Optimization Analysis of Parametric passive Energy-saving Design for Residential Buildings

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Abstract. Taking residential building in hot summer and cold winter area as research object, this paper established a model based on passive energy-saving design, and combined artificial neural network(ANN) and genetic algorithm(GA) models to analyze lighting, sunlight, and plot ratio, etc. In addition, for the experimental test of multiple sets of data samples, the optimized passive design combination scheme was sought to verify the possibility of parametric optimization design based on genetic algorithm(GA).

1. Introduction

With the continuous development of computer technology, building physics and energy consumption simulation technology has been widely used in building engineering. According to the evaluation of the building performance index, the designers constantly adjust the building scheme in combination with the results of computer simulation feedback, so as to get the best design scheme repeatedly. Therefore, it is obviously difficult to optimize the building performance in the design stage. For example, improving the window-wall ratio of buildings can improve indoor lighting and reduce the energy consumption of artificial lighting, but it can increase the energy consumption of building heating and cooling. In practical projects, although designers can balance the diversified requirements of building performance through multiple scheme comparisons, it is difficult to optimize the influencing factors of building performance on the basis of meeting the requirements of basic energy saving standards.

2. Parametric analysis of building performance

In response to this problem, some scholars have tried to use multi-objective optimization algorithm and building performance analysis software to optimize the parameters of building design with the goal of building energy consumption and environmental performance. Znouda Essia, Manazan Marco and others took the heat gain control of building solar radiation as the design goal, applied ESP-r and Radiance software to calculate, and optimized the parameters such as shading type, angle and depth according to different climate conditions. Torres Santiago and Gagne Jaime aimed at indoor illumination and dazzle control, and optimized and analyzed the building layout, outer window size and shading through the calculation of Radiance by software. Based on the annual sunshine radiation and structural performance, turrin Michela used Ecotect and STAAD. Pro software to calculate the
objective function and optimized the application of roof shape in large span buildings. Compared with multi-scheme, multi-objective optimization can find the feasible solution of building performance optimization by calculating the functional relation, and improve the accuracy and efficiency of energy saving design.

The analysis of building performance usually takes years as the cycle. In the process of target optimization, it is often necessary to simulate the performance of multiple groups of schemes, which is prone to the phenomenon of simulation time-consuming.

Conversely, in order to shorten the calculation cycle, simplify the calculation process, and realize multi-objective optimization simulation, it will lead to lower performance analysis accuracy.

In order to solve such problems, many researchers have further improved the process of performance optimization by introducing neural network (NN) models in the process of objective optimization. Kalogirou Soteris optimized solar extreme heat area and storage size with the goal of full life cycle economic benefits. Magnier Laurent, Zemella Giovanni, Wang Zizhen and others carried out optimization research on the palisade structure, shading, lighting and control of energy-consuming equipment with the goal of thermal comfort, building lighting, cooling and heating energy consumption. Asadi Ehsan carried out technical optimization research on building roof and exterior wall materials, exterior Windows and solar panel types, aiming at building energy consumption, comfort level and economic benefits of transformation. Sun Cheng adopted the method of NN prediction and multi-objective optimization to analyze the natural lighting and thermal performance of office buildings. In the above research, the NNGA and the calculation of building performance simulation were coupled, but the research mainly focused on the operational control strategy or material and component properties, and lacked consideration of the design-related influence parameters; In addition, part of the research have carried out energy-saving design from the perspective of engineering, which lack the support for the early-stage decision-making.

For a long time, the principle of green building design has always been to consider passive design, active design as a supplement, but how to exert the maximum potential of passive design and provide decision-making for the early design has become the bottleneck of passive design. Taking residential architecture as an example, combined with the passive design ideas and processes of residential buildings, the coupling NNGA model and multi-objective optimization method were used to explore the parametric performance design ideas based on GA, and combined with case analysis.

3. Performance parameterization design based on GA

The theory of building climate adaptability is a systematic analysis method which combines the local climate conditions and gives specific design principles of building energy saving and control technical measures on the premise of satisfying the quality of indoor thermal environment. The theory of building climate adaptability gives priority to the passive method and maximizes the indoor comfortable thermal environment with little or no active equipment, thus saving energy.

