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Analysis of influencing factors of passive building energy consumption in hot summer and cold winter area

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Abstract. Under the background of urbanization and the improvement of living standard, building energy consumption is increasing day by day and energy saving and consumption reduction in construction industry is imminent. As a new type of energy-saving healthy and livable building, passive building will inevitably become the development trend of future buildings. Based on the factors that affect the energy consumption of passive buildings in hot summer and cold winter areas, this paper finds out the main influencing indexes, calculates the accurate index weight by AHP and corrects it by entropy weight method in order to be more objective. Finally, the method is applied to an example and relevant suggestions are put forward based on the research results and the examples.

1. Introduction

Building energy consumption is growing rapidly, so building energy conservation has become the focus of energy conservation. China began to explore the application of energy-saving buildings in the 1970s and 1980s, The concepts of green building, prefabricated building, sustainable building and passive building have emerged, Among them, passive buildings have the advantages of more energy-saving architectural design, more comfortable living space, better air quality, To meet the needs of modern people for living comfort, Can alleviate the problem of building energy consumption, As a result, the construction industry gradually favored, And exploring the influence factors of passive building energy consumption is more beneficial to the development of passive building, It is of great significance.

2. Literature review

In terms of factors affecting the energy consumption of passive buildings, U.Teoman Aksoy^[1], the influence of passive design parameters such as building shape and orientation position on heating demand is studied. Amelija V.Djordjević^[2] put forward the solar system design strategy of passive building to reduce the annual heating energy demand. Danny and other^[3] summarize three aspects of building energy consumption optimization: enclosure structure, internal conditions, energy supply system. Nord, Natasa and other^[4] use standard schedules, Simulated the behavior of the occupants, To study whether occupant behavior significantly changes building energy saving performance. Li Simeng, Lang Bing and other^[5] analyze the effect of natural ventilation design strategy on reducing building energy consumption from each stage of project design. Li Wan, Jiang Yan and other^[6] used



numerical simulation software to establish building energy consumption model, Multiple corresponding input parameters were selected from the parameters of enclosure structure and air conditioning system for single factor sensitivity analysis. For example, Li Manyang, Wang Qingping and Ning Wei ^[7] take a passive high-rise residential building in Tianjin, DeST software is used to simulate and analyze it year-round, It turns out, The HVAC system adopts intermittent operation mode and internal shading facilities, The energy consumption of building air conditioning is greatly reduced. Li Hui, Chen Hong and other ^[8] according to the Hubei Province residents of the status of household energy use of air conditioning habits, The energy saving effect of passive housing standard in Hubei province is analyzed by using energy consumption simulation software. Qian Cheng, Gong Yanfeng and other ^[9] simulated the building energy consumption of typical residential buildings in Nanjing area under the continuous heating mode under different thermal parameters, air tightness and ventilation mode. The results show that the heating and air conditioning load can be minimized by improving the thermal system of the enclosure structure and changing the air tightness of the building. Wang Zhen Liu Qingxi and other ^[10] summarized and put forward the technical means to reduce the running energy consumption through the simulation calculation of the project energy consumption, the actual measurement of the daily living and running energy consumption, the test and analysis of the daily lighting and other equipment power affecting the running energy consumption, and the COP of the refrigeration unit.

3. Method

3.1. Construct a passive building energy consumption influencing factor index system

Based on the above-mentioned documents and field inspections of some passive building projects, this article establishes passive building energy consumption factors from secondary indicators such as technology application, energy use behavior, equipment systems, and three-level indicators such as overall planning and design, personnel and equipment schedules, and air-conditioning system forms. Index system, as shown in Table 1.

Table 1. Index System of Influencing Factors on Energy Consumption of Passive Building.

