper chooses AHP to select suitable evaluation index to analyze the influence factors of fresh air system on indoor environment in green building, and find out the existing problems of fresh air system in the actual operation of green building. It provides a reasonable reference for the optimization of fresh air system.
2. Construction of evaluation system of fresh air system in green building

2.1 Determining the evaluation index of green building fresh air system
In the past people mainly changed indoor air quality by opening windows to change air quality. This method is not only inefficient but also brings extra load to air conditioning system[4]. And with the increasing outdoor air pollution, the traditional ventilation and air exchange methods are difficult to meet the requirements of indoor air quality[5]. This paper makes a questionnaire survey on the actual users of the fresh air system in green buildings.

2.2 Establishment of a comprehensive evaluation index system for the fresh air system of green buildings
The comprehensive evaluation index system of green building fresh air system consists of three parts: target layer, criterion layer and control layer. According to the requirements of GB/T50378-2014 for indoor environmental quality control, the standard layer selects indoor air quality and indoor thermal environment. The three indexes of indoor acoustic environment constitute[6], which mainly reflect the influence of fresh air system on indoor environment in green buildings. The evaluation indexes of the control layer mainly include: indoor CO₂ concentration, indoor respirable particulate matter concentration, indoor fresh air volume and indoor airflow organization influence on indoor air quality, indoor air temperature, indoor air temperature, The influence of indoor air humidity and indoor air flow velocity on the indoor thermal environment, the noise generated by indoor air supply pipes, air outlet and indoor air treatment equipment, The influence of the noise caused by the vibration and so on the indoor environment. Finally, the comprehensive evaluation index system of green building fresh air system is established according to AHP.

3. Determine the weight of evaluation index of green building fresh air system

3.1 Improved analytical hierarchy process
The Analytic hierarchy process, referred to as AHP[7], was put forward by Professor Sadie, an operational research expert at the University of Pittsburgh in the 1970s. The AHP divides the related factors into target layer, criterion layer and control layer, then qualitative and quantitative analysis. The principle is as follows: firstly, the problem is hierarchized and decomposed into different factors, and then hierarchical clustering is carried out according to the relationship and membership among the factors. Then the relative weight of each factor is obtained by solving the eigenvector of the judgment matrix by analyzing and comparing the factors in each layer, and introducing the scale method of 1~9 ratio to construct the judgment matrix. In the end, the relative importance order of the scheme to be selected relative to the final target is calculated, and by weight analysis, the ranking of the corresponding factors is found out[8].

Traditional (AHP) uses 9-scale method to quantify human judgment. The evaluation of evaluation objects mainly depends on human experience, subjective factors occupy the dominant position, and it is easy to produce judgment errors[9]. Therefore, by improving the traditional and establishing a 3-scale judgment matrix, the judges can make a relatively important judgment on the two factors and get more accurate data[10].

3.2 Evaluation process

3.2.1 Construction of comparison matrices
According to the comprehensive evaluation index system of green building fresh air system, this paper makes a questionnaire survey on the staff of a green office building in Beijing by means of questionnaire. According to the comprehensive evaluation index system of green building fresh air system, the evaluation index is quantified. By comparing the three factors that affect indoor environment, indoor air quality, indoor thermal environment and indoor acoustic environment.
According to the collected questionnaire, the data are analyzed and summarized to set up the criterion layer 3 scale comparison matrix of the evaluation system of the fresh air system of green building.

\[ m_{ij} = \begin{cases} 
5 & \text{The } i\text{-th factor is more important than the } j\text{-th factor} \\
3 & \text{The } i\text{-th factor is not as important as the } j\text{-th factor} \\
1 & \text{The } i\text{-th factor is as important as the } j\text{-th factor} 
\end{cases} \]

According to the analysis of the data in this paper, the comparison matrix is obtained as follows.

| factor       | Indoor air quality | Indoor thermal environment | Indoor sound environment |
|--------------|--------------------|-----------------------------|-------------------------|
| Indoor air quality | 1                  | 3                           | 5                       |
| Indoor thermal environment | 1/3                | 1                           | 5                       |
| Indoor sound environment | 1/5                | 1/5                         | 1                       |

