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A Genetic Algorithm of Computer-Aided Architectural Design Based on BIM

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Abstract. Building Information Modeling technology is an emerging engineering digital design method in the architectural design industry. In which the architectural information model and comprehensive civil engineering design, related inspection and pipe network control can be realized. This paper analyzes the building scheme decision-making model based on BIM genetic algorithm. In this article, authors have analyzed a diverse application of BIM technology in energy conservation. According to the results obtained it has been examined that in the optimized scheme compared to the original design scheme, the building energy consumption is reduced by 16%, the natural lighting is increased by 1.5%, and the natural pressing hours are increased by 10%. After multi-objective optimization, the building integrated design scheme makes the building energy consumption lower, the natural lighting and natural ventilation effect are improved, which reflects the advantages and design effect of building integrated design. This paper is grounded on BIM computer-aided architectural scheme optimization research that has a progressive and imperative consequence.

Keywords: Building Information Modeling (BIM) Technology; Genetic algorithm; Computer aided; Optimization; Architectural Design; BIM Application; multi-objective optimization.
DOI: https://doi.org/10.14733/cadaps.2023.S3.225-237

1 INTRODUCTION

In recent years, the world has promulgated many relevant policies to promote the development of green buildings. For example, the State Council recently issued the "13th Five Year plan" comprehensive work plan for energy conservation and emission reduction. By 2020, the green building construction area of cities and towns will account for more than 50% of the newly-built building area"[1]. Thus, we can see the development potential of green buildings in China. Green building is based on fully understanding nature, respecting and conforming to nature. To reduce energy consumption and meet the requirements of natural light and natural ventilation, the shape of the building is likely to be different from the traditional square shape [2].

To reduce the wind load, most buildings are cylindrical. To use more natural light, most of the buildings may have uneven floors. The special appearance of buildings leads to more difficulties in structural design and construction drawing [3]. In the face of increasing large building volumes and increasingly cooperative design units, the existing technical means have been unable to meet the needs of the market. There are green buildings, which pay attention to the whole life cycle of the building, and there will be information transmission faults with traditional technology [4]. The emergence of BIM brings a dawn to solve the above problems.

BIM is the second information revolution in the construction industry after the comprehensive application of CAD technology in the 1990s.As one of the most emerging technologies in the current construction industry, BIM promotes the technical evolution of the construction industry from two-dimensional CAD to three-dimensional BIM. BIM, as a collection of highly integrated three-dimensional information data, can effectively solve the technical problems such as information transmission fault, large number of repeated modeling work, and poor coordination among different disciplines in the traditional green building design practice. In the structural design, the application diagram of BIM is shown in Figure 1. Therefore, this paper based on BIM computer-aided architectural design optimization research has a positive and important significance [5].

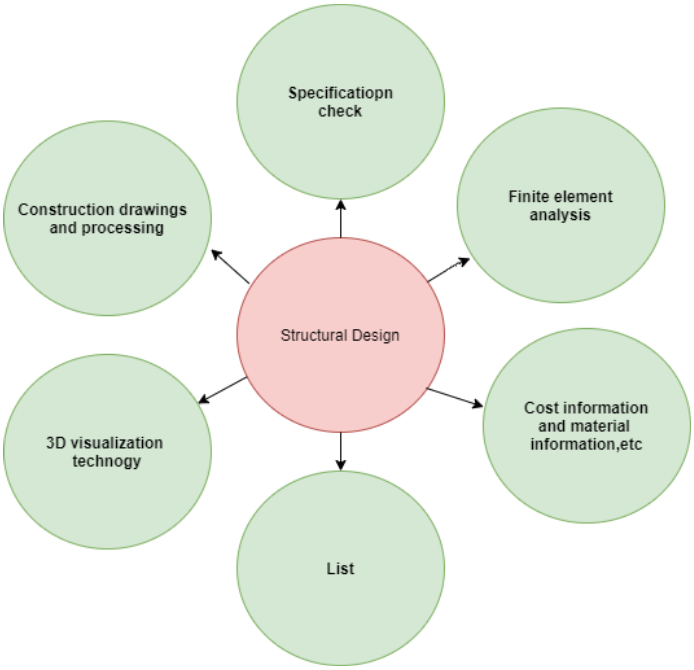


Figure 1: Application diagram of BIM in structural design.

