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An overall structural performance modeling and multi-objective optimization design method for Huizhou architecture based on BIM platform

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ABSTRACT

This paper first outlines the theoretical method of parametric modeling of BIM technology in building structural design, and introduces Revit and Dynamo software to ensure the interactivity and sharing of data while parameterizing the influencing factors of the building structure and automating the extraction of data. Multiple linear regression analysis and the least squares method are used to quantitatively analyze the building energy consumption and the enclosure structure, and to construct a calculation model for the overall structural energy consumption of the building. In order to maximize the comfort of the users and minimize the source consumption of Huizhou architecture, NSGA-III algorithm is introduced to design the multi-objective optimization model of Huizhou architecture. Finally, the optimization effect of the model is verified through simulation and emulation tests. The results show that: the proportion of time that the internal temperature of the antechamber of the building is in the thermal comfort zone is the highest throughout the year (38.29%), and the thermal insulation performance of the building is insufficient; the average illuminance of the compartment space does not meet the lighting requirements (52.07 Lux), and there is a lack of diversity in the lighting design; and it is necessary to optimize the thermal insulation performance of the building enclosure structure to ensure the comfort and livability of the indoor environment. In addition, between the optimal solution and the worst solution interval of the annual energy consumption value and the absolute comfort value of Huizhou architecture, the maximum difference between the energy consumption and comfort indexes is 1.051×10^7kwh and 0.807, respectively, which can be used for the intuitive analysis of the BIM model and the comparison of the solutions.

Keywords: BIM technology, multivariate linear regression analysis, Huizhou architecture, NSGA-III algorithm, multi-objective optimization model

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1. Introduction

Chinese folk dwellings are a secret treasure of human architecture. China is a vast country with a large area, and due to the differences in people's ethnicity, residence, environment, climate and other factors, Chinese folk dwellings also present a great variety of faces. One of them is located in the south of Anhui province, and Jiangxi wuyuan area of a kind of residential is one of the excellent representatives, this kind of residential we call the Huizhou architecture [1-3]. Huizhou traditional architectural culture is grand and complete, distinctive personality and can be integrated into the natural landscape, style and can be harmonized, rich and diverse types and can be self-contained system, craftsmanship exquisite and gorgeous and the overall simplicity and freshness [4-6]. The layout of the Huizhou architecture is rare in the world for the layout of the work, the structure of the clever, the beauty of the decoration, the creation of the fine, but also a pearl in the ancient Chinese architectural school.

With the improvement of information technology, a new design and management mode centered on engineering digital modeling has gradually come into people's view, and the concept of building information modeling (BIM) has been put forward. BIM technology can be applied in the structural design stage of architectural projects, and the designers can gradually deepen and improve the structure according to the architectural functions and usage requirements [7-10]. In the process of establishing the BIM model, information integration and real-time sharing of cross-disciplinary design data can be realized between different disciplines, thus avoiding the problems of untimely and insufficient data and information sharing that may occur in the traditional design process [11-13]. This not only improves the quality and efficiency of the work in the structural design phase, but also provides reliable data for the construction phase and the operation and maintenance phase, thus providing a strong support in the digital transformation process of the construction industry [14-16]. By summarizing and analyzing the relevant modeling algorithms, a fast urban scene modeling method suitable for characteristic buildings is derived, and an automatic and fast urban scene modeling method for the Huizhou style is searched by analyzing the characteristics of the architectural structure and architectural style of Huizhou architecture [17-19].

Utilizing BIM technology to complete the project requires the owner, designer and builder to be proficient in the way it is applied, and although this poses a number of challenges, there is no doubt about the advantages that come with it such as efficient work, complete information, and sound management. Hamidavi, T. et al. build automated architectural design models based on the BIM collaborative platform in the form of proof-of-concept prototypes, and utilize relevant tools to extract the input data of the building structural model and subsequently generate and update alternatives to the structural model automatically for structural engineers to support the optimization of the building structural performance [20]. Sherif, M. et al. showed that the process of optimizing the building design needs to be based on the building structural alternatives, and that by using advanced optimization frameworks integrated with technologies such as structural design, BIM modeling, and computer programming, the can automatically optimize the architectural layout and structural elements of the design alternatives, which improves the efficiency of the design iterations [21]. Afzal, M. et al. showed that structural design optimization can help to improve the design quality, cost efficiency, safety, and structural reliability of the building projects, etc., and that the BIM technology and optimization algorithms play a prominent role in achieving the process of optimization of sustainable structural design, which makes the exchange of information during the design process smoother and more automated [22]. Bagnolo, V. et al. have studied historical buildings and found that the process of modeling complex architectural elements is a major challenge for the application of BIM models, which contributes to the structural optimization of historical buildings through the analysis of recurring elements and governed by the principles of the architectural order, which are progressively extended to different other cases through possible changes [23]. do Carmo, C. S. T. et al. investigated the structural optimization strategies in architectural BIM projects, where the insertion of an information transfer manual structure into the BIM system can facilitate the exchange of information between architects and structural engineers, significantly improving the material consumption, sustainability, and the structural performance of building projects [24].

Due to the continuous development of digital construction, combining intelligent algorithmic programs to process and analyze the large amount of data contained in the BIM building information model to achieve real-time scheduling of BIM information can promote further optimization of the building structure. Quispe, L. et al. examined the parametric and generative design of BIM technology for complex structural concepts, addressing the traditional modeling process of manual measurement extraction and information exchange tasks, developing suitable algorithmic programs to automatically create structures adapted to the designer's criteria, increasing the efficiency of the modeling process [25]. Caetano, I. et al. introduced the BIM architectural design paradigm incorporating algorithmic design, which is able to influence the overall design solution selection by limiting the objectives such as the construction date and the financial budget, and in addition to that, with the help of the computer-assisted design it is possible to significantly increase the algorithmic efficiency of the BIM process [26]. Hamidavi, T. et al. combined genetic algorithms to establish a framework for optimization of building structural design, which can extract data from architectural models to generate structural models and achieve efficiency gains in cost and time of building projects through collaborative work and design innovation [27]. Tafraout, S. et al. utilized genetic algorithms in a BIM platform to automatically derive the optimal structure for a given building configuration, design the relevant building constraints through a multi-objective optimization method, and efficiently generate the optimal building structure that meets the predefined criteria and satisfies the structural design requirements under the continuous iteration of the genetic algorithm [28]. Mangal, M. et al. proposed a reinforced concrete structural optimization framework that combines the BIM technology with a three-stage hybrid genetic algorithm that the international design codes and constructability constraints are fully considered, and 3D models are used to visualize the optimization design results, and the study shows that the proposed optimization framework is able to quickly and accurately minimize the area of reinforcing steel [29].

