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Optimization of substation enclosure performance and carbon emission analysis based on OED

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Abstract. To explore the thermal performance parameters of substation enclosure parameters and interaction and influence degree, using the DeST software simulation and orthogonal test method to building load minimum as the target parameters, select external wall heat transfer coefficient, roof heat transfer coefficient, outer window heat transfer coefficient and orthogonal test factors, carry out the four factors three level L_9 (3^4) Orthogonal test analysis, studied the influence of each factor and its interaction on the building load, and finally obtained the optimal combination of factors under the comprehensive boundary conditions. At the same time, the correlation between load and outdoor temperature in the optimal scheme of unmanned substation and the carbon emission results before and after optimization are also explored. The results show that through univariate analysis, with the heat transfer coefficient of exterior wall, roof and window, the cumulative cooling load is not linear. Through the orthogonal experimental analysis, the significance of substation building is> roof exterior wall> south Angle> window, and the optimal is A_1-B_1-C_2-D_2The annual cumulative building cooling load is 20165.59 kW · h, and the peak cooling load appears on July 24. The operating condition of 0 ~ 9kW accounts for 90.6% of the annual operating time. There is a strong linear correlation between the building cooling load and the outdoor temperature (R^2=0.65), the energy saving rate of the final optimized scheme is 17.71%, and the carbon saving rate is 26.72%. The research content of this paper provides reference for the renovation of existing buildings and the design of new buildings in substation buildings.

Keywords: Substation, Orthogonal Test, Envelope Structure, Cooling Load, Carbon Calculation.

1. Introduction

On September 22,2020, General Secretary Xi Jinping solemnly declared at the 75th UN General Assembly that “China should reach a carbon peak by 2030 and achieve carbon neutrality by 2060” [1] . This is China’s initiative as a responsible major country to deepen the community of a shared future for mankind in economy, energy and environment. At the same time, the realization of the “two-carbon” strategy is also a key strategy for the high-quality development of the power industry in the future. In the urbanization construction, substation is a key link in the urban transmission network. With the proposal

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of the "double-carbon" strategy, it is of great significance to promote and build green and low-carbon substations.

Zhang Jun (2019) [2] with the method of "actual measurement + simulation + mechanism analysis", we explore the basic characteristics of prefabricated cabin substation, and summarize the optimal energy saving scheme through the combination of different energy saving technologies; Xiong Tianjun (2021) [3]. With the method of "research + simulation" deeply analyzed the energy transmission relationship of substation buildings, and found that ventilation and air conditioning is an important part of the energy consumption of substation buildings, and the passive energy saving technology represented by strengthening natural ventilation can significantly reduce the energy demand of the building itself, and realize the energy saving target of 60%; Chen Weiying (2022) [4]. The indoor physical environment of an old industrial building was studied by the method of "simulation + orthogonal test", which analyzed the lighting coefficient, the internal lighting standard rate, the dynamic lighting time and evaluation, and significantly improved the indoor natural lighting effect; Yi Er Yi (2022) [5]. In order to optimize the envelope structure of office buildings in the method of "simulation + orthogonal test", an economic analysis was conducted to obtain the optimal combination scheme; Li H X (2020) [6]. Using the new hybrid method of "orthogonal array test (OAT) and data envelope analysis (DEA)", five parameters of external envelope structure, outer window, air tightness, shading type, window wall ratio were considered to fit the optimal design scheme; Liu Z A (2022) [7]. With the method of "orthogonal design + numerical simulation", we analyze the influence of energy in different climate, and obtained the load contribution ratio of different envelope; QuY (2021) [8]. This paper has optimized the energy consumption and thermal comfort value of PCM integrated building envelope, and finally the optimal material ratio is obtained.

In order to solve the scientific problem of substation building envelope structure parameter design, this paper studies the lowest load as the research goal, through the orthogonal test method as the parameter coupling rules and data processing method, on the roof, exterior wall, Windows, south substation building load under the coupling, select the optimal combination scheme, and guide the carbon row calculation results, the effect before and after the optimization, the optimal combination form.

2. Model and parameter design

2.1. Physical model and assumptions

Based on the building environment special simulation DeST software to discuss the load of case building, DeST adopts the method of the dynamic model of building thermal process, comprehensively considering the building envelope structure and the heat release of heat storage and objects, including the room long wave radiation heat exchange between the enclosure surface and air convection heat exchange, through the room heat balance method of 8760 hours by simulation, the year of the building load and the state space method to calculate the substation under different roof, exterior walls, Windows and south Angle [9]. The types of components used mainly include project location, envelope thermal parameters, room parameters, ventilation times, etc. The single-floor building area of the substation building is 1,501 m^2, 1 floor, 10.3m height. The design site is Ningbo, and the climate area is hot summer and cold winter. The schematic diagram of DeST building model is shown in Figure 1.