### Table 1. Comparison judgment matrix of layer B with respect to layer A

3.2.2 Construction of judgement matrix

To calculate the ranking index of each factor, \( r_i = \sum_{j=1}^{n} c_{ij} \). \( r_{\text{max}} = \max\{r_i\} \), \( r_{\text{min}} = \min\{r_i\} \), \( d_i = \frac{r_{\text{max}}}{r_{\text{min}}} \)

The matrix \( M \) is dimensionless and transformed into a judgment matrix \( A \). \( r_i \) is the sum of all elements in line \( i \) of matrix \( A \).

\[ A = \begin{bmatrix} a_{11} & a_{12} & \ldots & a_{1n} \\ a_{21} & a_{22} & \ldots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \ldots & a_{nn} \end{bmatrix}, \quad a_i = \left( \frac{r_i - r_{\text{max}}}{r_{\text{max}} - r_{\text{min}}} (a_{max} - 1) + 1 \right)^{-1} \]

According to the calculation of comparison matrix, the criterion layer judgement matrix of evaluation system of fresh air system of green building can be calculated by formula (2).

\[ A = \begin{bmatrix} 1 & 1/3 & 3 \\ 3 & 1 & 5 \\ 1/3 & 1/5 & 1 \end{bmatrix} \]

3.2.3 Determination of weights

In this paper, the sum product method is used to determine the weight value of the importance of each element[11]. According to the judgment matrix, the process of calculating the judgment matrix and the product method is as follows.

1. Normalized calculation of elements in judgment matrix by column

\[ \overline{a}_{ij} = a_{ij} / \sum_{k=1}^{n} a_{kj} \quad i, j = 1, 2, \ldots, n \]  

(1)

2. The rows of elements of a normalized matrix are added together

\[ \overline{w}_i = \sum_{j=1}^{n} \overline{a}_{ij} \quad i = 1, 2, \ldots, n \]  

(2)

3. Divide the added vector by \( n \) to get the weight vector

\[ \overrightarrow{w}_i = w_i / n \]  

(3)
(4) Computing maximum eigenvalue

\[ \lambda_{\text{max}} = \frac{1}{n} \sum_{i=1}^{n} (Aw)w_i \]  

(4)

According to the weight calculation formula (1)-(4), we can calculate the weight value of each factor of the criterion layer in the evaluation system of the green building fresh air system, such as the weight value of each element of the criterion layer shown in Table 2.

Table 2. Weights of elements in the criteria layer

| Indoor air quality | Indoor thermal environment | Indoor sound environment | \( W_i \) |
|--------------------|---------------------------|-------------------------|---------|
| 0.230              | 0.218                     | 0.333                   | 0.260   |
| 0.693              | 0.654                     | 0.556                   | 0.634   |
| 0.077              | 0.137                     | 0.111                   | 0.106   |

From table 2, we can get the order of the weight value of the three evaluation criteria of indoor air quality, indoor thermal environment and indoor sound environment, which are \( 0.634 > 0.260 > 0.106 \). According to the same calculation method in this paper, the weight of different factors in the evaluation system of green building fresh air system can be calculated in turn. \( W_1 = (0.125,0.125,0.405,0.343) \), \( W_2 = (0.618,0.297,0.086) \), \( W_3 = (0.75,0.25) \). The comprehensive weights of different factors in each criterion layer to the total target can be calculated, as shown in Table 3.

Table 3. Comprehensive weight values of different factors to the overall objective

| \( X_1 \) | \( X_2 \) | \( X_3 \) | \( W_i \) |
|---------|---------|---------|---------|
| 0.260   | 0.634   | 0.106   | 0.033   |
| 0.125   | 0.125   | 0.033   |
| 0.405   |         | 0.105   |
| 0.343   | 0.618   | 0.392   |
| 0.297   | 0.086   | 0.055   |
|         | 0.75    | 0.079   |
| 0.25    |         | 0.027   |

According to the comprehensive weights of different factors in each criterion layer listed in the table, the order of magnitude is \( 0.392 > 0.191 > 0.105 > 0.089 > 0.079 > 0.055 > 0.033 > 0.033 > 0.027 \). It can be seen that indoor temperature and humidity have a great impact on indoor thermal environment while indoor thermal environment is comfortable.