First-level index	Secondary indicators	Three-level indicators
Evaluation of influencing factors of passive building energy consumption in cold winter and hot summer areas (S)	Technical Application (A1)	Master planning and design (B1)
		Enclosure structure design (B2)
		Thermal bridge treatment (B3)
		Renewable energy utilization (B4)
		Airtight structure design (B5)
	Energy use behavior (A2)	Personnel and equipment work and rest (B6)
		Open windows for ventilation (B7)
		Use model of inner shading facility (B8)
		Air conditioner usage mode (B9)
	Equipment system (A3)	Air conditioning system form (B10)
		Refrigeration unit COP(B11)
		Average lighting power per unit area (B12)
		Average equipment power per unit area (B13)

3.2. Level analysis-entropy method

Hierarchical analysis-entropy weight method takes entropy value as correction coefficient, constructs weight correction model to correct the results of AHP, and obtains the correction weight of each level index. The main steps of Hierarchical Analysis-entropy weight method are as follows.

- (1) Determine the hierarchical structure of evaluation indicators

Take the first-level, second-level, and third-level indicators in Table 1 as the target level, criterion level, and index level, respectively, to establish a systematic hierarchical structure.

(2) Establish a judgment matrix

After the hierarchy is determined, it is necessary to establish a judgment matrix to solve the index weight, that is, to assign the weight of each element under a certain index. The establishment of the judgment matrix needs to be combined with the expert opinion, that is, the influence degree of the two factors on the target is judged by the expert scoring. According to the certain scale value, the judgment matrix $B = (b_{ij})_{n \times n}$ is constructed as follows:

$$\begin{bmatrix} b_{11} & b_{12} & b_{13} & \cdots & b_{1n} \\ b_{21} & b_{22} & b_{23} & \cdots & b_{2n} \\ b_{31} & b_{32} & b_{33} & \cdots & b_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & b_{n3} & \cdots & b_{nn} \end{bmatrix}$$

The B_i is the next level of the A index, Among them $i=1, 2, \dots, n$; b_{ij} is the element of the judgment matrix, The value rule is as follows: B_i is as important as B_j , $b_{ij}=1$; B_i is a little more important than B_j , $b_{ij}=3$; B_i is more important than B_j , $b_{ij}=5$ per cent; B_i is more important than B_j , $b_{ij}=7$ percent; B_i is more important than B_j , $b_{ij}=9$; If the relative importance of the B_i 、 B_j is between the above, $b_{ij}=2, 4, 6, b_{ji}$ is always equal to the reciprocal of b_{ij} .

(3) Calculate the weight of the compared element from the judgment matrix, the formula is

$$\alpha_i = \frac{(M_i)^{1/n}}{\sum_{i=1}^n (M_i)^{1/n}}, \quad M_i = \prod_{j=1}^n b_{ij} \quad (1)$$

In the formula, α_i = the weight of the B_i index obtained by the traditional analytic hierarchy process; M_i is the product of the elements in the same row of the judgment matrix.

(4) The consistency test of the judgment matrix, the formula is

$$CR = \frac{CI}{RI}, \quad CI = \frac{\lambda_{\max} - n}{n - 1}, \quad \lambda_{\max} = \frac{1}{n} \sum_{i=1}^n \frac{(B\alpha)_i}{\alpha_i} \quad (2)$$

Where $(B\alpha)_i$ is the i element of vector $B\alpha$; CI as a consistency indicator, RI is the random consistency index of the judgment matrix, A judgment matrix used to measure different orders, Determine whether it has satisfactory consistency. Because the RI values of different order judgment matrices are different, Enumerate the RI value of order 1-9 judgment matrix (as shown in Table 2); CR random consistency ratio, At $CR < 0.1$, The judgment matrix has satisfactory consistency; At $CR > 0.1$, The judgment matrix needs to be adjusted and modified

Table 2. Average random consistency index.

Matrix order n	1	2	3	4	5	6	7	8	9
RI	0	0	0	0	0.12	0.24	0.36	0.41	0.45

(5) Using entropy technology to modify the weight calculated by the traditional analytic hierarchy process, the formula is^[11]

$$\beta_j = \frac{v_j \alpha_j}{\sum_{j=1}^n v_j \alpha_j}, \quad v_j = \frac{(1 - s_j)}{\sum_{j=1}^n (1 - s_j)} \quad (3)$$

$$S_j = -(1/n) \sum_{i=1}^n (r_{ij} \ln r_{ij}), \quad r_{ij} = \frac{b_{ij}}{\sum_{i=1}^n b_{ij}}$$

In The formula: the α_j is the weight of the j index obtained by the hierarchical analysis entropy weight method; the v_j is the information weight of the j index; and the S_j is the entropy value by the first index.