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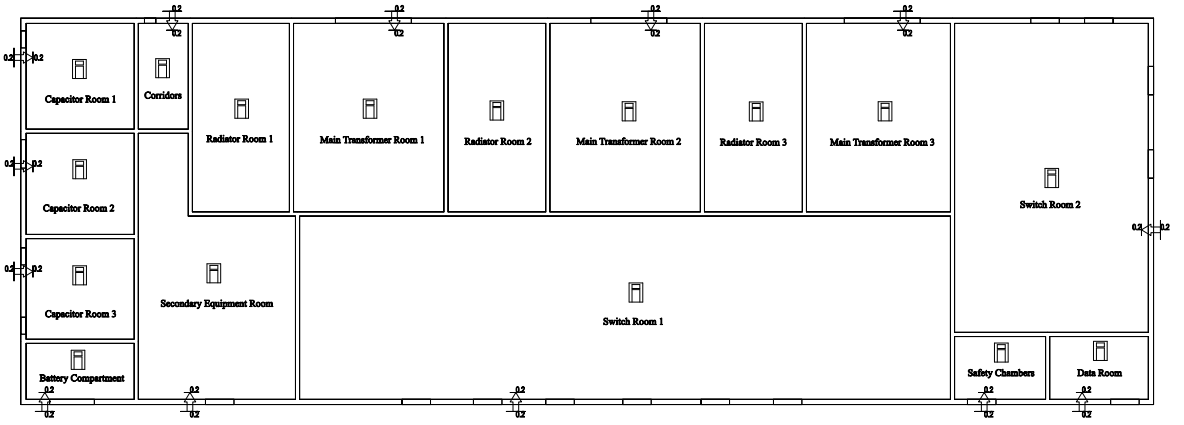


Figure 1. Schematic representation of the De ST model.

The room types of this project mainly cover capacitor room, secondary equipment room, power distribution device room, battery room, etc. The assumptions for load calculation are as follows:

(1) The substation is an unattended machine room, and there is almost no wet load source in the whole machine room, and the personnel scattered humidity and fresh air load are ignored;

(2) The corridor belongs to the transitional room, without any production equipment, and the room type is defined as an empty room;

(3) Considering the permeability effect of the combined effect of wind pressure and thermal pressure in the building, the ventilation frequency is selected as 0.5ach according to the empirical value [10].

2.2. Parameter and boundary condition setting

(1) Outdoor calculation parameters

The dry bulb temperature in summer is 35.1℃, summer air conditioning is 28℃, summer ventilation outdoor calculation temperature is 31.9℃, winter air conditioning is-1.5℃, winter relative humidity is 79%, winter ventilation outdoor calculation temperature is 4.9℃;

(2) Interior design parameters

From 26 to 28℃ in summer and 15℃ in winter. The relative humidity is not greater than 68% in summer and not more than 79% in winter.

(3) The thermal parameters setting of the envelope structure refers to the relevant requirements of GB51245-2017 Unified Standard for Energy Saving Design of Industrial Buildings and GB50019-2015 Code for Design of Heating and Ventilation and Air Adjustment of Industrial Buildings as well as the common engineering practices in the location, and the initial scheme is finally determined as: external wall 1 (W / m.$0^{2}\cdot$ K), roof of 0 (W / m.$65^{2}\cdot$ K), outer window 3 (W / m.$2^{2}\cdot$ K), 270° to the south corner.

2.3. Mathematical model

DeST solve the basic method of building thermal process is the state space method, its method characteristic is on the space difference and time keep continuous, in the process of solving, the internal space temperature field uneven simulation object can be divided into several temperature nodes, internal space temperature is uniform simulation object alone as a temperature node, the temperature of these nodes is continuously change with time. The thermal balance equation for indoor air is:

$$\rho_a c_{\mathrm{pa}} V_a j\omega T_a = \sum_j h_{\mathrm{in}} f_j\left(T_{j1} - T_a\right) + c_p \rho G(T_o - T_a) + Q_{\mathrm{iner}} + Q_{\mathrm{hvac}}$$

c_{pa} ρ_{a} $V_a G$For the specific heat capacity of the air, indicating the density of the air, is the volume of the air; is the air volume entering the indoor room through penetration and natural ventilation; is the part