The generalized passive design covers a wide range of content. In terms of the architectural design process, it is necessary to consider the relationship between environmental parameters and natural energy and related elements in architectural design. Environmental parameters include: solar radiation, sunshine, wind environment, etc. Architectural elements include layout, orientation, palisade structure, ventilation, and shading.

Passive design requires the designers to meet the relevant requirements of green building through organizational elements on the basis of understanding the local climate characteristics and satisfying the comfort requirements. Therefore, combined with the energy saving requirements of residential buildings and the content of passive design, this paper combed the design process of passive residential buildings (Figure1).
As the energy consumption of buildings is affected by many factors such as the shape of the building and the thermal performance of the palisade structure, the energy consumption of the buildings corresponding to different combinations of factors will be different. The ANN model has the characteristics of autonomous learning. It can input the different influencing factors as parameters into the model. The NN can automatically adjust the weights to accurately predict the energy consumption of buildings and the comfort of indoor thermal environment.

Using passive influence factors as parameters, combined with the analysis of the relationship between various factors affecting energy consumption and energy consumption, ANN method was used to establish a fast prediction model of building performance (building energy and thermal environment), Using the known input and output data as learning and test samples, the network model was simulated and tested to obtain an optimized network model, and the relationship between different parameters on the building thermal environment and energy consumption was analyzed.

4. Design case analysis
Taking Wuhan City in the hot summer and cold winter area as an example, the parametric design method was introduced in the early stage of the site design, so that the various indicators of the building can be optimized for the building sunshine on the basis of satisfying the rigid requirements. The project has a flat terrain with a total land area of 197,800m² and a plot ratio of 2.8 (±10%). Taking a single group in the scheme as the research object, and the sunshine duration of the building was taken as the optimization target to optimize the design.

4.1. Problem setting
In the site design stage of the building, various indicators need to be allocated and accounted for. Many designers often distribute them by experience, or even design the site for the purpose of meeting the national norms. For many problems, it is only qualitative calculation. Failing to maximize the utilization of environmental resources throughout the base.

In order to solve this series of complicated problems in the early stage of architectural design and optimized the architectural performance, this paper based on Rhino and Grasshopper parameterized platform to control the parameters in the early stage, so that residential buildings could meet the requirements of various specifications to achieve the optimal solution of the scheme design. In Grasshopper, the indicators required by each specification were first input into it, so that each output
result could be linked to Ecotect software for calculation while meeting the specification requirements, and the calculation result was imported into the GA simulator Octopus for judgment (every The results of one operation were compared and eliminated), and finally the optimal solution was output. In the process of case calculation, the basic parameters of the building in the site were set as follows: the building size was set to 20m×15m, the building height was 2.9m, the total height of the building was less than 100m, and the building monomer was optimized on the basis that the sunshine time met the standard requirements (2h sunshine time on great cold day).

4.2. Variable control

Through the method of establishing coordinate system, the site contour and building position were determined, the plane size of the building was determined, the number of floors and height of the building were divided, variables and optimization objects, limiting factors, plot ratio and other control indicators were input, so as to establish the optimization system. In the optimization process, the independent variables were the size, location, height, and angle of the building, while the factors controlling and limiting them were various specifications.

The control, calculation and determination of fireproofing distance and sunshine distance between buildings were carried out by establishing the coordinate system. At the same time, due to the large number of buildings, in order to optimize the calculation, the algorithm was redefined with the computer language in python, so that it could only search nearby buildings in the calculation process and reduced the calculation amount. At the same time, the volume ratio was input as the control index, so that the whole independent variable was controlled within the range of the volume ratio. Variable control is shown in figure 2.