In the Figure 1, certain modules of BIM structural design are enlisted which are as follows: specification checking, finite element analysis, cost information and material information, List, 3D visualization, construction drawings and processing

1.1 Contribution

The innovation of this paper is to use BIM Technology-Based Green low-energy building integrated optimization design process and BIM collaborative design implementation method [6]. The integrated optimization design of building performance prediction model under the three sub-objectives of the building is integrated and optimized, and the building integrated optimization design based on BIM Technology is deeply studied [7].

1.2 Organization

The article is thus organized in the following order. Literature reviews of various techniques and algorithms are detailed in Section 2. Section 3 discusses the Research methods, application and standards based on BIM technology. The lack of BIM application software and its solution .Section 4 discusses about the Results and analysis of BIM technology. Finally, the manuscript is concluded in Section 5.

2 LITERATURE REVIEW

To improve the building performance, experts and scholars have done a lot of research work. A single building energy-saving measures to a variety of parallel implementation of energy-saving measures, building energy-saving undertakings through the limitations of traditional building energy-saving research, and have achieved certain results [8]. The author has analyzed the color, structure, location, size, and other factors of the external window. The research considered that the double glass structure and the green selection of the outer window glass would have the effect of thermal insulation on the building [9]. In this article the influence of moisture level on the energy-saving performance of dry buildings. The results show that the changes of moisture properties in the initial drying process often account for a large part of the total load, which has a significant impact on building energy consumption [10, 11]. In this work a solution is proposed to the problem that the calculation of building envelope in building energy consumption analysis is limited, which requires developers not only to optimize the performance of the application, but also to optimize the energy consumption, to realize the estimated performance and energy consumption in one program as much as possible [12].

Researcher has proposed an optimized control system, using an improved genetic algorithm to reduce building light energy consumption. The results show that according to the environmental impact, the building lighting energy consumption can be reduced by 25-32% [13, 14]. In this article conducted a case study on HVAC (heating, ventilation and air conditioning) commissioning of new buildings, and compared and analyzed the design energy consumption and the calculated energy consumption [15]. Through the research, it is proved that under the condition of reducing the performance gap, the suggestions of energy saving and consumption reduction can be put forward through the commissioning of HVAC [16]. This work has studied the energy saving potential of building envelope design and actual operation optimization. The results show that the heating energy consumption index specified in the latest energy efficiency standard of Tianjin is still 30.9% higher than that of EnEV in 2009 and 49.7% higher than that of the passivhaus standard [17, 18].

Author has proposed the calculation and optimization process of building energy conservation in the early stage of architectural design through extensive research [19]. This paper has established a multi-objective optimization design model based on multi-objective optimization algorithm and genetic algorithm to improve indoor thermal comfort time and reduce building load [20]. The research has started from the optimization of outdoor thermal environment of urban residential areas, and based on parametric design and multi-objective optimization algorithm, carried out the green optimization design of urban residential areas. This work has studied how to use interpolation weather data to improve building energy simulation calibration to determine the site meteorological parameters of building location [21]. The article has proposed a simple method to reduce the energy consumption of air treatment units suitable for commercial buildings.

According to the fan Affinity Law, the time control program of multistate operation is used to reset the pipeline pressure value, and the considerable energy consumption is obtained [22].

There is various research gaps in the literature reviewed, due to the complexity and unpredictability of the building in the long operation cycle. The limitation also lies because of the energy consumption of the building in the life cycle becomes complex. The difference between traditional and BIM based electrical system design. Is shown below in the Figure 2 which illustrates how manual exchanging of data takes place by incorporating CAD drafting and electric design studies to give the output as BIM tool capable to do drafting calculation analysis and planning in single platform. These limitations are being addressed in this article to overcome the challenges of traditional and BIM based electrical system design and propose new computer-aided designs for feasible performance.