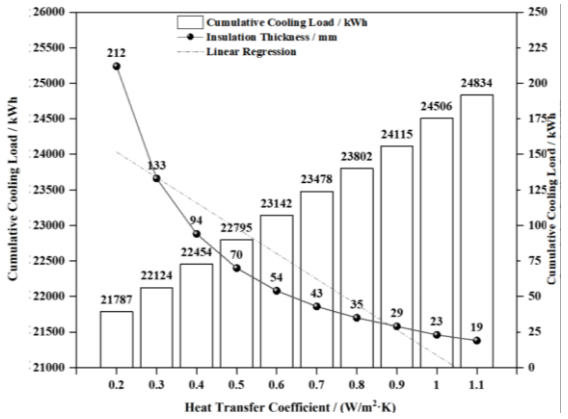
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of the indoor heat production into the indoor air through convection; is the heat provided by the indoor air conditioning. Q_{inner} Q_{hvac}

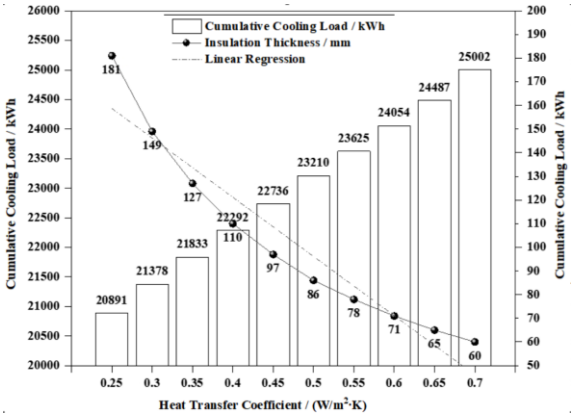
3. Study on the optimization strategy of orthogonal trial design

3.1. Univariate analysis

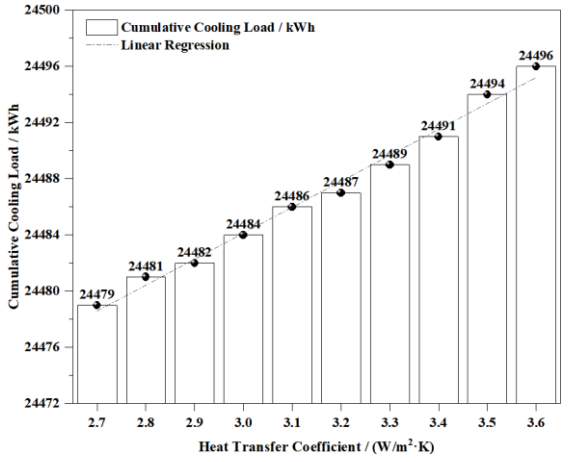
Univariate analysis is a process of calculating the numerical index of this factor in sequence under the premise that the control level of other factors remains unchanged. In the process of univariate analysis, the influence degree of different heat transfer coefficient / south Angle on the annual cumulative cooling load index is selected, and the results of univariate analysis are shown in Figure 2.



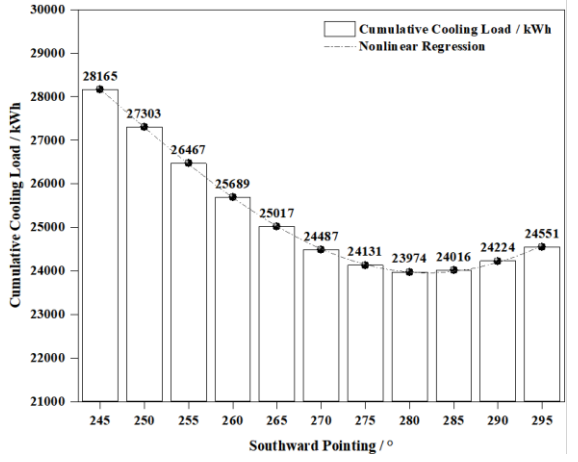
(A) Single-factor analysis results of the external wall.



(B) Results of the roof univariate analysis.



(C) Results of single-factor analysis of external Windows.



(D) Univariate analysis of the southbound angle.

Figure 2. For the univariate analysis.

According to Figure 2, With the decrease of the heat transfer coefficient, Its cumulative cooling load also decreases, The external wall has a more significant impact on the load, The difference of the scheme in a single factor is 3047kW·h; The roof decreases with the heat transfer coefficient, Its cumulative cooling load also decreases, And its reduction rate is higher than the external wall, The extreme difference of the scheme in a single factor is 4111kW·h; The regulation of the heat transfer coefficient of

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the external window has no significant influence on the indoor cumulative cooling load, This is mainly because the substations are unattended substations, Without indoor natural light and illumination, So the south-facing window area is smaller, The overall impact on the indoor cooling load is also small; In the factor analysis of the southward angle, A significant nonlinear relationship between the heat transfer coefficient and the cumulative cooling load, The range of the scheme in a single factor is 4191kW·h, And the due south is not the lowest point of the load, The lowest point is 10° N-W.

