Analysis on Influencing Factors of Energy Consumption of Public Buildings in Cold Areas

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Abstract. DeST-c software was used to build the building model, and the single factor experiment method was used to carry out the simulation study. Under the condition that only single factor was changed and other influencing factors were unchanged, the influence law of each energy influencing factor on energy consumption was analyzed, and the influencing factors were Analysis of the impact degree on energy consumption, the results are as follows: body shape coefficient > outer window heat transfer coefficient > outer wall heat transfer coefficient > south window ratio > roof heat transfer coefficient > north window and wall ratio, namely, body shape coefficient, outer window transmission. The thermal coefficient and the external wall heat transfer coefficient are the main influencing factors of building energy consumption.

1. Introduction

At present, with the rapid development of construction industry, the problem of environmental pollution is becoming more and more serious, especially the low proportion of clean heating in northern China, the state has introduced a series of policies on clean heating to improve this situation. Coal to electricity, coal to gas and other boiler reconstruction projects are increasing in the north, which needs to do the fine operation of the heating system, and the energy-saving transformation of the enclosure structure is of great significance to the fine operation of the system, so the construction of energy-saving buildings is imperative.

How to reduce the energy consumption of building heating in cold areas is a difficult problem. We can achieve it by improving the thermal insulation level of building enclosures (including exterior walls, roofs, doors and windows, etc.). Therefore, it is necessary to study the impact of building enclosures on building energy consumption in cold areas. Many domestic scholars have done a lot of research work in this field. Liang Zhen used DOE-2 software to establish shopping mall building models, and used Harbin, Beijing, and Shenzhen as examples to conduct simulation calculations, applied orthogonal test design theory to design the experiment and analyze the test results, and obtained the building energy consumption of shopping malls in different regions. The main influencing factors, and conducted an energy-saving analysis[1]. Li Yingying takes a high-rise office building in Changsha as an example, establishes a typical energy consumption model, uses the energy consumption simulation software eQUEST to set up, calculates the annual building energy consumption under different building models and equipment conditions, and analyzes the calculation results. The results show that indoor temperature setting, power density of equipment and lighting, and
the type of outer window are the significant factors affecting the energy consumption of high-rise office buildings in hot summer and cold winter prime [2]. In addition, Qin Xuan et al studied the influence factors of energy consumption of public buildings in Xiamen [3]; Zhang Lijuan et al studied the influence of outer windows on typical buildings in cold areas [4]. However, most scholars have only studied the significance of various factors in the study of energy consumption, but have not studied the influence of factors on the law and degree of influence. In order to solve this problem, this paper analyzes the impact of building energy consumption on the concrete reconstruction.

2. Selection of Factors Influencing Building Energy Consumption and Building Modelling

By consulting the relevant literature, we can see that the main influencing factors of energy consumption of public buildings in cold areas are external wall heat transfer coefficient, outer window heat transfer coefficient, roof heat transfer coefficient, window wall ratio, body shape coefficient and so on. In order to analyze the influence law of various factors on energy consumption and the degree of influence, this paper uses the single factor experimental method to study, using the dest-c software to simulate.

This paper chooses a toll station and a toll station in the service area as the building model. The building is located in Yangyuan County, Zhangjiakou, and is a comprehensive building. The building elevations are shown in Figure 1 below. The building area is 1062.72m², the outer wall $K = 0.609 \text{ W/(m}^2\cdot\text{K)}$, the inner wall $K = 1.308 \text{ W/(m}^2\cdot\text{K)}$, the roof $K = 0.284 \text{ W/(m}^2\cdot\text{K)}$, and the outer window is the universal plastic hollow glass window. It is now simplified to design with DEST-c energy consumption simulation software to build a building model.

![Figure 1. Building elevation](image)

3. Effects of Factors on Energy Consumption

3.1. Only change the external wall heat transfer coefficient

Set the external wall heat transfer coefficient from $0.25 \text{ W/(m}^2\cdot\text{K)}$ to $1.75 \text{ W/(m}^2\cdot\text{K)}$ to analyze the relationship between the external wall heat transfer coefficient and energy consumption. We analyze the influence law of each factor according to the change of heat consumption index. With the increase of heat transfer coefficient of exterior wall, the heat consumption index is increasing, almost linearly. The results are shown in figure 2 below.
3.2. Only the roof heat transfer coefficient is changed

The roof heat transfer coefficient increases from 0.2 W/(m²·K) to 1.5 W/(m²·K), which is simulated and analyzed by DeST-c software. From figure 3 above, we can see that the heat consumption index is almost linearly related to the roof heat transfer coefficient, and the larger the roof heat transfer coefficient is, the greater the heat consumption index is.

3.3. Only change the outer window heat transfer coefficient

Only change the outer window heat transfer coefficient from 1.5 W/(m²·K) to 5 W/(m²·K), study the effect of the outer window heat transfer coefficient on energy consumption, the simulation analysis results are shown in figure 4 below. The larger the heat transfer coefficient of the outer window, the larger the heat consumption index, and the almost linear trend.