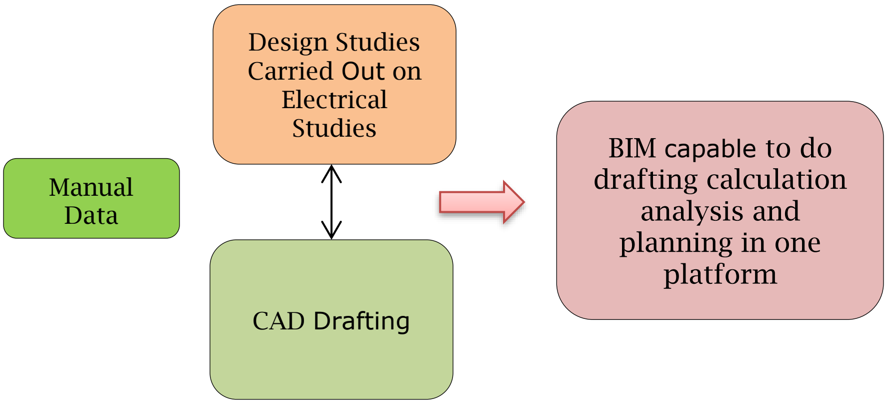


Figure 2: Difference between traditional and BIM based electrical system design

3 RESEARCH METHODS

3.1 Application of BIM in Green Building Design

As far as the traditional design mode is concerned, the records of data and information are arbitrary, and there are differences in professional types. In many cases, the specific definition will not be carried out. Therefore, in the actual process of conversion from design to simulation, it is necessary to re-establish the model and manually input the obtained parameters, which makes it difficult to guarantee the quality of work and improve the efficiency of work. In this mode, the building performance analysis, especially the energy consumption analysis, is difficult to be changed according to the energy consumption analysis data after the scheme is completely determined. Therefore, the building performance analysis has become a form and has little effect on building energy conservation. It blindly increases the energy-saving technology to achieve the goal, which will increase the construction cost, which is not conducive to the sustainable development of the building in the later period. After the application of BIM Technology, in an ideal state, the relevant parameters can be directly stored in the BIM model as information. Through the professional data exchange model similar to GXML (Guideline extensible Markup) and DXF (Drawing Interchange Format), the ecological simulation software can extract the corresponding parameters from the model, which greatly simplifies the process of ecological simulation analysis and improves the work efficiency [23].

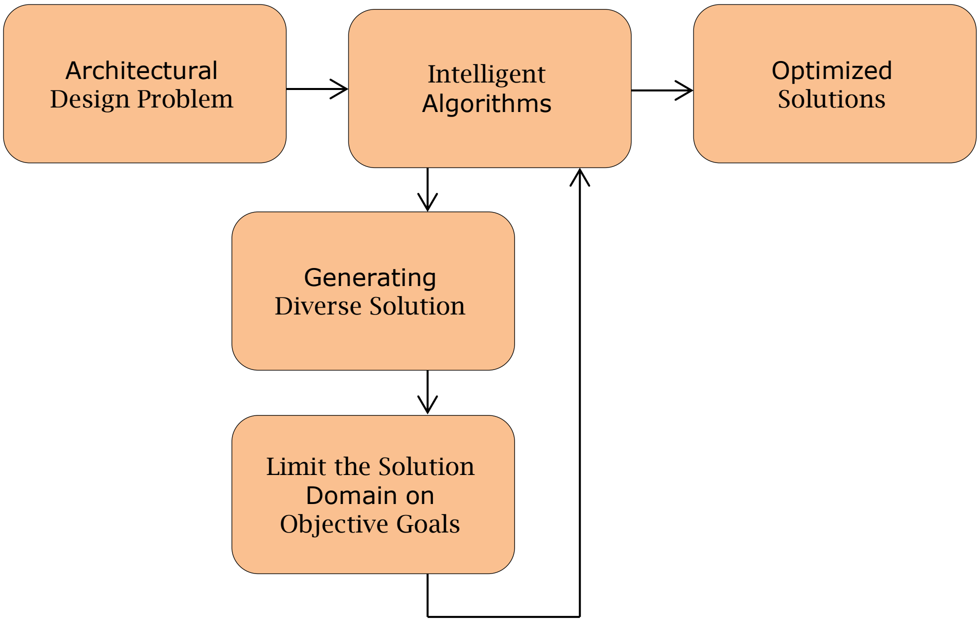


Figure 3: Computer-Aided Design (CAD) workflow.