In this paper, we first sort out the BIM technology and parametric modeling methods, and select Revit and Dynamo as the modeling software in this paper. Based on NSGA-III, we solve the multi-objective optimization problem of Huizhou architecture, and improve the variation operator and crossover operator in NSGA-III, and propose an improved non-dominated sorting genetic algorithm to improve the solving efficiency of NSGA-III algorithm. Based on the two objective functions of user comfort and building energy consumption in the multi-objective optimization problem of Huizhou architecture, the fitness value of each individual is obtained through normalization, and the crossover probability and variance probability with differences are set. The cross-over probability and variance probability of individuals are adjusted through the adaptive mechanism to accelerate the convergence of NSGA-III algorithm. Finally, the multi-objective optimization and simulation of Huizhou traditional architecture are carried out, and the simulation verifies the application effect of NSGA-III algorithm in the overall structure of Huizhou architecture.

2. Multi-objective Optimization Model Construction for Huizhou architecture

2.1. Theoretical approach to BIM parametric modeling

2.1.1. Theoretical approach to BIM technology. Building Information Modeling (BIM) [30], is a general term for the process and results of designing, constructing, and operating a construction project according to the digital representation of its functional and physical characteristics throughout its life cycle. Comprehensive definition of BIM, can be summarized as, BIM is both the result of the model is the process, is the entire building life cycle of all the data information detailed digital expression, that is, BIM technology is the use of model information on the project throughout the design, construction, construction, operation of the integrated management process. The use of BIM technology can realize the integrated management of the whole life cycle of the entire project, through the establishment of a database consisting of a three-dimensional model of the building and its component attributes, through the model of the data information to call the model information and the relevant professional information to share and transfer, for the processing of information, the integration of a huge advantage:

1) BIM model information has the integration and connectivity. BIM model is a technical digital overall model, each professional information are collected in the BIM platform, the model of each part of the information is interconnected, any parameter modification can be modified on the basis of the initial model, if a parameter in the model changes, all the relevant model information will be changed, the corresponding plans, elevations, etc. will also appear associated updates, drawings and models are interconnected, reducing the model changes. The drawings and models are related to each other, which reduces the possibility of data omission in model change and saves the time of model checking.

2) Consistency and coordination of BIM data and information. The BIM platform can realize the coordination of information in all aspects of the whole life cycle of the building from conceptual design to demolition stage, and it can insert, extract, improve and modify data in the model at any time in different phases of design and construction, and it can complete the transmission of design information and construction information without reestablishing the model, and it can provide a data platform that can coordinate the sharing and exchange of information among various stakeholders, and then efficiently coordinate the model modification and management work among various parties. It provides a data platform that can coordinate the information sharing and exchange among various stakeholders, so as to efficiently coordinate the model modification and management work of various parties.

3) Simulation and visualization of BIM model information. BIM model is expressed in three-dimensional view, in the modeling process can be presented in all angles of the model form, in the process of complex architectural and structural modeling, can be displayed in all aspects of the construction of the more complex nodes, what you see is what you get, through the parameter linkage modification in order to save manpower and time costs. The use of BIM model visualization features, the difficult structure, pipeline part of the construction can be simulated, in the targeted program optimization, can be based on the actual situation of the scene on the model for dynamic control, through the BIM model to simulate the scene of the real situation, timely detection of possible problems in construction, easy to adjust the corresponding program, to be able to more effective management of the construction order to improve the site management level.

2.1.2. Theoretical approaches to parametric modeling. Parametric technology is a revolutionary technology in the field of computer-aided design (CAD) technology, which has emerged as a core concept in BIM technology, as the manufacturing industry requires a higher degree of automation and intelligence, which requires a more relevant technical support. Unlike two-dimensional modeling, parameters and models are interrelated in the BIM-based modeling process. When parameters are modified, the model will be driven to change, and accordingly, if the model changes, the values of the relevant parameters will also be changed. On the one hand, the flexible and controllable system avoids a lot of repetitive labor brought about by scheme modification; on the other hand, its WYSIWYG feature facilitates the viewing of contradictions in multiple systems during the construction process and the coordination of various professions.

From the application principles and methods, parametric technology is not a necessary condition for the use of BIM technology, no parameterization can also be achieved BIM technology, but from the modeling operation of the degree of convenience, software processing speed, the complexity of the system platform interaction and other aspects of the analysis, at present, the use of BIM parametric modeling technology in order to better and more comprehensive to achieve the effect of the application of BIM. Different from the traditional three-dimensional modeling based approach, the basic principle of parametric modeling is to control the factors of shape generation are converted into function variables, the shape generation logic into algorithms or function relationships, by changing the function variables to drive the algorithm to generate a variety of shapes, the focus is not on the geometric shape itself, but to control the logic of geometric shape generation law. The use of parametric variables and algorithmic procedures to generate three-dimensional models, compared with the traditional manual modeling is more accurate, faster modeling speed, can achieve the model at any time linkage, greatly improving the efficiency of modeling.

In order to design and build more accurate and reasonable shape of Huizhou architecture parametric design method has been gradually extended from the early conceptual design to the program design, and has become the technical requirements that must be possessed by the sub-projects in many current landmark buildings. Based on this, parametric technology is utilized to build BIM models, drive model generation through data parameters, and integrate model data through BIM technology in order to deliver it to other parts of the project's full life cycle.

2.2. Construction of the overall structural energy consumption analysis model for Huizhou architecture

2.2.1. Selection and Establishment of Architectural Models. Revit is chosen as the BIM platform software for this experimental study, and the gbXLM files output from Revit can be imported into the powerful database of the GBS cloud computing platform, so that the interactivity and sharing of data are guaranteed.

The information interaction between Revit and GBS has a fixed file format. Before simulating the energy consumption of a building in the GBS cloud, information settings should be made in Revit for the building model that has been spatially divided, in which the energy settings contain basic information such as the location and type of the project, which will be displayed in the information interaction text. The text in gbXML format can be exported from Revit and imported into the GBS cloud to perform the building energy simulation for the project. The txt or excel file can be used to open the gbXML text, from which we can find that the text represents the different spatial areas of the building in the form of coordinate points, and the text includes information about the material and thermal performance of each space.

2.2.2. Building information automation setup and extraction process design. In order to study the influence of different parts of the building envelope on the energy consumption of the building, parameter settings and automated extraction of data and information on the influencing factors of the building envelope are carried out through Dynamo visualization programming. The change of thermal performance analysis attributes of different parts of the building envelope is mainly driven by changing the family type and material type of the building envelope, and the change of geometrical parameters of different parts of the building envelope is mainly driven by the change of the limiting conditions such as the size of the windows and the window-to-wall ratio. The design flow of building information automation setting and extraction technology is shown in Figure 1.