3.2. Determination of the factor level

According to the "2 single-factor analysis", Exwall, roof and exterior windows decrease with the heat transfer coefficient, Its cumulative cooling load will also decrease accordingly, This paper focuses on exploring the thickness of the insulation layer of the material structure, Through "(a) unifactor analysis results of external wall and (b) unifactor analysis results of roof" in Figure 1, we can see that the thickness of the insulation layer also increases significantly with the decrease of the heat transfer coefficient, Considering the cost of raw materials, installation costs, procurement costs, and carbon emissions in the structure, Combined with the analysis process and research conclusions of literature [5] and literature [11], The value of the final heat transfer coefficient factor is the intermediate parameter; While the numerical change of the southward angle is a nonlinear change, Therefore, the value is chosen on both sides of the lowest point. The table of each factor level is shown in Table 1.

Table 1. Table of each factors.

	Parameter 1	Parameter 2	Parameter 3
exterior wall ($W/m^2 \cdot K$)	0.4	0.5	0.6
exterior window ($W/m^2 \cdot K$)	2.7	3	3.3
roof ($W/m^2 \cdot K$)	0.45	0.55	0.65
South corner (°)	275	280	285

3.3. Test working condition design

The orthogonal test design realizes multi-factor and multi-level interaction through the orthogonal test table, which maximizes the number of trials while ensuring test science. The orthogonal test table is based on the orthogonal test principle, and this test examines the influence of four factors on the construction load, so L is selected in the selection of the experimental table$_9$ (3^4) Orthogonal table as the test reference, where L is the code of orthogonal table; 9 is the number of orthogonal tests; 4 is the test factor; 3 is the level number of factors, namely the state parameter value of each factor [12]. The influencing elements are inserted in each column of the orthogonal table and converted into the value of each element through the level numbers in the orthogonal table. The numbers in parentheses are the values of the selected variables, and the numbers before parentheses are the numbers of each level. The intuitive analysis of orthogonal combinations of test factors is shown in Table 2.

Table 2. L_9 (3^4) Visual analysis table of the orthogonal combination of test factors.

Test number	Factor			
	Exterior wall (A)	Roof (B)	Exterior window (C)	South Angle (D)
1	1 (0).4	1 (0).45	1 (2).7	1 (275)
2	1 (0).4	2 (0).55	2 (3).0	2 (280)
3	1 (0).4	3 (0).65	3 (3).3	3 (285)
4	2 (0).5	1 (0).45	2 (3).0	3 (285)
5	2 (0).5	2 (0).55	3 (3).3	1 (275)
6	2 (0).5	3 (0).65	1 (2).7	2 (280)

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Table 2. (continued).

7	3 (0).6	1 (0).45	3 (3).3	2 (280)
8	3 (0).6	2 (0).55	1 (2).7	3 (285)
9	3 (0).6	3 (0).65	2 (3).0	1 (275)

Note: The values outside the parentheses represent horizontal numbers, and the values in the parentheses represent horizontal values.

4. Results and analysis of the orthogonal tests

4.1. Analysis of the test results

Through DeST software, nine experimental schemes are simulated in turn. Through the intuitive analysis of the test data, the trend of the influence of each experimental scheme on the cumulative cooling load can be known. The results of the cumulative cooling load of each test site are shown in Figure 3.