3.2 Optimization Process of Genetic Algorithm

The main operations of genetic algorithms include selection, mutation, and crossover. Among them, selection refers to obtaining suitable individuals from the previous generation population according to the fitness value of different individuals with the help of specific means. When multiple functions (FX) are solved in the corresponding value range U (X1, X2, Xn) the genetic algorithm can be used to solve the problem. Generally, there is a contradiction between the solution sets y (one Xi maximizes one FX and the other FX minimizes the other). No Xi in the value range can make all FX optimal, but there will be a series of values at a certain edge. These solution sets are Pareto optimal solutions. The basic mathematical model of multi-objective improvement and perfection problem is: if XRm is a constraint set of multi-objective optimization model. X1 is more accurate and reasonable, then the Pareto optimal solution of X1 multi-objective optimization model can be solved [24]. It was the parametric modeling and recent advances in using intelligent optimization algorithms without knowing computer coding that generated a new wave of research. Rigorous researchers continued contribution to this field in recent years

3.3 Building Scheme Decision Model Based on BIM Genetic Algorithm

The building energy consumption and physical environment performance are largely affected by the building scheme decision, mainly due to the gradual reduction of the space for the improvement and perfection of building and energy conservation and physical environment during the design process. In this scheme design, we not only consider the energy consumption, indoor comfort, and other single objectives, but also comprehensively consider the influence relationship between the objectives and the parameters including the exterior enclosure system of windows and walls, so that the parameters can meet the requirements of multiple objectives at the same time, which requires the optimization design under multi-objective. The influence design of an architectural scheme refers to the mutual dependence and mutual influence of multiple influencing factors, and the overall design of the building can be optimized by comprehensive consideration.

3.3.1 Selection of architectural scheme design parameters

The main research objects are building energy consumption under thermal comfort, natural lighting under light comfort, and natural ventilation under wind comfort. In the multi-objective optimization design of buildings, it is necessary to sort out and analyze the influencing factors of architectural design that are compulsory in designing the smart city in future as well.

Building Influencing Factors	Thermal Comfort	Light and Comfortable	Wind is Comfortable	Coupling Effect
Building Towards	√	√	√	√
Building Size	√	√	√	√
Open Area of Transparent Envelope	√	√	√	√
Transparent Envelope Material	√	√	-/-	√
Non-Transparent Envelope	√	-/-	-/-	-/-
Window Wall than	√	√	√	√
Sky Angle	-/-	√	-/-	-/-

Table 1: Selection of influencing factors of architectural design.

It can be seen from Table 1 that the building orientation, size, opening area of the transparent enclosure structure, window to wall ratio, and other factors are the key design elements to be considered in the process of building optimization design. The building orientation is generally selected randomly within 360 degrees, from which the optimal orientation is selected. The building size is limited by the length-width ratio of the building site, and there is also a selected bottom area. Although the physical performance of the enclosure structure whether transparent or nontransparent enclosure is less related to the indoor natural ventilation comfort. However, the significant influence factors of indoor thermal comfort and natural lighting comfort are strong, so this is taken as the key factor in the design, that is, the optimization factor.

3.3.2 Design optimization process

In Genetic Algorithm process of multi-objective optimization the determination of fitness function and population is analyzed. Fitness function is the survival environment of genetic algorithm simulating natural selection. Generally, the prediction model or the model after deformation is taken as the fitness function, and the three functions that have been set are directly used in this paper. The size of the population generally determines the quality of the optimization results. Some experts suggest that the selection range is 20 ~ 200.The classical parallel selection method is used to generate the initial population, and then the genetic process is calculated until the optimal boundary is calculated.

3.3.3 Optimization prediction model

Three objective functions are established from three aspects of building energy consumption, natural lighting, and natural ventilation. Through genetic algorithm and energy consumption software, the building integrated design optimization under several optimization variables, such as building orientation, envelope heat transfer coefficient, and transparent enclosure opening area material, is carried out, so that the building design scheme can meet the requirements of natural ventilation and lighting, and meet the building energy saving. The objective function is as follows:

$$MinF(x) = \begin{Bmatrix} \min F_{energy}(X) \\ -\max F_{lighting}(X) \\ -\max F_{ventilation}(X) \end{Bmatrix} \tag{3.1}$$

The optimization algorithm is the genetic algorithm toolbox in MATLAB to calculate the non-dominated sorting genetic algorithm. However, it is difficult to use the genetic algorithm toolbox to set some parameters in the objective function, so we choose some programs to write and call the GA (gamultiobj) function in MATLAB to solve the multi-objective genetic algorithm.