![Variable control and structure diagram.](image)

4.3. Interface calculation and iterative calculation

In the calculation, the core decision algorithm was the judgment of the facade of the building and the subdivision calculation of the south facing. In order to judge each facade of the building, the facade of each building was divided into small square surfaces. After the establishment of the coordinate system, the Y-axis direction was defined as the north direction. By comparing the absolute value of the Angle between the normal direction and the negative direction of the Y-axis, the orientation of the whole building could be judged. Then, linkage grasshopper and Ecotect carried out GA screening calculation. As shown in figure 3, iterative optimization calculation was carried out for the scheme. In the iterative process, in order to meet the basic requirements of the base, the maximum value of sunshine and daylighting was taken as the goal to screen and calculate the parameters.
4.4. Result output

In the Grasshopper calculation process, each of the independent variables satisfying the qualifications was optimized. First of all, the sunshine hours should be controlled so that each output unit satisfied the cold weather for more than two hours, and the output results in heat radiation as a judgement requirement, input the multi-objective optimization calculation in Octopus, and finally the optimum solution was obtained. The idea was to combine the solar radiation with the layout form of the buildings in the group to establish the algorithm, obtained the optimal results, and then adjusted according to other factors to assist the design process to obtain the optimal solution. The setting of the optimization goal and the idea of the system were critical. In iterative calculations, there was also the possibility of no optimization results. In this study, combined with the optimization results of the iterative calculation in Figure 3, 8 optimization calculation data were selected for analysis, as shown in Table 1.

### Table 1. Compares and screens the optimized calculation results.

| Serial number | Calculated floors of a single building | Building orientation | Average sunshine time | Calculated plot ratio | Compliance with the goal |
|---------------|----------------------------------------|----------------------|-----------------------|-----------------------|--------------------------|
| 1             | 28; 28; 28; 17; 14                     | NE17°; NE26°; NW15°; NW14°; NE11° | 6.92h                 | 2.76                  | True                     |
| 2             | 28; 29; 28; 16; 15                     | NE8°; NE6°; NW15°; NW14°; NE11° | 7.12h                 | 2.78                  | False                    |
| 3             | 28; 26; 28; 17; 17                     | NE9°; NE7°; NW15°; NW5°; NE23° | 7.12h                 | 2.78                  | False                    |
| 4             | 28; 26; 28; 17; 17                     | NE8°; NE6°; NW15°; NW21°; NE23° | 8.41h                 | 2.76                  | True                     |
| 5             | 31; 28; 29; 13; 15                     | NE8°; NE6°; NW15°; NW21°; NE23° | 6.91h                 | 2.78                  | True                     |
| 6             | 18; 33; 33; 16; 16                     | NE8°; NE6°; NW15°; NW21°; NE23° | 6.10h                 | 2.78                  | False                    |
| 7             | 18; 33; 33; 16; 16                     | NE8°; NE7°; NW15°; NW21°; NE29° | 6.63h                 | 2.78                  | True                     |
| 8             | 18; 33; 33; 16; 16                     | NE14°; NE7°; NW15°; NW21°; NE29° | 7.39h                 | 2.78                  | False                    |

(True means meet the goal, False means spacing does not match)
Table 1 shows the results of eight optimization calculations that meet the parameter requirements. On this basis, programs 2, 3, 6 and 8 were eliminated because the building spacing did not meet the requirements. Programmes 1, 4, 5 and 7 meet the basic requirements. Therefore, further case evaluation is carried out for the four schemes, and the calculation results of the four schemes are shown in figure 4.

![Scheme 1 to Scheme 7](image)

**Figure 4.** Optimization scheme for iterative calculation.

5. Conclusion
The basic idea of performance parametric design is to implement multiple analysis and optimization solutions to the factors affecting the comfort and energy consumption of building units and groups through the program modules (custom program code) built into the parameterization software GH (these factors). Including orientation, layout, sunshade components, window-to-wall ratio, thermal coefficient of envelope structure, etc.; finally, by balancing the influence of various factors on the building, the integration of building performance and design optimization.

In the process of green building creation, the combination of passive design and parametric technology solves the problems encountered in architectural design with clear logical thinking, which not only improves the design efficiency, but also improves the accuracy of technical application. Therefore, the passive parameterization technology not only has a broad development space in the green building performance design, but also provides favorable support for the architect's green building creation.

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