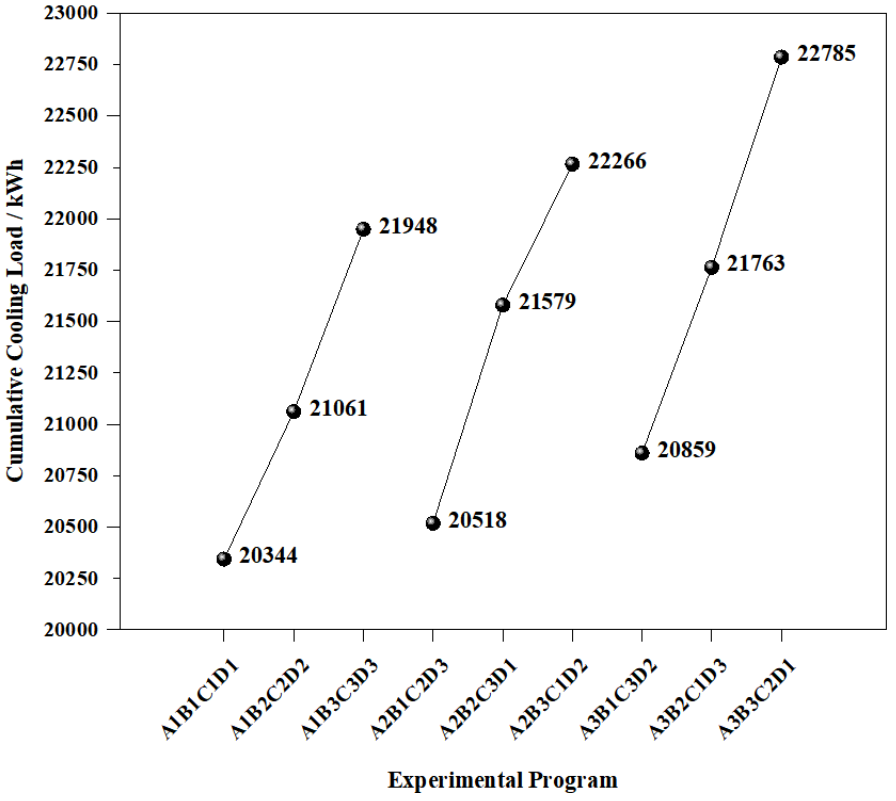


Figure 3. Results of the orthogonal test experiments.

As can be seen from the data display in Figure 3, it can be seen that the values of the 9 schemes are significantly different, and the difference hierarchy is quite significant, among which the minimum value is 20344kW·h and the maximum value is 22785kW·h. The numerical distribution difference between the test points is reasonable.

4.2. Analysis of the mean value results

For the test results, the effect of the interaction of each factor level on the cumulative load was studied through the comparative simulation of different schemes, and the calculation results of the mean value of each test site are shown in Figure 4.

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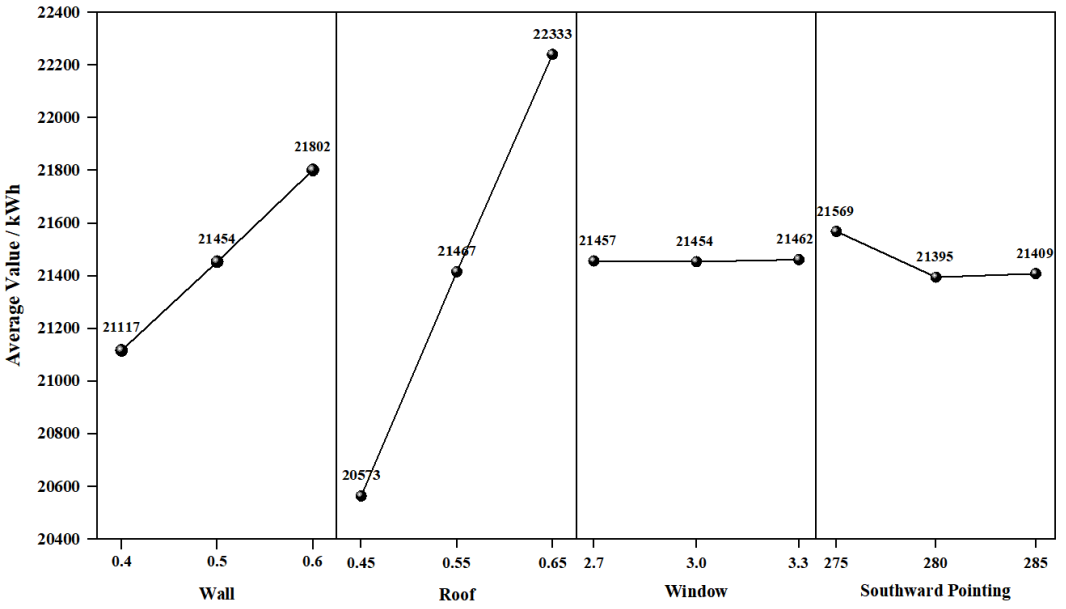


Figure 4. Results of each water factor.

Through the mean result analysis, we can intuitively find out the optimal level of each factor, so as to determine the optimal level collocation of the design scheme. The optimal goal discussed in this paper is "the lowest building load". It can be seen from the mean results of Figure 4 that the optimal scheme of each factor is A_1-B_1-C_2-D_2.

4.3. Extreme results analysis

In the test, the significance level of each factor is evaluated through the difference analysis, in which the size of the difference value explains the influence relationship between the factors and the test index, the larger the difference value is, the higher the higher the influence on the test index. The calculation principle of the difference value is as follows:

$$k_{ij} = \frac{1}{n}\sum_{j=1}^{n} K_{ij}$$

$$R_i = max\left(K_{ij}\right) - min\left(K_{ij}\right), (i = 1, \cdots, 4)$$

In formula: K_{ij}Is the test value corresponding to the j th level of the i th factor; k_{ij}Is the average of the test value for the j level of the i factor; n is the number of the j level of the i factor; R_iIs the extreme difference value of the i th factor, and the calculated results are shown in Table Table 11.