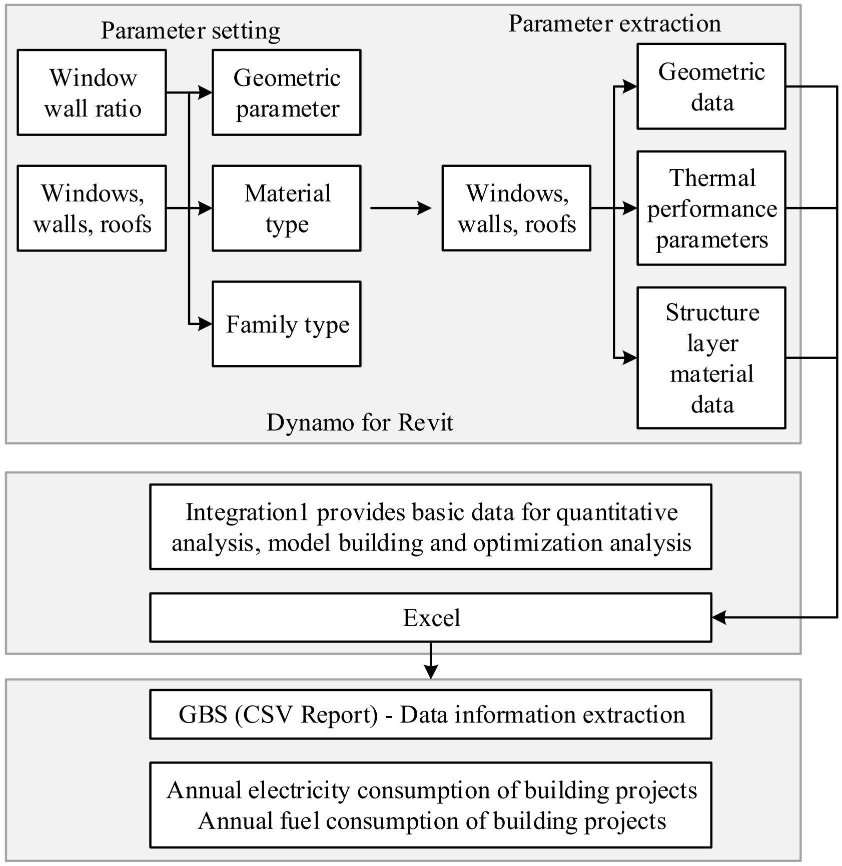

Fig. 1. Flowchart of automatic setting and extraction of building information

2.2.3. Quantitative Analysis of Building Energy Consumption and Envelopes:

1) Quantitative analysis of thermal performance of external walls. Multiple linear regression analysis [31] was used to obtain quantitative relationship expressions between heat transfer coefficients, thermal resistance, and thermal mass of the exterior wall and the building's electricity consumption and fuel usage:

$$F_e = 1889201.29 + 41912.13WA_1 + 3540.939WA_2 + 1639.1WA_3 \quad (1)$$

$$F_f = 14948363.7 + 1240952.53WA_1 - 146630.2WA_2 - 5974.6WA_3 \quad (2)$$

where,

F_e - Annual electricity consumption, kwh;

F_f - Annual fuel usage, MJ;

WA_1 - wall heat transfer coefficient, $\mathrm{W/(m^2 \cdot K)}$;

WA_2 - wall thermal resistance, $\mathrm{(m^2 \cdot K)/W}$;

WA_3 - wall thermal mass, kJ/K.

2) Quantitative analysis of thermal performance of external windows. Using the ordinary least squares method of step-by-step regression analysis of the influence factors, the quantitative relationship between the heat transfer coefficient of the external window, shading coefficient, daylight heat gain coefficient, visible light transmission rate and the building power consumption, fuel usage expression is shown below:

$$F_e = 1847397.02 + 10006.13W_1 + 54178.72W_2 - 19726.83W_3 + 129485.1W_4 \tag{3}$$

$$F_f = 13517300.22 + 452340.35W_1 + 1132926.63W_2 - 373350.05W_3 - 1555003.11W_4 \tag{4}$$

where,

F_e - Annual electricity consumption, kwh;

F_f - annual fuel use, MJ;

W_1 - window heat transfer coefficient, $\mathrm{W/(m^2 \cdot K)}$;

W_2 - shading coefficient;

W_3 - Visible light transmittance;

W_4 - daylight heat gain coefficient.

3) Quantitative analysis of roof thermal performance. Multiple linear regression of the thermal parameters of the roof using the ordinary least squares method was used to obtain the quantitative relationship expressions between the roof heat transfer coefficient, thermal resistance, thermal mass and the annual electricity consumption and fuel use as shown below:

$$F_e = 2054037.46 + 20382.83R_1 - 518.98R_2 - 19.15R_3 \tag{5}$$

$$F_f = 15705620.14 + 510629.84R_1 - 20974.49R_2 - 85.04R_3 \tag{6}$$

where,

F_e - Annual electricity consumption, kwh;

F_f - Annual fuel use, MJ;

R_1 - roof heat transfer coefficient, $\mathrm{W/(m^2 \cdot K)}$;

R_2 - roof thermal resistance, $\mathrm{(m^2 \cdot K)/W}$;

R_3 - roof thermal mass, kJ/K;

4) Quantitative analysis of window-wall ratio. The expression for the quantitative relationship between the window-wall ratio and the annual electricity consumption and annual fuel use of the building is:

$$F_e = 1728368.14 + 622664.09WWR \tag{7}$$

$$F_f = 120830\ 17.24 + 7294235.85WWR \tag{8}$$

F_e - Annual electricity consumption, kwh;

F_f - Annual fuel use, MJ;

WWR - window-wall ratio.

2.2.4. Building energy consumption calculation model construction:

1) Building energy consumption simulation project design. In order to obtain the factors and quantitative relationship of the influence on the annual energy consumption of the building under the comprehensive role of the building envelope, the construction forms of different parts of the building envelope are randomly combined. The building energy consumption simulation experiment is designed, and 455 groups of energy consumption simulation data under different construction combinations of the building envelope are obtained, of which 317 groups of data are randomly selected

for correlation and regression analyses, and the remaining 138 groups of experimental data are used to validate the regression model.

2) Building energy consumption calculation modeling. According to the results of correlation analysis between building energy consumption and thermal performance, appropriate parameters are selected and regressed through the regression platform for the building energy consumption calculation model.

It is assumed that the annual electricity consumption of the building is modeled as:

$$F_e = \beta_{e1} + \beta_{e2}WH + \beta_{e3}RH + \beta_{e4}WIR + \beta_{e5}WW + e \tag{9}$$

Assume that the annual fuel usage of the building is modeled as:

$$F_f = \beta_{f1} + \beta_{f2}WH + \beta_{f3}WR + \beta_{f4}RH + \beta_{f5}WIR + \beta_{f6}WW + e \tag{10}$$

where: F_e - Annual electricity consumption of the building, kwh;

F_f - Annual fuel use of the building, MJ;

WH - wall heat transfer coefficient, $\mathrm{W/(m^2 \cdot K)}$;

RH - roof heat transfer coefficient, $\mathrm{W/(m^2 \cdot K)}$;

WR - wall thermal resistance, $\mathrm{(m^2 \cdot K)/W}$;

WIR - window thermal resistance, $\mathrm{(m^2 \cdot K)/W}$;

WW - window-wall ratio.