4 RESULTS

4.1 A Project Case Study

The project is located in a primary school in Kunming. The building is a two-story frame structure with a total building area of 394M2. Assuming that the research object of the architectural design scheme is a rectangular building, the length and width of the building are a, and b, the first floor height is 4.2m, and the second floor height is 3.6m. The North window opening of the building is AG1, the south window opening of the first floor is AG2, and the north window opening of the second floor is AG3.The opening area of the south window on the second floor is AG4, the building faces north by East 14 degrees, the wall is made of 200 mm thick aerated concrete block, the window is plastic steel window, the heat transfer coefficient of the window is 2.73w/m2, the day lighting transmission ratio is 0.35, and the roof waterproof grade is grade II.

4.2 Design Parameter Selection and Scheme Determination

4.2.1 Initial design scheme parameters:

The window-to wall ratio in the south and north directions is 0.17. The ordinary rectangular single-layer window is used for day lighting windows. The heat transfer coefficient of the window is 3.20, the transmittance is 0.55, and the heat transfer coefficient of the wall is 1.10. The roof structure is 40mm reinforced concrete + 0.8mm asphalt felt + 2mm waterproof layer + 20mm cement mortar + 30mm cement expanded perlite + 120mm reinforced concrete. The external wall structure is: 20 mm cement mortar + 20 mm thermal insulation mortar + 200 mm aerated concrete block + 20 mm cement mortar plastering. Ecomat, a plug-in of Ecotect software, is used to calculate the heat transfer coefficient of building exterior wall, roof and transparent enclosure windows.

4.2.2 Parameter setting of multi-objective optimization design

The selected research object does not include the air conditioning system, only the solar radiation load and conduction load are calculated. The optimization model of building scheme design under the three objectives of building energy consumption, natural ventilation, and natural lighting, the selection of influencing factors of building scheme design is carried out as shown in Table 2 and Table 3.

Parameter	No. Of Calculations	Rate	Mutation Rate	Indoor Temperature	Relative Humidity	Air Conditioning Hours	Mean Internal Surface Reflection Ratio	Terrain Parameters K/A
Values	20000	0.80	0.01	22℃	50%	10	0.75	0.21/0.33
Parameter	Tph	Tpc	Tth	Ttc	FPS_1	FPS_7	KC	SC
Values	0	28	5	22	0.47	0.38	1.0	0.51
Parameter	East	West	South	North	East	West	South	North
Values	4.13	4.13	4.39	1.14	7.5	7.5	3.62	3.37
Parameter	East	West	South	North	Cd	-/-	-/-	-/-
Values	5.77	5.78	8.3	10.99	0.65	-/-	-/-	-/-

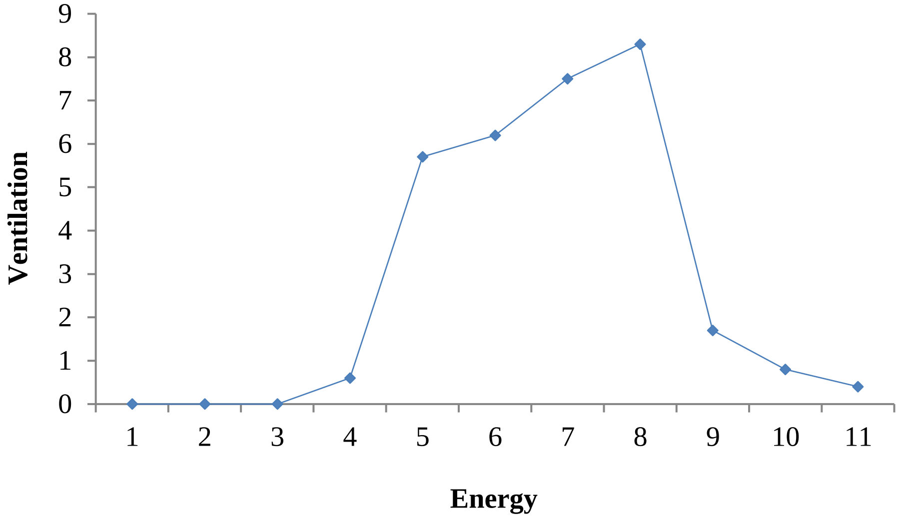
Table 2: List of basic parameters.

