Research on Energy Efficiency Design Optimization of Office Building Based on Doe Orthogonal Test

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Abstract. In this paper, based on the statistical methods of DOE orthogonal test method coupled with numerical simulation of building energy consumption, taking the office buildings in hot summer and cold winter regions as examples, 13 factors which affect the energy consumption and material cost are selected as the independent variables. Method of orthogonal experimental design is used to generate multiple sets of experimental cases. The per unit energy consumption and the per unit material cost increment as its object function, the results of the analysis to understand the impact of various factors and the impact of primary and secondary analysis.

1. The current status of office building optimization design.
Office buildings are more common types of buildings in public buildings. They are not only in high demand, but also have a greater impact on energy consumption and the environment due to their complexity of functions and diversity of designs.[1] Therefore, the rationality of the design of office buildings has become a subject that cannot be ignored in today's energy and resource shortage. At present, relevant research on the optimization design of office buildings is also being carried out continuously. Considering the greenness of buildings has become the basic principle that must be followed in mainstream design.

2. Research methods

2.1. Design of Experiments
The experimental design is an important branch of mathematical statistics. It mainly discusses how to arrange the test reasonably and how to analyze the data obtained from the experiment.[2] Belong MethodologyThe scope. It is a technique for economically and scientifically arranging experiments. Since the use of experimental design methods in agricultural production by RAfisher in the 1920s, experimental design methods have been widely developed, statisticians. We have found many very effective experimental design techniques.[3]
2.2. Orthogonal experimental design

Orthogonal analysis is one of the most commonly used methods in experimental design. Based on probability theory, mathematical statistics and practical experience, the standardized orthogonal table is used to arrange the experimental scheme, and the results are calculated and analyzed. Finally, the optimization scheme is quickly found, a scientific calculation method for efficiently dealing with multi-factor optimization problems.

In the 1950s, Japanese statistician Takaguchi Taguchi expressed the most widely used orthogonal design in the experimental design, and made a well-known contribution to the wider use of experimental design in terms of method explanation.[4-11]

2.2.1. Test factor setting

According to the existing research at this stage, this paper screens out the thirteen factors in the four aspects of building design that have great influence on building energy efficiency and material cost as the experimental factors, namely orientation, number of layers, aspect ratio, window height, Shading form, south facing window ratio, east-west window ratio, north facing window ratio, window structure, south wall structure, east-west wall structure, north wall structure, roof structure. See Table 1 for the selection of test factors.

Table 1. Test Factor Selection.

| Factor type       | Factor Code |
|-------------------|-------------|
| Orientation       | Oriented a  |
| Body shape        | Number of layers b |
| coefficient       | Aspect ratio c |
|                   | Window height d |
| Shade form        | e |
| Window            | South facing window ratio f |
|                   | East and west window ratio g |
|                   | North facing window ratio h |
| Window structure  | Window i |
|                   | South facing wall j |
|                   | East and west wall k |
|                   | North wall l |
|                   | Roof m |

Table 2. Test Factor Level Setting -1.

| Code | Unit       | Level  |
|------|------------|--------|
| a    | °          | 0 22.5 45 |
| b    | Floor      | 6 12 24 |
| c    | -          | 0.5 1 2 |
| d    | m          | 1.2 1.8 2.4 |
| e    | Type       | None A1 A1 |
| f    | -          | 0.2 0.5 0.8 |
| g    | -          | 0.2 0.5 0.8 |
| h    | -          | 0.2 0.5 0.8 |
| i    | Type       | Glass A Glass B Glass C |
| j    | Type       | Wall A Wall B Wall C |
| k    | Type       | Wall A Wall B Wall C |
| l    | Type       | Wall A Wall B Wall C |
| m    | Type       | Roof A Roof B Roof C |
### Table 3. Test Factor Level Setting -2.

| Name Setting | Setting |
|--------------|---------|
| Glass A(B, C) 6 white glass double silver - 50 film(silver ced12, 6 white glass) +12a / argon +6 white glass
| Wall A(B, C) 57(50, 27)mm PUR + 190mm Concrete Hollow Block + 20mm Lime-cement Mortar
| Roof A(B, C) 20mm Cement Mortar + 128(110, 54)mm EPS + 120mm Concrete + 20mm Cement Mortar

The other parameters selected in the case are set according to the requirements of the thermal performance simulation of the public building energy-saving design standard GB50189-2015. In addition, the floor area of each building is 1600m², and each variable selects three levels, see Table 2 and Table 3. Test factor level setting.

#### 2.2.2. Test target setting

In order to study the indicators of building energy efficiency and material cost impact, the appropriate unit quantity should be selected as the target value. In this paper, the unit building area energy load (kw·h/m²) and the unit building area material incremental cost (yuan/m²) are selected as indicators.

### 3. Application of orthogonal test

#### 3.1. Orthogonal test calculation

The 13 factors selected in this paper, each factor selects three levels. If the exhaustive rule is used, a total of $3^{13}=1594323$ cases will be generated. According to the needs of the experiment, this paper selects the orthogonal analysis method for analysis, and obtains the $I^{27}(3^{13})$ orthogonal table of the appropriate test process by looking up the table, ignoring the interaction between the factors, and corresponding the factors with the orthogonal test table. After the 27 cases of this trial were obtained.