It is assumed that in the model, the response variable F_e can be approximated as a linear function of the explanatory variables wall heat transfer coefficient WH, roof heat transfer coefficient RH, window thermal resistance WIR, and window-to-wall ratio WW; the response variable F_f can be approximated as a linear function of the explanatory variables wall heat transfer coefficient WH, wall thermal resistance WR, roof heat transfer coefficient RH, window thermal resistance WIR, and window-to-wall ratio WW; $\beta_{e1}, \beta_{e2}, \beta_{e3}, \beta_{e4}, \beta_{e5}$ and $\beta_{f1}, \beta_{f2}, \beta_{f3}, \beta_{f4}, \beta_{f5}, \beta_{f6}$ are coefficients of the model's explanatory variables, which represent the average unit change of a single explanatory variable with the average unit change in the explanatory variables while other explanatory variables are held constant: e is the random error term obeying a normal distribution $N(0, \delta^2)$.

Ordinary Least Squares (OLS) is a commonly used method in linear regression models, and the above hypothetical regression model was regressed using OLS to solve for the estimated values of the explanatory variables and explanatory variables in the case where the residuals e are minimized as in the following equation:

$$\begin{aligned} F_e = {} & 2379272 + 50559.87WH + 56329.15RH \\ & -128822.4WIR + 361253WW \end{aligned} \tag{11}$$

$$\begin{aligned} F_f = {} & 13236102 + 1167866.5WH - 180147.5WR + 664035.2RH \\ & -4350507.4WIR + 7592204WW \end{aligned} \tag{12}$$

The goodness-of-fit tests were performed on the equations respectively, and the corrected goodness-of-fit values of annual electricity consumption were calculated to be 0.9834 and 0.9648, reflecting the fact that the proportion of variance that could be explained by the above regression equations was 98.34% and 96.48% respectively. The goodness of fit is relatively high and the models all pass the goodness of fit test.

The regression equations passed the statistical significance test of P=0.01, which means that the probability of inter-sample variation due to random sampling error is less than 0.01.

The value of F-test is calculated from R^2, the F-values of the above regression equations are 758.44 and 529.63 respectively, both are greater than the critical value of F-statistic at significance level $a = 0.05$, and the models all pass the F-test.

2.3. *Multi-objective optimization model construction for Hui architecture*

Multi-objective optimization [32] refers to the balanced optimization of a problem with multiple objective functions and constraints, this process is not purely to pursue a particular objective to achieve the optimal, usually seeks the optimal combination of multiple objectives to achieve the overall optimality of the problem or system. In multi-objective optimization problems, the objectives are often in conflict with each other, and the improvement of one objective may cause the reduction of another objective. The purpose of multi-objective optimization is to find the diversity of the solution set and make trade-offs between various objective functions. In real life, there are a large number of multi-objective optimization problems and research in multi-objective optimization. A multi-objective Pareto optimal solution is one in which the entire parameter space does not have any one decision vector Pareto dominating a particular decision vector. Pareto optimal frontier means that the objective function corresponding to all non-inferior solutions constitutes the non-inferior optimal objective domain, i.e., the objective function value corresponding to the Pareto optimal solution.

In the optimization of the building system of Huizhou architecture, energy saving and environmental protection and user comfort are often in conflict, and the problem can be weighed by multi-objective optimization. Usually, the users of Huizhou architecture often need higher comfort to meet their own needs, but the user's high comfort is based on the high energy consumption of the Huizhou architecture system, how to get Huizhou architecture energy consumption and user comfort to meet the two power program is an urgent problem. The demand-side optimization of the Huizhou architecture system is to improve the user comfort in different types of Huizhou architecture scenarios by constructing a user comfort function model for different types of Huizhou architecture diversely from the four aspects of thermal environment comfort, visual environment comfort, acoustic environment comfort, and air quality based on the results of selecting the user comfort preferences of the different types of Huizhou architecture in the previous chapters. Therefore, its overall optimization goal is to improve the overall user comfort. The goal of the supply side of the operation process of Huizhou architecture is to reduce energy emissions, especially to reduce the use of fossil energy and increase the proportion of clean energy use. Therefore, the overall optimization objective of the energy supply side of the Huizhou-style architecture is to reduce the cost of energy consumption. This paper is a multi-objective optimization problem with two objective functions, compared with the research results of three objective functions for the Pareto optimal frontier hypersurface, the multi-objective optimization results in this paper are obtained as a two-dimensional curve.

The mathematical formulation of the multi-objective optimization problem is represented as follows:

$$MOP \min_{p\in c} F(t)=[-F_1(p),F_2(p)]^T \tag{13}$$

$$c=\{p:g(p)\le 0,a\le p\le b\} \tag{14}$$

$p=[p_{rt},p_{rl},p_{rs},p_{ra}]^T$ is the vector of decision variables, $f_i(t)$ is the objective function, and g_i represents the constraints of the problem. When and if there is no point $p\in c$ such that $f_i(t)\le f_i(t^*)$, then $p^*\in c$ is the Pareto optimal solution set of the multi-objective optimization problem. In this paper, we need to maximize the comfort of the users of the Huizhou architecture, and the energy consumption of Huizhou architecture system is minimum, while the total function is minimum, so the direction of the comfort function of the users of Huizhou architecture should be negative in order to satisfy the overall minimum. As for the importance of the two objective functions of user comfort and building energy consumption in Huizhou architecture, this paper does not make a difference, and the default is equally important, so it does not consider the weight relationship between the two.

Here the objective function of user comfort in Huizhou style architecture can be expressed as:

$$Maximize F_1(t)=\omega_1\left[1-\left(\frac{p_{at}(t)-P_{ct}}{P_{ct}}\right)^2\right] +\omega_2\left[1-\left(\frac{p_{av}(t)-P_{cv}}{P_{cv}}\right)^2\right] +\omega_3\left[1-\left(\frac{p_{as}(t)-P_{cs}}{P_{cs}}\right)^2\right] +\omega_4\left[1-\left(\frac{p_{aa}(t)-P_{ca}}{P_{ca}}\right)^2\right] \tag{15}$$

$p_{at}(t), p_{av}(t), p_{as}(t), p_{aa}(t)$ indicates the actual power consumed by heat, vision, sound and air quality. $P_{ct}, P_{cl}, P_{cs}, P_{ca}$ represents the standard power consumed by the four aspects of heat environment, visual environment, sound environment and air quality under the relatively comfortable conditions in this Huizhou architecture, respectively, and takes the average value, which is a constant. ω_i is the comprehensive evaluation value of user comfort in thermal environment, visual environment, acoustic environment and air quality for different types of southern Huizhou-style architecture users.

In terms of energy saving in Huizhou architecture, this paper selects the intelligent building energy consumption cost as the objective function, and the objective function is expressed as follows:

$$Minimize\ F_2(t)=\sum_{t=1}^{T} c_e[p_{at}(t)+p_{av}(t)+p_{as}(t)+p_{aa}(t)] \tag{16}$$

The cost of energy consumption is uniformly expressed as the cost of electricity serving its heat, sight, sound and air quality. c_e is the price of electricity, which is different for different types of Huizhou architecture. The comfort constraints of thermal environment, visual environment, sound environment and air quality are all between 0 and 1.