4.3 Building Model Calculation

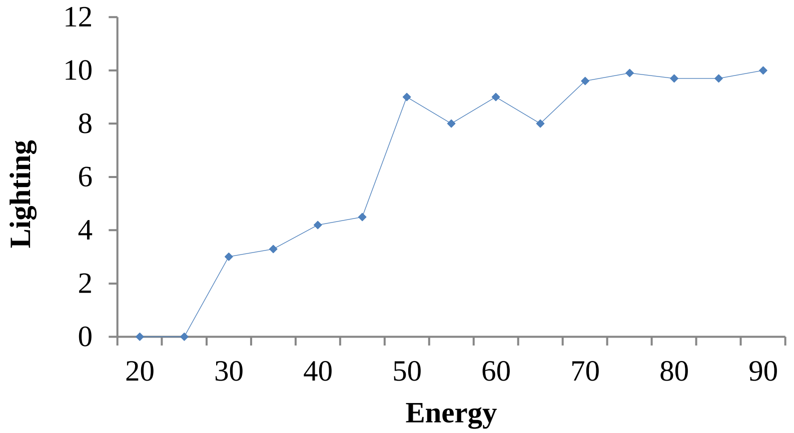
According to the target prediction model, the Pareto Diagram of the spatial optimal boundary formed by three objective functions of building energy consumption, natural lighting, and natural ventilation is shown in see Figure 4. The building scheme generated by the target prediction model is a solution set, not a scheme. It is necessary to select the 70 generated schemes according to functional requirements or preferences, and carry out further design according to other requirements. Some schemes in Pareto solution are listed as shown in Table 4. After the integration and optimization, the minimum building energy consumption is taken as the most important selection basis. Therefore, the value of influencing factor of No. 7 is selected as the final scheme in the scheme stage.

Optimize parameters	Humanly scaled mouth AG1(m2)	Humanly scaled mouth AG2(m2)	Humanly scaled mouth AG3(m2)	Humanly scaled mouth AG4(m2)
Values	0.2≤2*AGi/(a*H)≤0.8			
Optimize parameters	External wall heat transfer coefficient (k1)	Roof heat transfer coefficient (k2)	Heat transfer coefficient of outer window (k3)	Transmission ratio of exterior window (r)
Values	k1≤1.5	k2≤1.1	k2≤5.5	0.28,0.35,0.40,0.48,0.55,0.66,0.77,0.83

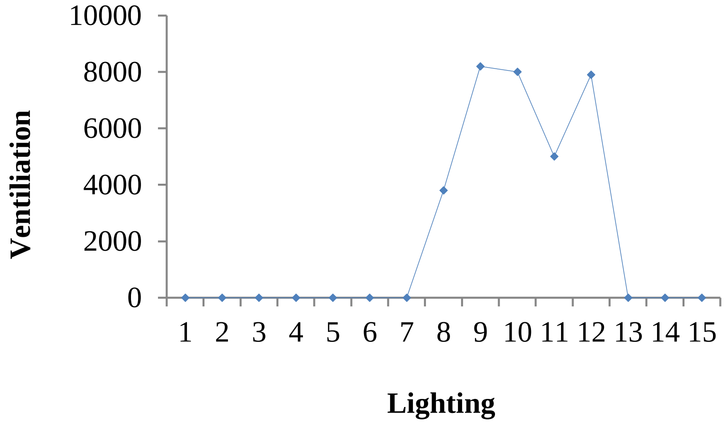
Table 3: List of optimization parameters.



(a)



(b)



(c)

Figure 4: Short, centered caption, terminated with a full stop Pareto optimal boundary of case design optimization in (a), (b), and (c).