3.4. Only change the window wall ratio

3.4.1. Only change the south-facing window-to-wall ratio from 0.25 to 0.6, using DeST-c software to simulate and analyze. From figure 5 above, we can see that as the ratio of the south window wall increases, the heat consumption index becomes smaller, and the ratio of the south window wall is approximately inversely related.

3.4.2. The ratio of the north window wall increased from 0.25 to 0.6 to study the effect of the change on energy consumption. Through the following figure 6, we can see that with the increase of the north window wall ratio, the heat consumption index is more and more large, and the influence law is opposite compared with the south window wall ratio.
3.5. Only the body shape coefficient is changed.

In this paper, the body shape coefficient is changed mainly by changing the number of floors. Let the number of buildings increase from 1 floor to 10 floors. The corresponding body shape coefficients are 0.506, 0.367, 0.321, 0.298, 0.284, 0.274, 0.268, 0.263, 0.259, 0.256, according to the software simulation results to analyze the impact of changes in body shape coefficient on energy consumption, see Figure 7 above. As the shape factor decreases, the heat consumption index becomes smaller and smaller.

4. Effect of Factors on Energy Consumption

The influence law of exterior wall, roof, outer window heat transfer coefficient, window wall ratio on energy consumption is obtained by simulation and analysis in the last section, but the influence degree of each influencing factor on energy consumption is not clear. This section mainly studies the influence degree of each influencing factor on energy consumption, and can use sensitivity coefficient to reflect the influence degree of different factors on energy consumption. As follows:

\[ S_i\% = \left( \frac{\Delta L_i}{L} \right) \left( \frac{\Delta P_i}{P} \right) \]

In the Eq: \( L \) — basic benefit index of the project when uncertain factors remain unchanged; \( \Delta L_i \) — the amount of change in the project benefit index caused by the change of uncertain factors, \( \Delta L_i = L_i - L \); \( P \) — the value before the change of uncertain factors; \( \Delta P_i \) — the amount of change in uncertain factors, \( \Delta P_i = P_i - P \).

The following formula can be obtained by applying Eq (1) to the study of the effect of various factors on energy consumption:

\[ \bar{S}_i = \left( \sum_{m=1}^{n} \frac{100(\Delta L_i/L)}{(\Delta P_i/P)} \right) C(n, m) \]

In the Eq: \( n \) — the number of solutions for the change of energy consumption influencing factors; \( C(n, m) \) — take out the number of combinations of \( m \) programs from \( n \) programs; Other symbols are the same as Eq (1).

For example, in studying the influence of the external wall heat transfer coefficient on the energy consumption, \( L \) is the heat consumption index of the building model under the reference external wall heat transfer coefficient, 138.33 kJ/m²·h; \( P \) is the reference external wall heat transfer coefficient of the building model, 0.609 W/(m²·K); the external wall heat transfer coefficient changes 7 times, that is, \( n = 7 \), \( C(n, m) = C(7, 2) = 21 \). In the analysis of the influence of other factors on energy consumption, the calculation method is the same as above. The calculated results are shown in Figure 8 below. From the graph, we can see that the sensitivity coefficient of the influencing factors is positive and negative. When the sensitivity coefficient is positive, it shows that the influencing factors are in the same direction as the change of heat consumption. When the sensitivity coefficient is negative, the heat consumption index decreases when the influence factor increases.
Figure 8. Sensitivity coefficient of influencing factors

1—Heat transfer coefficient of external wall; 2—Roof heat transfer coefficient; 3—Heat transfer coefficient of exterior window; 4—South window to wall ratio; 5—North facing window to wall ratio; 6—Shape coefficient

5. Conclusion

Based on the simulation calculation of the building model of a toll station and a toll station in the service area, the following conclusions can be drawn:

1. With the increase of the heat transfer coefficient of the exterior wall, the heat transfer coefficient of the roof and the heat transfer coefficient of the outer window, the heat consumption index is increasing, almost linearly, and the heat consumption index is smaller and smaller with the decrease of the body shape coefficient (the increase of the number of layers).

2. The north-south window wall has the opposite effect on building energy consumption. With the increase of the ratio of the south window wall, the smaller the heat consumption index is, the inverse relation is to the ratio of the south window wall, and the larger the ratio of the north window wall is, the bigger the heat consumption index is.

3. The sensitivity coefficient is used to calculate and analyze the influence degree of each influencing factor on energy consumption, and the sensitivity coefficient of each factor is obtained in order from large to small: body shape coefficient > outer window heat transfer coefficient > exterior wall heat transfer coefficient > south window wall ratio > roof heat transfer coefficient > north window wall ratio. This indicates that the influence of the body shape coefficient on the energy consumption is the largest, and the heat transfer coefficient of the outer window is several times. For the window wall ratio, the general north and south change together, so the effect of the roof heat transfer coefficient on the energy consumption is the least.

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