Taking the thermal environment comfort as an example, if we want to make $\left[1-\left(\frac{p_{rt}-P_{ct}}{P_{ct}}\right)^2\right]\in[0,1]$, then $0<p_{rt}(t)\le 2P_{ct}$ is required, and the rest of the comfort constraints can be obtained in the same way. In turn, the constraints for this study are obtained as follows:

$$s.t.\begin{cases}0<p_{at}(t)\le 2P_{ct}\\ 0<p_{av}(t)\le 2P_{cv}\\ 0<p_{as}(t)\le 2P_{cs}\\ 0<p_{aa}(t)\le 2P_{ca}\\ 0<p_{at}(t)+p_{al}(t)+p_{as}(t)+p_{aa}(t)\le p_{max}(t)\end{cases} \tag{17}$$

2.4. Algorithm Design of Multi-Objective Optimization Model for Huizhou Architecture

2.4.1. Algorithm design:

1) Coding and population initialization. When solving the multi-objective problem, the first step is to encode the problem, the encoding method should be selected according to the type of the problem and the characteristics of the decision variables, the establishment of the actual characteristics of the decision variables in the target problem and the algorithm of individual genotypes of the two

correspondences between the two, so that the genetic algorithm can be successfully carried out in the subsequent operations of the algorithm to solve the problem, and to take the appropriate encoding method to improve the efficiency of the algorithm to solve the problem. In this paper, the binary to decimal coding method is used. In this paper, the number of optimization variables is 4, first of all, the binary coding of variables, and then binary to decimal, the binary coding length of each variable is 10, and then according to the upper and lower limits of the variable value range, the decimal coding is converted to a real number within the range of 0-2. In this paper, we first generate the number of individuals twice the initial population, and select the individuals by non-dominated sorting and reference point operator, in which the individuals with more excellent performance constitute the initial population.

2) Genetic operation. Selection operator is the key step of NSGA-III algorithm [33-34], and this paper adopts tournament selection. First, a certain number of individuals with better fitness value and excellent performance are selected as offspring in the parent population, and the cycle is repeated to get the next offspring population. The segment exchange between two cross loci in the individuals of the parent generation is selected, and the coding of repetitions is adjusted according to specific mapping rules. In this paper, we use a combination of two types of mutations: swapping and inversion. Swapping is to swap the genes between two randomly selected loci in an individual, and inversion is to arrange the segments between two randomly selected loci in an individual in reverse order.

3) Elite strategy. The NSGA-III algorithm introduces the elite strategy, which combines the parent population with the offspring population generated after genetic operations such as crossover and mutation, and obtains the ordinal value by stratifying the individuals through the fast non-dominated sorting with the small habitat operator based on the reference point, and calculates the density value. The initial population for the next iteration is selected based on the computed ordinal and density values, which allows the initial population for the next iteration to retain the best individuals of the parent and child populations.

4) Algorithm termination conditions. In the NSGA-III algorithm process, judgment conditions are set to confirm whether the optimal solution is generated, and the number of iterations for the termination of the algorithm is generally taken as an integer within [100, 1000], i.e., when the loop reaches the specified number of times, the loop is stopped and the results are output. In this paper, we test and analyze the results of the algorithm under different iteration numbers, and set the number of iterations for the termination of the algorithm as 500 generations.

2.4.2. Adaptive probability adjustment mechanisms. In this paper, based on the multi-objective optimization model of Huizhou-style architecture, an adaptive probability adjustment mechanism is designed in the NSGA-III algorithm to solve the problem. In this paper, the adaptive cross probability and variance probability are calculated by designing the individual adaptation value, and the higher the individual adaptation value, the better the performance of the individual, i.e., the lower the energy consumption, the lower the cost, and the higher the indoor thermal comfort of Huizhou architecture.

The individual objective function values are normalized;

1) Calculate the minimum and maximum values of each objective function in the population by calling the set consisting of the minimum value $z_j^{\min}$ of each objective function $M(j=1,2,3...m)$ in each generation of population P_t the ideal point, denoted $z_{\min}=(z_1^{\min},z_2^{\min},...z_m^{\min})$. The set of vectors consisting of the maximum value $z_j^{\max}$ of each objective function is the minimum point, and the set is denoted $\overline{z}_{\max}=(z_1^{\max},z_2^{\max},...z_m^{\max})$.

2) Normalize each objective value in P_t:

$$f_{ij}^{'} = \frac{f_{ij} - z_j^{\min}}{z_j^{\max}} \tag{18}$$

The total objective function value is obtained by taking the average value; the individual adaptation value is calculated according to the formula.

In this paper, the mean value after individual normalization is processed, and the individual adaptation value f_i^z is calculated by the following formula, $f_{i1}^{'}$ is the heat consumption of the building, $f_{i2}^{'}$ is the cost of the enclosure structure, and $f_{i3}^{'}$ is the value of the indoor thermal environment comfort index PMV.

$$f_i^z = \ln\left[\left(\sum_{j=1}^{m} f_{ij}^{'}\right) / m \right]^{-1} \tag{19}$$

The cancellation of each objective function measure is based on the fact that the algorithm can obtain a set of feasible solutions, and by normalizing each objective function, the problem of non-uniformity of measure and different value ranges between the objective functions is solved, which prevents the emergence of the situation in which the other objective functions are dominated by a certain objective function.

After normalization, the formula for calculating the individual crossover probability P_{ci} is:

$$P_{ci} = \begin{cases} \dfrac{f_{\max} - f_i^z}{f_{\max} - f_{avg}} & f_i^z \geq f_{avg} \\ k_1 & f_i^z < f_{avg} \end{cases} \tag{20}$$

where:

P_{ci} - the crossover probability of the i nd individual;

f_i^z - the fitness value of the i th individual;

$f_{\max}$ - the maximum value of fitness in an individual;

f_{avg} - the average fitness value;

k_1 - taking the value of 1.0.

After normalization, the formula for calculating the individual variance probability P_{mi} is:

$$P_{mi} = \begin{cases} 0.005 & f_i^z = f_{\arg} \\ k_2 \dfrac{f_{\max} - f_i^z}{f_{\max} - f_{\arg}} & f_{\arg} \leq f_i^z \leq f_{\max} \\ k_3 & f_i^z < f_{\arg} \end{cases} \tag{21}$$

where:

P_{mi} - the probability of variation of the i nd individual;

k_2, k_3 - takes the value of 0.5.

The adaptive probability adjustment mechanism designed in this paper improves the crossover and mutation operations in the NSGA-III algorithm, which makes the NSGA-III algorithm more varied, more extensive, and more efficient in searching the solution space of the problem.

2.4.3. Algorithm flow. The improved NSGA-III algorithm flow is briefly described below, and the improved NSGA-III algorithm flowchart is shown in Fig. 2.