Because the index system of this subject is composed of three levels, the required comprehensive weight should be multiplied layer by layer, that is:

$$w_k = \beta_j \times \beta_j^k \quad (4)$$

In the formula: w_k is the final comprehensive weight; β_j is the weight of the second-level index; β_j^k is the weight of the third-level index.

4. Results and Discussion

This paper selects a passive construction project in Jiangsu Province. The project covers an area of 19,100 m², with a total construction area of 23,100 m². The project fully considers the climate characteristics of hot summer and cold winter areas, adopts passive technologies such as thermal insulation, natural ventilation, and natural lighting according to local conditions. In addition, the project uses ground source heat pumps and water storage, solar light heating, fresh air heat recovery, and high efficiency and energy saving. Various applicable green building technologies such as lighting and intelligent control.

The experts are invited to score the indexes that affect the energy consumption of the project and use the above model to evaluate them, then establish the matrix, test the consistency and correct the weight. According to formula (1)~(4), the results are shown in Table 3~6 and Figure1.

Table 3. Calculation of index weights at the criterion level.

S	A1	A2	A3	α (Initial weight)	β (Correction weight)
A1	1	2	3	0.540	0.497
A2	1/2	1	2	0.297	0.377
A3	1/3	1/2	1	0.163	0.127

Consistency check $CR=CI/RI=0.008<0.1$; $\lambda_{max}=3.009$

Table 4. Technical application index weight calculation.

A1	B1	B2	B3	B4	B5	α (Initial weight)	β^3 (Correction weight)	w_k (final weight)
B1	1	1/4	1/2	1/2	1/3	0.077	0.061	0.030
B2	4	1	3	3	2	0.413	0.342	0.170
B3	2	1/3	1	1	1/2	0.135	0.140	0.070
B4	2	1/3	1	1	1/2	0.135	0.140	0.070
B5	3	1/2	2	2	1	0.240	0.317	0.158

Consistency check $CR=CI/RI=0.016<0.1$; $\lambda_{max}=5.072$

Table 5. Calculation of the weights of energy use behavior indicators.

A2	B6	B7	B8	B9	α (Initial weight)	β^3 (Correction weight)	w_k (final weight)
B6	1	3	4	1/3	0.270	0.42	0.157
B7	1/3	1	2	1/4	0.122	0.11	0.041
B8	1/4	1/2	1	1/5	0.076	0.04	0.015
B9	3	4	6	1	0.532	0.44	0.164

Consistency check $CR=CI/RI=0.042<0.1$; $\lambda_{max}=4.114$

Table 6. Weight calculation of equipment system indicators.

A3	B10	B11	B12	B13	α (Initial weight)	β^3 (Correction weight)	w_k (final weight)
B10	1	1/4	3	1/3	0.134	0.135	0.017
B11	4	1	5	3	0.529	0.428	0.054
B12	1/3	1/5	1	1/4	0.068	0.029	0.004
B13	3	1/3	4	1	0.269	0.408	0.052