Table 3. Results of mean extreme range analysis of building load in multivariable combination simulation.

	exterior wall	roof	exterior window	The south corner
range	684.66	1759.33	7.33	174.0

The analysis of the extreme difference results can intuitively compare the primary and secondary factors of this experiment, reflecting the degree of influence of each factor level on the test results. According to the principle of orthogonal test, the greater the extreme difference of the design factors, the greater its influence on the comprehensive index. According to the analysis results in Table 3, the influence order of each influencing factor on the building load of the substation is the roof> outer wall> south Angle> outer window.

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5. Optimization scheme of building load calculation and simulation analysis

5.1. Annual load calculation results of the building

According to the above analysis, the goal-oriented optimization scheme based on "the lowest building load" is A_1-B_1-C_2-D_2, That is, the external wall heat transfer coefficient is 0 (W / m.$4^{2\cdot}$ K); Roof heat transfer coefficient is 0 (W / m.$45^{2\cdot}$ K); the heat transfer coefficient of the outer window is 3 (W / $m^{2\cdot}$ K); The optimal south angle is 280°. This paper simulates the annual construction load of the optimized optimal scheme combined with D e ST software, and the annual dynamic load results of the optimal scheme are shown in Figure 5.

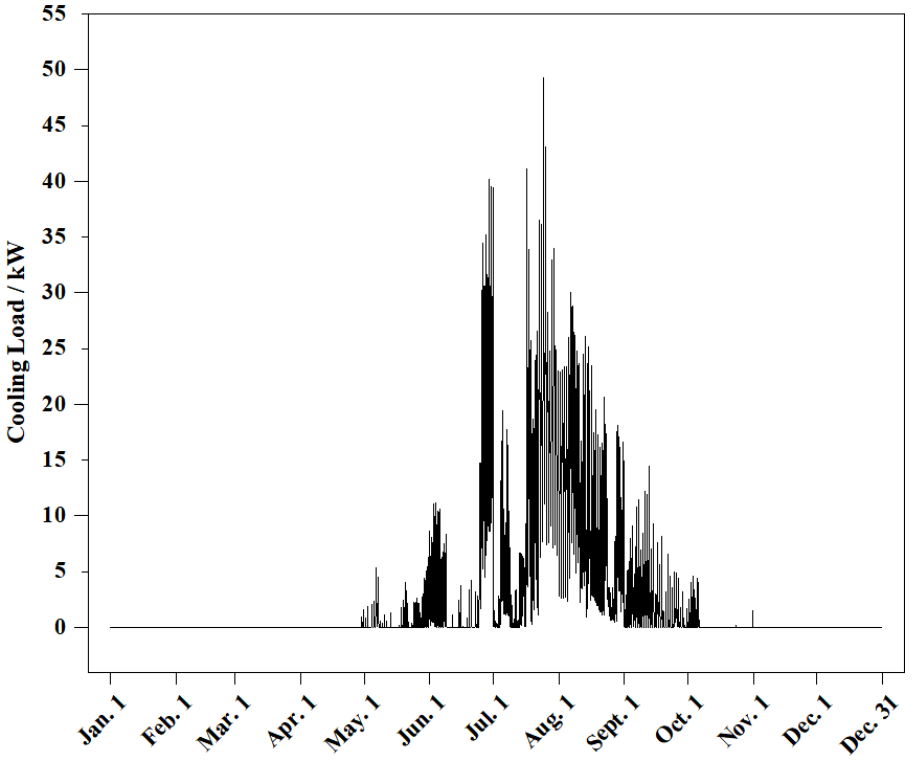


Figure 5. Results of building cooling load successively.

According to the analysis of Figure 5, the peak cooling load appeared on July 24, and the value is 49.28kW, and the annual cumulative cooling load of the building is 20165.59 kW · h. Compared with the initial building, the energy saving rate is 17.71%, and the optimization results are relatively ideal.

5.2. Construction load frequency analysis

Through "figure 5 building cooling load by results" load characteristics of performance, load change curve has obvious fluctuation changes, and in the actual operation of partial load operation, this paper to "10k W" for the segmentation, for the annual load value the frequency analysis, cooling load frequency statistical results as shown in figure 6.