Step1 randomly generate individuals and select by tournament method to generate initial population P_0 of size N;

Step2 perform adaptive crossover and mutation on individuals in P_0 to generate offspring population Q_0 of size N;

Step3 combine initial population P_0 and offspring population Q_0 into population R_0 of size $2N$;

Step4 obtain the ordinal value by non-dominated sorting stratified population R_0, and prune population R_0 by calculating the density value of individuals using the reference point operator for individuals in the same stratum, to obtain the initial population P_1 with the number of individuals N for the next round of the cycle;

Step5 Judge whether the iteration termination condition is satisfied. If so, stratify the population and output the individuals in the first layer; otherwise, go to the second step to carry out the loop operation.

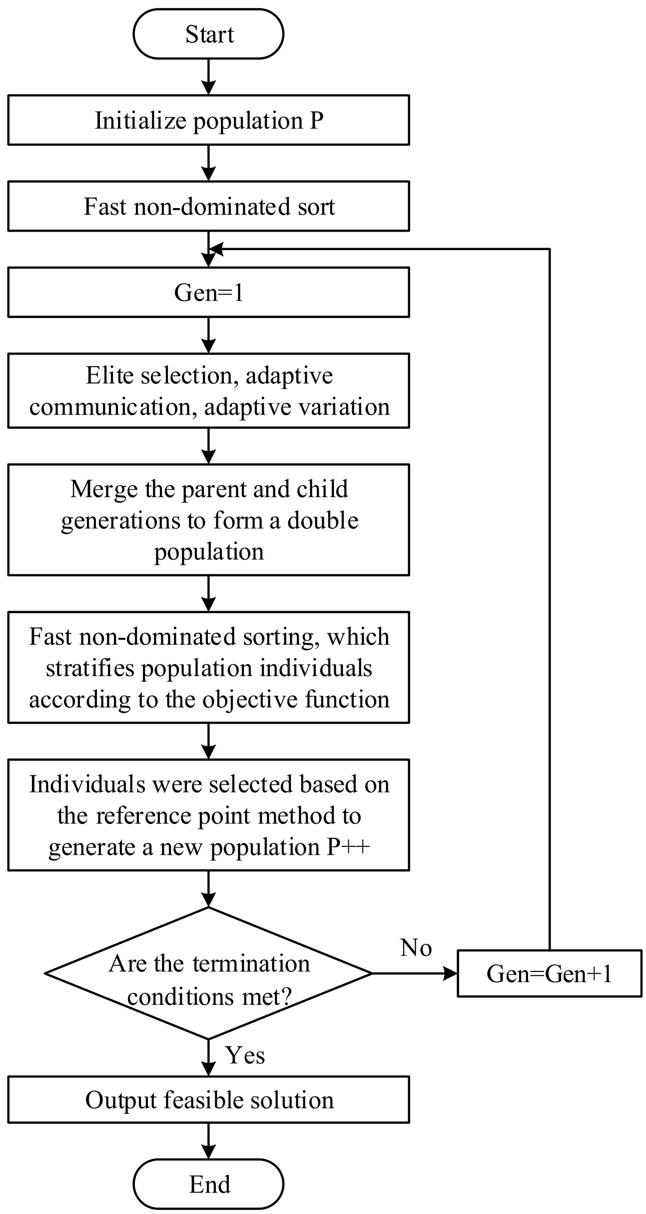

Fig. 2. Flowchart of the improved NSGA-III algorithm

3. Overall structural performance and multi-objective optimization results of Huizhou architecture

3.1. Analysis of simulation results of Huizhou architecture

3.1.1. Analysis of the indoor thermal environment. The whole year was selected as the simulation cycle for the energy simulation analysis under the standard climatic conditions of Huizhou region, during which the building was assumed to adopt a natural ventilation strategy. The envelope material parameters of the selected dwellings were imported into Grasshopper for analysis, in which the solar radiation absorption rate of the walls was set at 0.48, while that of the roof was set at 0.69. The results of the indoor thermal environment analysis are shown in Table 1. The simulation data show that the temperature fluctuation trends of different functional zones within Huizhou architecture are similar, which indicates that the enclosure structure of the simulated houses performs poorly in terms of heat preservation and insulation, and that changes in the outside temperature have a significant impact on the indoor temperature. The results of the indoor thermal environment analysis are shown in Figure 3. The proportion of time that the internal temperature of the building was in the thermal comfort zone throughout the year was 38.29%, with a relatively high proportion of thermal comfort time in the vestibule space, which explains why residents tend to stay in the hall area most of the time, as its temperature is more suitable compared to other rooms.

Table 1. Results of indoor thermal environment analysis

Floor number	Room name	Area (m^2)	The time ratio of the thermal comfort interval(%)
1	Vestibule	65	40.27
	Backcourt	25	39.97
	Waiting room	20	38.27
	Bedroom	16	37.97
	Bedroom	16	39.77
	Wing room	15	36.77
	Wing room	15	35.97
	North hall	56	36.87
	South side bedroom	15	38.57
2	South side bedroom	15	38.27
	Northern side bedroom	15	38.47
	Northern side bedroom	15	38.47
	South hall	15	38.17
The time standard of the building satisfies the thermal comfort interval(%)			38.29%

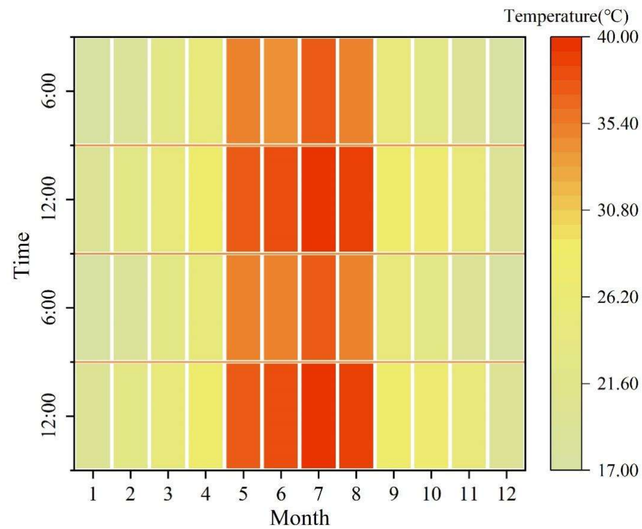

Fig. 3. Results of indoor thermal environment analysis

3.1.2. Light environment analysis. The initial model lighting simulation of Huizhou architecture is modeled by the simulation software Radiance. China is a vast country, and the difference in the sun's altitude angle between the north and the south at the same time is very large, which leads to different cloud shapes, cloud amount and outdoor illuminance in different areas. In order to facilitate the design of lighting, according to the illumination of China is divided into five light climate zones, Huizhou light climate is located in the partition for the Ⅳ zone (i.e., the outdoor natural light design illuminance value of 12,500 Lux), the selection of architectural finishing materials and reflective ratio of the value shown in Table 2. Neglecting the influence of indoor furniture-type facilities, only the permanent fixed ceiling, floor and wall are considered.