3.2.4 Consistency of judgement

Because of the complexity of objective things and the diversity of experts' subjective judgment, there is often inconsistency of judgment[11]. In reference, Saaty[7] pointed out that the decision makers should check the consistency of the judgment matrix, and when the judgment matrix is consistent, the judgment error will be smaller. Therefore, Saaty introduces the evaluation index of consistency ratio of judgment matrix, that is.

\[ C.R. = C.I. / R.I. \]  

(5)

Among them, a random consistency index, the specific values as shown in Table 4. C.I. As an indicator of consistency, that is.

\[ C.I. = \frac{(\lambda_{\text{max}} - n)}{(n - 1)} \]  

(6)
The judgment matrix is a completely consistent matrix when \( C.R. = 0 \), the judgement matrix is a satisfied consistent matrix when \( C.R. < 0.1 \), and the judgment matrix is not consistent when \( C.R. > 0.1 \).

| Order | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
|-------|------|------|------|------|------|------|------|------|
| RI    | 0.58 | 0.89 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

According to formula (5) and (6), the matrix is known, and the table 4 is used to calculate the index of the criterion layer, so the judgment matrix is consistent, that is, the criterion layer judgment matrix of the evaluation system of green building fresh air system is consistent. In the same way, the consistency evaluation index values of each judgement matrix in index layer are 0.006 ~ 0.008 and 0, respectively, which are less than 0.1. Therefore, the index layer judgment matrix is consistent.

4. Conclusion

- The weight value of indoor air quality 0.260 is smaller than that of indoor thermal environment 0.634. It reflects that the focus of attention on indoor environment is the comfort of indoor thermal environment. Therefore, in the future design of the fresh air system, we should try to meet the basic requirements of indoor air quality, improve the indoor thermal environment, bring thermal comfort to the indoor personnel, so as to achieve the purpose of energy saving and high efficiency.
- Based on the analysis of the influence of fresh air system on indoor environment in green buildings, it can be concluded that the comfort degree of indoor environment is the most affected by indoor thermal and wet environment, and its comprehensive weight values can reach 0.392 and 0.191 respectively. Traditional design often pays more attention to the improvement of indoor air quality by fresh air system, thus neglecting the influence of fresh air on indoor thermal environment and comfort.
- The noise produced by the pipeline equipment and outlet of the fresh air system occupies a large proportion of the indoor environment, and the comprehensive weight value of the noise produced by the indoor tuyere and the air pipe reaches 0.079. Therefore, the noise influence of the fresh air system can not be ignored.

Acknowledgments

This research was supported by State Key Laboratory of Air-Conditioning Equipment and System Energy Conservation, Guangdong Key Laboratory of Refrigeration Equipment and Energy Conservation Technology (No.ACSKL2018KT1208).

Reference

[1] China Society for Urban Studies. China Green Building 2018[M]. China architecture & building press. 2018: 49-51
[2] Jiang yi,Current building energy consumption in China and effective energy efficiency measures[J].HVAC,2005,5(35),30-40
[3] Guo rui,The Research on Evaluation Index System of Public Building Energy Consumption[D].Hunan universty,2004.
[4] Yang yu-jin,Indoor air quality of low energy consumption residential building in hot-summer and cold-winter area in China——Take Nanjing as an example[D].Nanjing University,2016.
[5] Gao xing,Sutdy and application in ventilation commitment and strategy for improving indoor air quality(IAQ)in hotel building[D].Dalian Universty,2005.
[6] Ministry of Housing and Urban-Rural Development of the People’s Republic of China. Assessment standard for green building: GB/T50378—2014[S]. Beijing: China architecture & building press, 2014
[7] Wang Lian-fen, Xu Shubai. Introduction to Analytic Hierarchy[M]. China RenMin University Press, 1990.
[8] Zhang tian-jun, Su lin ,Application of improved Analytic hierarchy process in Prediction of dangerous Grade of Coal and Gas outburst[J].Journal of Xi'an University of Science and Technology.2010 (5):536-541.
[9] LIU Yu-ling1,YOU Chun,Application of the Improved Analytic Hierarchy Process to Risk Assessment on Road Tunnel Construction[J].Safety and Environmental Engineering,2009,16(3):76-78.
[10] Hu You-yong,Liu Dong-dong,Application of Improved AHP in Subway Fire Risk Assessment[J].Journal of Beijing University of Civil Engineering and Architecture,2009,25(3):38-41,59.
[11] Zhang Bing-jiang,The Analytic hierarchy process and its Application[M].Publishing House of Electronics Industry,2014.1.