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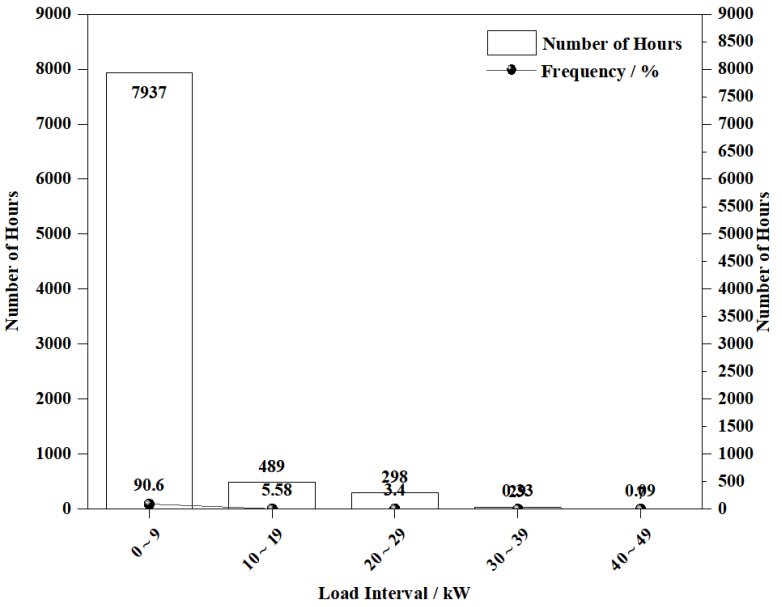


Figure 6. Frequency and frequency analysis results of building cooling load.

Through the analysis of figure 6 frequency results, building load is more significant imbalance phenomenon, in the process of annual operation, 0~9kW operating condition of 90% of the annual running time, most of the time node can through a small capacity unit single operation can meet the demand, and the process of operation throughout the year, the peak load frequency is less.

5.3. "Outdoor temperature-cold load" related relationship

Through the analysis of "figure 6 building cooling load by the results" can see that the annual load fluctuations in the hottest month peak, for unmanned substation, indoor space due to the lack of personnel factors, the indoor heat and wet environment and outdoor meteorological parameters will be stronger, to this paper choose the hottest month on July 15 to August 15, "outdoor temperature-cold load" linear correlation analysis, discusses the correlation between indoor load and outdoor meteorological parameters, the analysis results are shown in Figure 7. And give except the model equation by unary linear regression.

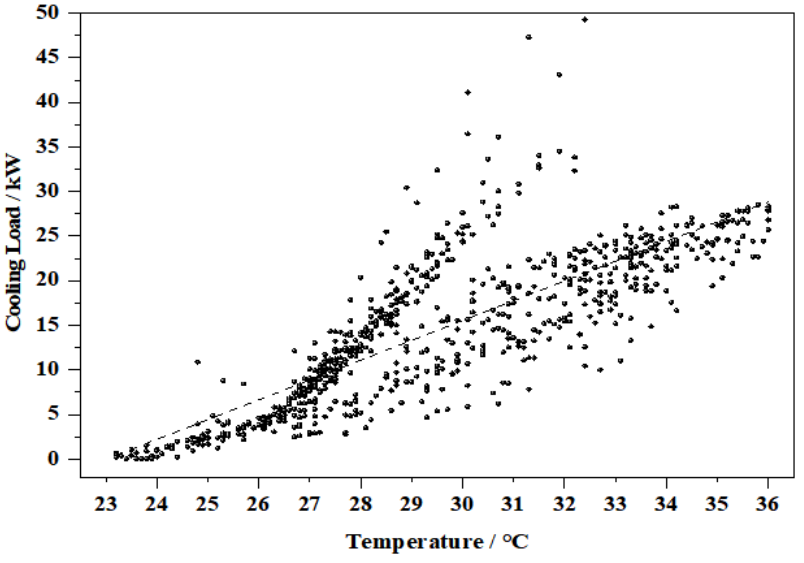


Figure 7. Correlation analysis of "outdoor temperature-cooling load" in the hottest months.

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$$y = -51.04 + 2.21x(R2 = 0.65)$$

Where: y is the cooling load value, kW; x is the outdoor air temperature; ℃.

According to Figure 7 and the fitted equation, there is a significant correlation between outdoor temperature and cooling load in typical months, a linear relationship is more significant, and there is a strong positive correlation between outdoor temperature and cooling load, and the correlation coefficient $R^2$0.65, indicating that 65% of indoor cold negative comes from the intervention of air temperature.

6. Carbon arrangement analysis

Buildings produce carbon emissions in all stages of material development, production, transportation, construction and demolition, operation and maintenance. Therefore, the whole life cycle carbon emission calculation should be carried out to have a comprehensive understanding of the impact of buildings on nature. The calculated boundary is the calculated range of greenhouse gas emissions related to the production and transportation, construction, demolition and operation of building materials. In the analysis of this paper, the Building Carbon Emission is calculated on the basis of GB / T51366-2019 and the Evaluation Requirements and Guidelines for Environmental Management and the Department of Housing and Urban-Rural Development (LCA). The results of the carbon emission analysis are shown in Figure 8.