Consistency check $CR=CI/RI=0.067<0.1$; $\lambda_{max}=4.181$

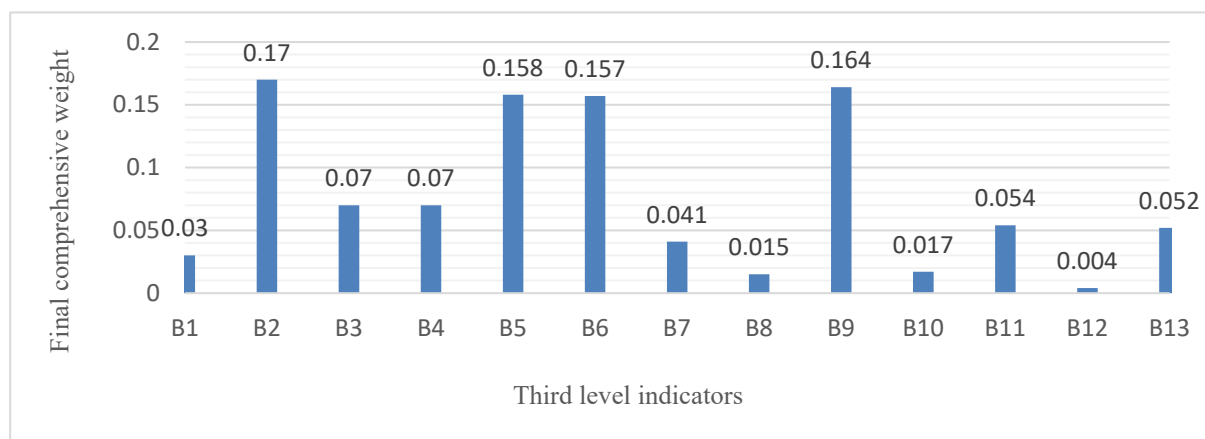


Figure 1. Final comprehensive weight of three level indicators.

According to the final comprehensive weight result calculated by the above example, it can be seen that the ones that have a greater impact on the energy consumption of passive buildings are B2, B5, and B9, which correspond to the thermal performance design of the envelope structure, the air-tight structure design, and the air-conditioning use mode. In order to allow passive buildings in areas with hot summers and cold winters to exert better energy-saving effects, this topic puts forward the following opinions based on the analysis results of actual cases:

(1) If the building envelope structure is optimized, the design of thermal performance parameters such as envelope structure heat transfer coefficient, shading coefficient, window-to-wall ratio, and window solar radiation heat gain coefficient is one of the most important factors. Using dynamic simulation energy consumption calculation software, calculate and compare the annual heating and air conditioning energy consumption of the reference building and the designed building. At the same time, it sorts out the thermal design parameters of the envelope structure used, and extracts the range of commonly used envelope structure design parameters for this type of building, so that it is convenient to choose what types and specifications of high-performance insulation panels and insulation performance door and window systems, etc.

(2) The overall airtightness of a building is determined by the amount of air that penetrates through the gaps between doors, windows and walls and roofs. There are big differences in the quality, airtightness, opening method, hardware accessories, and insulation performance of the external windows. The airtightness of the glass also depends on the adhesion between the glass and the frame. In addition, it has a switch structure, which has poor airtightness. Therefore, in view of the current problems, it is necessary to improve the air-tightness of building doors and windows, such as using new energy-saving glass, which has a small heat transfer coefficient, strong oxidation and corrosion resistance, and a strong structure. It is also necessary to ensure the airtightness during the installation of doors and windows and the construction of exterior walls and roofs, and ultra-low energy consumption of passive buildings can be achieved through refined construction.

(3) According to the characteristics of the heating and air-conditioning systems used by residents in residential buildings in our country, and the different needs of different households. The same difference causes the residents to use different air-conditioning systems. Some residential behaviors will directly affect the operating energy consumption of the heating and air-conditioning system, so you can guide personnel to use the environmental control system. For indoor personnel leaving the room for a short time, you can choose not to turn off the air-conditioning. From the perspective of comprehensive effects, it is Advantageously, when people leave the room for more than 1 hour, the room air conditioner selects the intermittent operation mode, which can promote the reduction of energy consumption in the room and is beneficial to building energy conservation.

5. Conclusion

At present, various energy-saving policies and requirements have shown that the development of passive buildings in China is improper. In order to achieve the ultra-low energy consumption index requirements of passive buildings in cold winter and hot summer areas, overall planning and design, thermal performance design of envelope structure, and heat protection are required. Passive technologies such as bridge treatment, renewable energy utilization, and air-tight structure design should be fully utilized. In particular, the thermal performance design and air-tight structure design of the envelope structure should be more standardized and strive for excellence. At the same time, it is necessary to ensure that the power of the building equipment system itself is low, the energy consumption is low, and the occupant's energy consumption behavior is standardized, so that the early investment can play its due effect and reflect the advantages of passive building energy saving.

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