Table 2. The decorative surface materials are chosen and reflected

Site	Reflection	Material
Ceiling	0.5924	Watchboard
Ground	0.5371	Water mill
Wall	0.5945	Template wall
Appearance surface	0.7642	White paint

The light environment analysis results are shown in Figure 4, according to the “green building evaluation standard” GB/T 50378-2019 in the article 5.2.8 of the light environment of the building put forward a clear requirement: residential building indoor main function space at least 65% of the area proportion of the area of the value of its lighting illuminance is not less than 280lx. analysis results show that most of the rooms of the lighting coefficient do not meet the standard requirements, only the foyer, Hall and back hall meet the lighting requirements of the building, the building compartments do not meet the lighting requirements, the average illuminance is only 52.07 Lux. in the subsequent optimization process should increase the lighting effect of the room to improve the indoor illuminance.

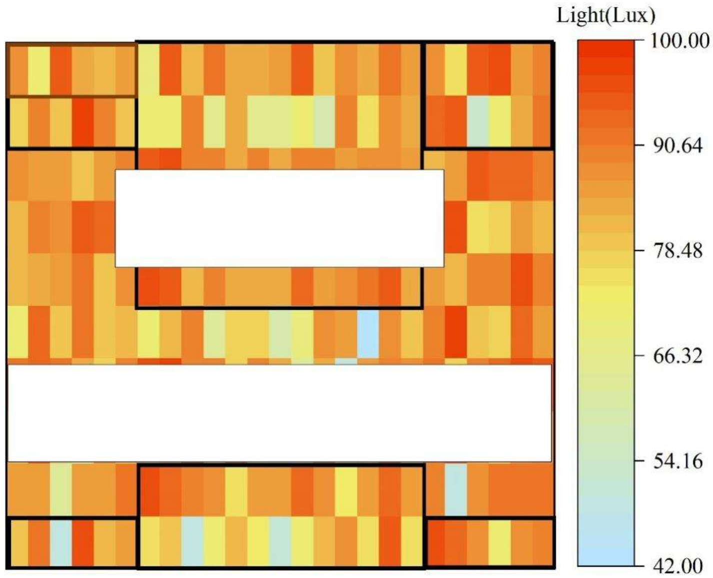

Fig. 4. Results of halo analysis

3.1.3. Analysis of building energy consumption. The initial model energy consumption simulation of Huizhou architecture is established through the simulation energy consumption software Ladybug Tools. The parameters are set as shown in Table 3, without considering the internal disturbance of electrical lighting and home appliances. The temperature control period is as follows: cooling period: 5.1-9.30, heating period: 11.1-3.1.The indoor temperature of heating is set to 16℃, and the indoor temperature of cooling is set to 27℃; the compartments and the back hall are selected as the main heating rooms. The number of air changes is set at 0.5 times/h.

Table 3. Building parameter

Project			Huizhou traditional residential buildings		
Figure coefficient S			0.6914		
Roof heat transfer coefficient K[W/(m²·k)]			2.5087		
External wall heat transfer coefficient K[W/(m²·k)]			3.9016		
Ground contact outdoor overhead or external floor heat transfer coefficient K[W/(m²·k)]			1.2115		
The heat transfer coefficient of the outer door and window, the shade coefficient	Face	Window ratio	Heat transfer coefficient	Summer comprehensive shade coefficient	The winter comprehensive shade coefficient
	southward	0.004	Window4.80	1	1
	North direction	0.006	Window 4.80	1	1
	East direction	0	Window 4.80	1	1
	westward	0	No window	0	0

The simulation results of cooling energy consumption and heating energy consumption are shown in Fig. 5 and Fig. 6, respectively. The energy consumption per unit area of the initial model of Huizhou architecture reaches 83.74 (kWh/m^2). To ensure the comfort and livability of the indoor environment, the heating and cooling needs of the house often lead to a large amount of energy consumption. This not only exacerbates the economic pressure on residents, but also contradicts China's standards and requirements for building energy efficiency. Therefore, optimizing the thermal insulation performance of building envelopes has become a key measure to reduce energy use and achieve energy saving and emission reduction goals.

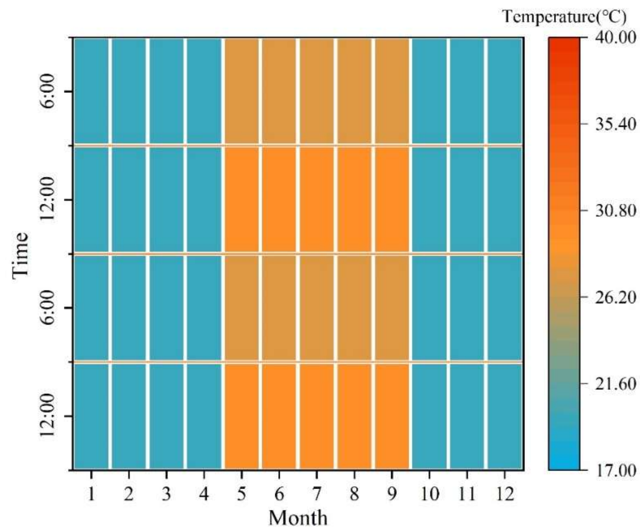

Fig. 5. Simulation results of refrigeration energy consumption

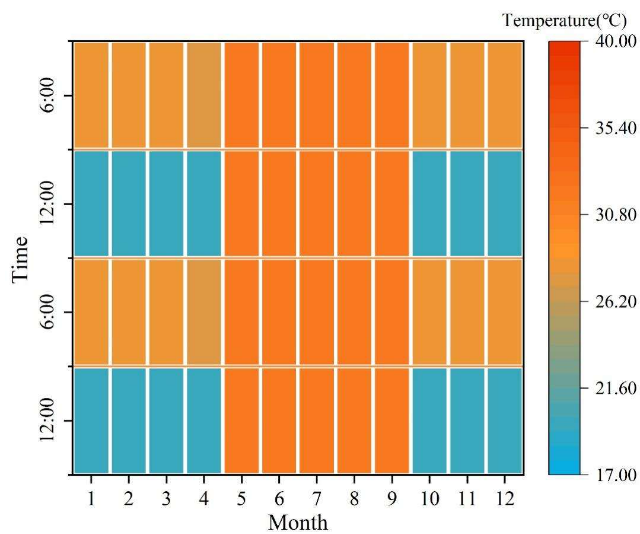

Fig. 6. Simulation results of energy consumption

3.2. Analysis of simulation results

3.2.1. Simulation results. The run ends after the number of iterations reaches the set value of 100 times, and the Pareto front of multi-objective optimization of energy consumption and thermal comfort can be obtained, and the optimal Pareto front is shown in Fig. 7. The vertical coordinate is the annual energy consumption, the energy consumption in kwh, and the horizontal coordinate is set as the absolute value of thermal comfort, running the simulation program of improved multi-objective optimization algorithm, and finally obtaining 50 sets of Pareto solutions that can be referred to by the case project.