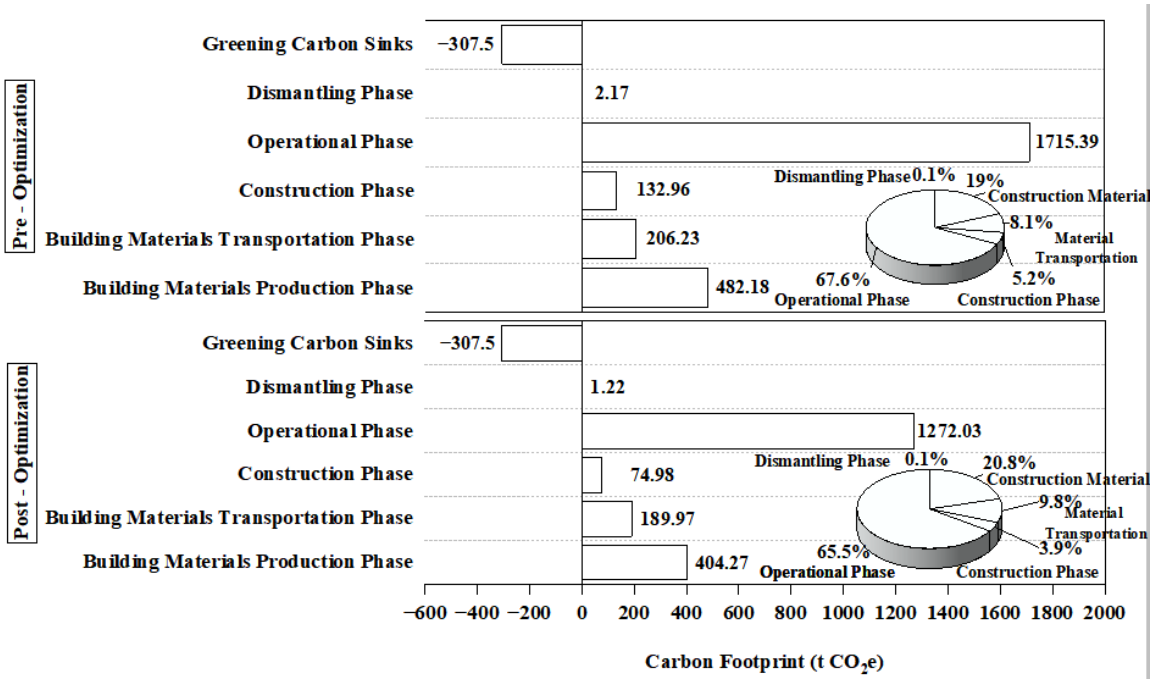


Figure 8. Results of the carbon emission analysis.

Through the optimization of the envelope structure materials, the production, transportation, construction, operation and final demolition stage of the substation have achieved the effect of emission reduction. Before the optimization, the carbon emission of the whole life cycle is 2231.43 t (including the green carbon sink offset), and the optimized carbon emission is 1634.97 t (including the green carbon sink offset), and the carbon saving rate is 26.72%. As the national “carbon peak, carbon neutral” target, carbon emissions control become a big industry, in the future, the country will be carbon quotas to the enterprise, promote the construction of green low carbon substation can effectively reduce the power industry carbon emissions, on the other hand also can promote the green energy projects, strengthen the efficiency of power grid use of clean energy.

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7. Conclusion

Through the analysis of the influencing factors of substation building energy load, this paper selects four influencing factors of roof, exterior wall, south Angle and window, and establishes orthogonal test and uses DeST simulation software, and conducts carbon emission analysis, and the following conclusions are drawn:

(1) Through single factor analysis, we can see that with the increase of heat transfer coefficient of external wall, roof and window, the cumulative cooling load of the building gradually increases, showing a linear relationship; In the comparison of azimuth scheme, the lowest point of the building is 10° north to west, showing a nonlinear relationship.

(2) According to the orthogonal experimental analysis, the significant factors affecting the cooling load of substation buildings are the roof> external wall> south Angle> Windows.

(3) The optimal combination scheme determined by the orthogonal test method is A1-B1-C2-D2, and the annual cumulative cooling load of the building is 20165.59 kW · h, with the energy saving rate of 17.71% compared with the initial building.

(4) In the load analysis in the optimal scheme, the peak cooling load occurred on July 24, the value is 49.28kW, and the operating condition of 0 ~ 9kW accounts for 90.6% of the annual operating time; through the linear regression analysis of "outdoor temperature-building cooling load" in typical summer months, there is a strong linear correlation between the building cooling load and outdoor temperature in unmanned substation (R^2=0.65).

(5) In the calculation of carbon emission in the whole life cycle of the building, the cumulative result of carbon emission in the optimized building is 1634.97 tCO2e, which is 26.72% less than that compared with before the optimization.

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