#### Table 4. Orthogonal Test.

| Case  | a  | b  | c  | d  | e  | f  | g  | h  | i  | j  | k  | l  | m  | $y_i$ | $y_i'$ |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|------|------|
| case1 | 0  | 6  | 0.5| 1.2| 0  | 0.2| 0.2| 0.2| 1  | 1  | 1  | 1  | 1  | 90.5 | 520.9 |
| case2 | 0  | 6  | 0.5| 1.2| 0.3| 0.5| 0.5| 0.5| 2  | 2  | 2  | 2  | 2  | 116.5| 573.4 |
| case3 | 0  | 6  | 0.5| 1.2| 0.6| 0.8| 0.8| 0.8| 3  | 3  | 3  | 3  | 3  | 125.2| 620.5 |
| case4 | 0  | 12 | 1  | 1.8| 0  | 0.2| 0.2| 0.5| 2  | 3  | 3  | 3  | 3  | 112.0| 491.3 |
| case5 | 0  | 12 | 1  | 1.8| 0.3| 0.5| 0.5| 0.8| 3  | 1  | 1  | 1  | 1  | 119.6| 565.7 |
| case6 | 0  | 12 | 1  | 1.8| 0.6| 0.8| 0.8| 0.2| 1  | 1  | 2  | 2  | 2  | 118.1| 595.1 |
| case7 | 0  | 20 | 2  | 2.4| 0  | 0.2| 0.2| 0.8| 3  | 3  | 2  | 2  | 2  | 116.8| 523.6 |
| case8 | 0  | 20 | 2  | 2.4| 0.3| 0.5| 0.5| 0.2| 1  | 1  | 3  | 3  | 3  | 114.4| 547.8 |
| case9 | 0  | 20 | 2  | 2.4| 0.6| 0.8| 0.8| 0.5| 2  | 1  | 1  | 1  | 1  | 120.1| 638.6 |
| case10| 0  | 20 | 2  | 2.4| 0  | 0.5| 0.8| 0.2| 2  | 3  | 1  | 2  | 3  | 117.0| 555.9 |
| case11| 22.5| 6  | 1  | 2.4| 0  | 0.5| 0.8| 0.2| 2  | 3  | 1  | 2  | 3  | 119.7| 587.2 |
| case12| 22.5| 6  | 1  | 2.4| 0.3| 0.8| 0.2| 0.5| 3  | 1  | 2  | 3  | 1  | 113.2| 613.1 |
| case13| 22.5| 12 | 2  | 1.2| 0  | 0.5| 0.8| 0.5| 3  | 1  | 3  | 1  | 2  | 115.2| 631.3 |
| case14| 22.5| 12 | 2  | 1.2| 0.3| 0.8| 0.2| 0.8| 1  | 2  | 1  | 2  | 3  | 116.7| 620.8 |
| case15| 22.5| 12 | 2  | 1.2| 0.6| 0.2| 0.5| 0.2| 2  | 3  | 2  | 3  | 1  | 113.0| 570.5 |
| case16| 22.5| 20 | 0.5| 1.8| 0  | 0.5| 0.8| 0.8| 1  | 2  | 2  | 3  | 1  | 119.5| 543.7 |
| case17| 22.5| 20 | 0.5| 1.8| 0.3| 0.8| 0.2| 0.2| 2  | 3  | 3  | 1  | 2  | 112.2| 498.7 |
| case18| 22.5| 20 | 0.5| 1.8| 0.6| 0.2| 0.5| 0.5| 3  | 1  | 1  | 2  | 3  | 120.0| 528.0 |
| case19| 45  | 6  | 2  | 1.8| 0  | 0.8| 0.5| 0.2| 3  | 2  | 1  | 3  | 2  | 117.2| 583.7 |
| case20| 45  | 6  | 2  | 1.8| 0.3| 0.2| 0.8| 0.5| 1  | 3  | 2  | 3  | 2  | 116.4| 604.6 |
| case21| 45  | 6  | 2  | 1.8| 0.6| 0.5| 0.2| 0.8| 2  | 1  | 3  | 2  | 1  | 115.7| 666.5 |
| case22| 45  | 12 | 0.5| 2.4| 0  | 0.8| 0.5| 0.5| 1  | 3  | 3  | 2  | 1  | 116.6| 533.7 |
| case23| 45  | 12 | 0.5| 2.4| 0.3| 0.2| 0.8| 0.8| 2  | 1  | 1  | 3  | 2  | 119.1| 559.3 |
Each level of each factor in the trial occurred 9 times in 27 groups of cases. In the table, the symbols, $I_j$, $II_j$, and $III_j$ refer to the indicators corresponding to the j-column factors taking the levels "1", "2", and "3", such as:

$$I_a = \sum_{i=1}^{27} y_i$$

- $y_i$, energy consumption per unit area of case i ; $I_a$, the average of the first level of factor A.