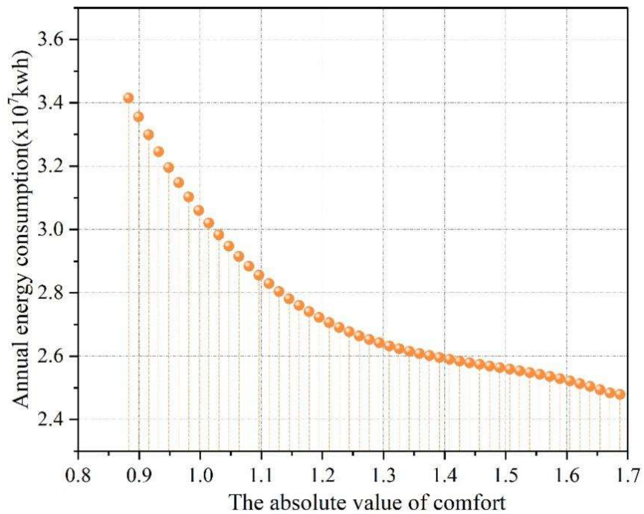

Fig. 7. The optimal pareto front is like

3.2.2. Analysis of results. After the end of 150 iterations, the distribution of non-dominated feasible solutions obtained at the end of iterations is shown in Figure 8. It can be seen that the value of the annual energy consumption of the building is between 2.487×10^{7}kwh-3.538×10^{7}kwh, and the absolute value of comfort is approximately distributed between 0.89-1.71. In the whole non-dominated solution, the feasible solution is selected according to different target demands, and when the lowest energy consumption of the building throughout the year is required, the energy consumption in the feasible solution obtained is 2.487×10^{7}kwh, and the worst solution of comfort 1.697 is also obtained at this moment. When the best comfort is required, the optimal solution for comfort is obtained as 0.89, while the worst solution for the annual energy consumption of the building is obtained at this moment as 3.538×10^{7}kwh. Between the optimal and worst solution intervals, the energy consumption can produce a maximum difference of 1.051×10^{7}kwh, and a maximum difference of 0.807 in the comfort index.

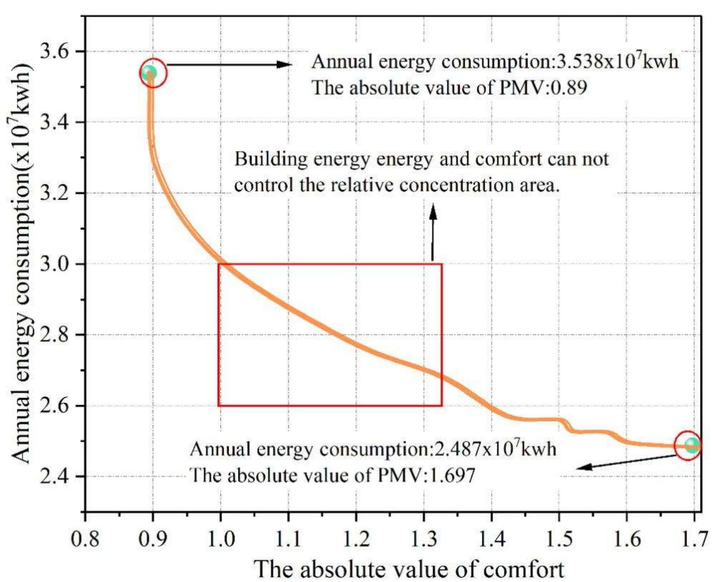

Fig. 8. The non-dominant feasible solution distribution after the iteration

The parameter settings of the non-dominated feasible solutions are shown in Table 4. In the obtained 50 groups of non-dominated feasible solutions, we extract the optimal feasible solutions that satisfy the energy consumption objective, the optimal feasible solutions that satisfy the comfort objective, and the optimal feasible solutions that satisfy the energy consumption and comfort indicators at the same time, and then we call the Dynamo parameter setting data to analyze the setting of decision-making parameters of the feasible solutions of the Pareto frontier with the data of the generated BIM model. The parameter settings of the non-dominated feasible solution part are shown in Table 4. The optimal solution to meet the energy consumption objective is 2.487×10^7kwh, at which time the building is oriented to the south, the window-to-wall ratio is 0.35, the facade material is structural insulated panel (SIP), and the glazing material is medium-transmittance insulating Low-E glass. The best solution to achieve the comfort goal is 0.89, when the window-to-wall ratio is 0.7, the glass material is high-transmittance monolithic glass, the exterior wall material is metal frame, and the building is oriented to the south-east by 25 degrees. Select the non-dominated feasible solution distribution is more dense area trade-off analysis to achieve the best feasible solution of energy consumption and comfort goals, first extract a group of solutions for analysis, the window-to-wall ratio is 0.6, the exterior wall material is insulated concrete, the glass material is double-layered ordinary glass, at this time, the annual energy consumption of 2.9125 × 10^7kwh, the absolute value of the thermal comfort of 1.0335. the experiment ultimately obtains the case of the project can be Reference to 50 groups of solutions, corresponding to 50 kinds of programs, the corresponding data can be parameterized to drive the BIM model to visually analyze the feasibility of the results, so it can be based on the different demand objectives of the simple program selection.

Table 4. Non-dominant feasible solution of some parameter Settings

Optimal solution	Annual energy consumption (× 10^7kwh)	PMV	Window ratio	Architectural orientation	Glass material	Exterior wall material
Energy target	2.487	1.697	South to 25	south	6	2
Energy & comfort	2.9125	1.0335	South to 55	East by south	2	3
Comfort target	3.538	0.89	North to 60	East by south	4	4

4. Conclusion

In this paper, with reference to the characteristics of the overall structural design of Huizhou architecture, the overall structural performance objective optimization model of Huizhou architecture based on NSGA-III algorithm is constructed on the BIM platform. The performance of the southern Huizhou architecture residence is modeled and simulated.

1) In this paper, the thermal comfort, lighting effect and energy consumption are examined in detail, and the factors affecting the overall performance of Huizhou architecture are analyzed, including insufficient heat preservation and insulation, and lack of diversity in lighting design. The proportion of thermal comfort time in the building vestibule space was relatively high throughout the year, and the proportion of time when the internal temperature was in the thermal comfort zone accounted for 38.29%. The average illuminance of the building compartment space is 52.07 Lux, which does not meet the lighting requirements. Therefore, in order to ensure the comfort and livability of the indoor environment, it is necessary to optimize the thermal insulation performance of the building envelope.

2) In this paper, we obtain the annual energy consumption value and the absolute comfort value of Huizhou architecture between 2.487×10^7kwh-3.538×10^7kwh and 0.89-1.71, respectively. Running the improved multi-objective optimization algorithm simulation program, this paper obtains 50 scenarios that can be referred to by the case project. The corresponding data can be parametrically driven BIM model to visualize and analyze the feasibility of the results and the simple comparison of the schemes.

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