Ag1 (m^2)	Ag2 (m^2)	Ag3 (m^2)	Ag4 (m^2)	K1	K2	K3	t	Energy Consumption	Natural Lighting System	Coefficient of Natural Compression
23.3	29.5	22.2	35.2	0.52	0.69	3.09	0.40	6931	4.80	5552
23.8	33.2	17.9	29.4	0.57	0.83	2.93	0.55	6919	6.25	6675
25.2	43.0	14.5	36.1	0.58	0.68	3.06	0.55	6547	7.11	6457
23.7	46.2	17.2	30.7	0.66	0.72	2.97	0.48	5951	6.16	6058
23.5	39.5	22.3	36.7	0.52	0.69	3.12	0.55	5824	7.30	6154
27.5	26.8	24.4	24.4	0.65	0.79	2.70	0.77	5847	8.64	6753
23.3	43.2	24.2	45.6	0.53	0.68	3.07	0.48	5580	5.56	6453
23.5	31.2	17.0	40.1	0.57	0.72	3.04	0.55	5953	6.70	6384
23.6	30.1	12.3	38.0	0.55	0.68	3.08	0.48	5956	5.44	6542
23.5	43.6	16.2	36.5	0.54	0.72	2.97	0.48	5951	6.26	6182

Table 4: Pareto solution list.

The calculation results show that the building energy consumption is 5580kw-h, the average day lighting coefficient is 5.56%, and the natural compaction hour is 6543h. The influencing factors of No.7, the energy consumption was verified by Ecotect software. Figure 5 then shows the variation of humanly scale with lighting system. Through simulation analysis, the energy consumption calculation result is 5803.5kw-h, and the error value is 4%, which is acceptable. Figure 6 shows the variation of heat transfer coefficient with the lighting system. The building energy consumption of the initial design scheme is 6671kwh / M2, the day lighting coefficient is 5.14%, and the natural pressure PA hour is 5891h.

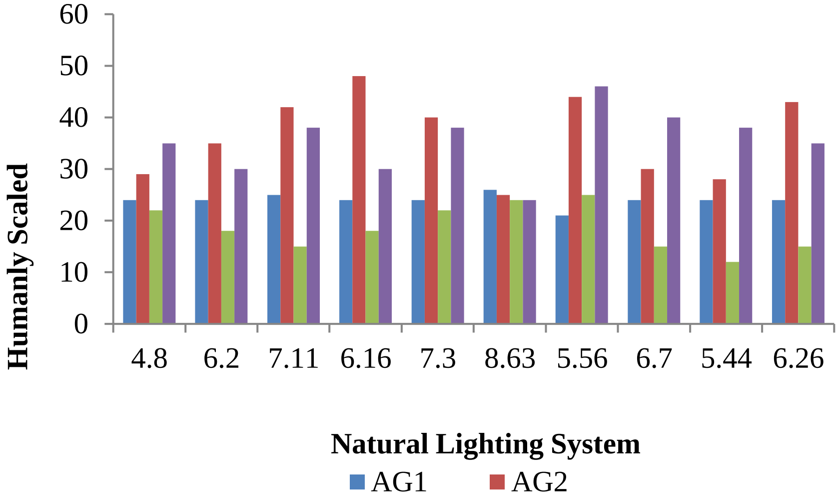


Figure 5: Variation of humanly scale with lighting system.

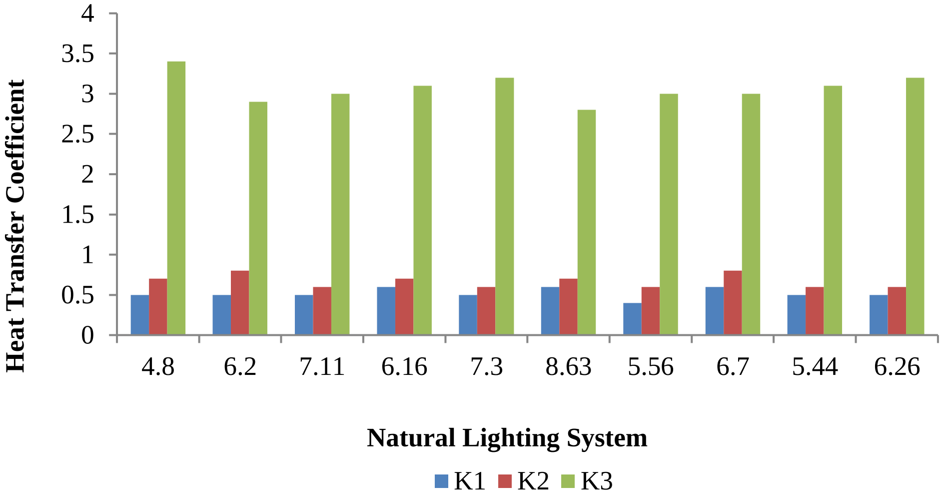


Figure 6: Variation of heat transfer coefficient with lighting system.