3.2. Analysis of orthogonal test results

According to the experimental results, the energy consumption calculation results are analyzed by the range analysis. The ranking of the primary and secondary factors of energy consumption in the building factors is ranked by the primary and secondary factors of the energy consumption calculation factors. Among the four factors, the most important aspect of the impact on energy consumption is the window, in which the east-west window wall has the greatest impact on energy consumption.

$$R_j = \text{max}\{ I_j, II_j, III_j \} - \text{min}\{ I_j, II_j, III_j \}$$

Table 5. Analysis of Energy Consumption Calculation Results (kw·h/m²).

| j | a   | b   | c   | d   | e   | f   | g   | h   | i   | j   | k   | l   | m   |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Ij| 114.80 | 114.12 | 114.61 | 114.60 | 114.21 | 113.52 | 111.28 | 112.53 | 113.33 | 114.35 | 114.77 | 113.79 | 114.08 |
| IIj| 116.30 | 116.30 | 116.05 | 116.74 | 116.29 | 116.33 | 116.76 | 116.38 | 116.01 | 116.40 | 115.96 | 117.32 | 116.41 |
| IIIj| 116.26 | 116.95 | 116.70 | 116.02 | 116.87 | 117.51 | 119.33 | 118.45 | 118.03 | 116.61 | 116.63 | 116.26 | 116.87 |
| Rj| 1.50  | 2.83  | 2.09  | 2.14  | 2.66  | 3.99  | 8.05  | 5.92  | 4.70  | 2.26  | 1.86  | 3.53  | 2.79  |

Table 6. Factor Ranking of Energy Consumption Calculation.

| Factor type | Factor name | Code | Case Order |
|-------------|-------------|------|------------|
| Orientation | Oriented    | a    | 13         |
| Body shape coefficient | Number of layers | b | 6 |
| | Aspect ratio | c | 11 |
| | Window height | d | 10 |
| | Shade form | e | 8 |
| Window | South facing window ratio | f | 4 |
| | East and west window ratio | g | 1 |
| | North facing window ratio | h | 2 |
| | Window | i | 3 |
| | South facing wall | j | 9 |
| Envelope structure | East and west wall | k | 12 |
| | North wall | l | 5 |
| | Roof | m | 7 |

For the cost difference analysis of the unit cost of material per unit area, see Table 7: Analysis of the material cost per unit area. The main factors of the factors affecting the material cost increment of the building unit area are listed in Table 8. Sub-factor ordering. Among the four influencing factors, the most influential factor on the material cost per unit area of the building is the window, in which the shading form of the window has the greatest impact on the material cost.
Table 7. Analysis of Material Cost Per Unit Area (yuan/m²).

| j  | a      | b      | c      | d      | e      | f      | g      | h      | i      | j      | k      | l      | m      |
|----|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| I  | 564.10 | 591.76 | 544.18 | 564.65 | 539.90 | 548.20 | 552.80 | 546.08 | 569.60 | 567.92 | 568.85 | 563.06 | 572.16 |
| II | 564.59 | 557.70 | 557.85 | 564.14 | 564.47 | 564.74 | 562.11 | 563.00 | 566.36 | 567.40 | 562.30 | 568.83 | 561.89 |
| III| 564.40 | 543.64 | 591.06 | 564.29 | 588.73 | 580.14 | 580.14 | 584.01 | 557.13 | 557.78 | 561.94 | 561.19 | 559.04 |
| Rj | 0.49   | 48.12  | 46.88  | 0.51   | 48.83  | 31.94  | 25.37  | 37.94  | 12.47  | 10.14  | 6.91   | 7.64   | 13.12  |

Table 8. Factor Ordering.

| Code | a | b | c | d | e | f | g | h | i | j | k | l | m |
|------|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Order| 13| 2 | 3 | 12| 1 | 5 | 6 | 4 | 8 | 9 | 11| 10| 7 |

Base on the above research, we can get the following conclusions under the two goals of energy consumption per unit area and material cost per unit area. The various factors of the window have a greater impact on the material cost per unit area and the energy consumption load per unit area, and the trend for the two target values is consistent. That is to say, the extreme values of these factors in the interval can simultaneously achieve the best effect of the building energy consumption per unit area and material cost per unit area. However, the factors of the storey height and the envelope structure (b, i, j, k, m) have opposite trends for the cost per unit area and the energy load per unit area of the building.

4. Summary
In this paper, the orthogonal test method is introduced into the energy consumption analysis and material cost analysis of office buildings in the hot summer and cold winter regions, and the influence factors and primary and secondary relationships of the thirteen factors in four aspects of the building are analyzed. According to the juxtaposition analysis of two orthogonal test results, it is possible to obtain whether the relationship between the energy consumption load per unit area of the building and the material cost per unit area of the building is consistent, and further analyze and judge the various factors in the process of change. Whether the optimal solution can be achieved simultaneously on the two target values provides a guiding significance for future architectural design optimization research.

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