In general, the multi-objective optimization of building integrated design scheme makes the building energy consumption lower, the natural lighting and natural ventilation effect are improved, which reflects the advantages and design effect of building integrated design. The percentage improvement of the proposed technique is depicted in Figure 7.

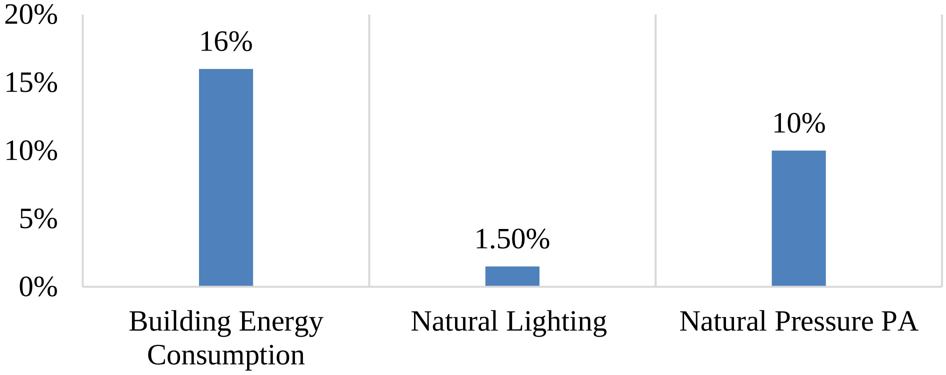


Figure 7: Percentage Improvement using Optimization Scheme.

Compared with the optimized scheme, the building energy consumption is reduced by 16%, the natural lighting is increased by 1.5%, and the natural pressure PA hour is increased by 10%. In this article, the calculation steps and principles of genetic algorithm are discussed. The design indexes of different exterior envelope structures which have significant influence on different objective functions are summarized and studied. Taking a small two-story frame structure building as an example, a genetic algorithm is used to optimize the design parameters of the external enclosure structure in the scheme stage. The computer software of Revit and Ecotect is used to compare the calculated structure with the initial scheme, which reflects the application advantages of genetic algorithm in the scheme design stage.

5 CONCLUSION

This paper mainly summarizes the problems existing in China's construction industry and the research status of low-energy buildings, this paper systematically studies the BIM Technology of building an information model. Building integrated design mode based on BIM Technology, single objective building energy consumption optimization and multi-objective building scheme optimization. Based on the three sub objectives of energy saving, indoor ventilation and sunshine comfort which should be considered most in building designs. In addition to the indoor use function of green low-energy buildings, the improved simplified model of temperature and frequency method, average natural lighting, and natural pressing hours are selected. The opening and transmittance of the window system, the sky shielding angle, and the wall heat transfer coefficient are defined as optimal variables. By means of the genetic algorithm, the Pareto optimization boundary is obtained and the optimal scheme is established. Taking a public building with two-story frame structure in Kunming as an example, the values of architectural design parameters and the range of optimization parameters are determined. The Pareto boundary model selected by optimization is compared with the initial scheme, and the results show that the three sub-objectives i.e. energy saving, indoor ventilation and sunshine comfort are improved. Compared with the optimized scheme, the building energy consumption is reduced by 16%, the natural lighting is increased by 1.5%, and the natural pressure PA hour is increased by 10%.

6 FUTURE SCOPE

The advent of BIM architecture information age, there is not enough research on the integrated optimization design of buildings based on BIM Technology. The advantages of BIM technology, such as collaboration and visualization, are helpful to the integrated design of buildings. It is necessary to conduct in-depth research using a large number of practical experiences and theoretical knowledge. Green and low energy consumption design is a complex system integrating in planning, architecture, thermal engineering, and other disciplines. It is necessary to systematically summarize and discuss on the premise of a large number of all-round architectural practices and knowledge theoretical systems. At present, although a large number of researchers are carrying out the analysis experiments at the level of improvement and perfection, and have obtained certain research and analysis results, they still face many problems there is a scope of BIM technology to imbibe here. The multi-objective and single objective design of the genetic algorithm is implemented, and the number of parameters is also very limited. In the future, further research and analysis should be carried out from the aspects of architectural design stage and architectural form.

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