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Construction of Building an Energy Saving Optimization Model Based on Genetic Algorithm

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ABSTRACT

The building envelope structure is the cause of a major part of energy consumption, with exterior walls and windows being the main energy-consuming components. Traditional building energy conservation measures often overlook the demand for human comfort, especially in areas characterized by hot summers and warm winters. For this paper, the authors concentrated on indoor comfort, with a focus on optimizing the heat transfer coefficient of windows and exterior walls using a genetic algorithm. They used a genetic algorithm to explore the performance optimization of exterior walls and windows in the enclosure structure. To aid this effort, they constructed a building energy-saving optimization model. In addition, they created an optimization model in an attempt to reduce building energy consumption. They took the heat transfer coefficients of the outer window and the outer wall as the optimization parameters of the established model, and they compiled the optimization program using MATLAB. The experimental results showed that the heat transfer coefficients of exterior walls and windows in cold regions are 0.4459 and 2.7875, respectively, while the heat transfer coefficients in warm winter and hot summer regions are 0.66, 1.98, 1.026, and 1.59. The conducted work provides a reference for the optimization design of the heat transfer coefficient of external walls and windows as a measure to enhance building energy efficiency.

KEYWORDS

Building Energy Conservation, Enclosure, Genetic Algorithm, Thermal Comfort

INTRODUCTION

With the improvements on the socio-economic level, the modern construction industry has exhibited major development. The construction industry accounts for a large proportion of China's overall energy consumption, which is also continuously increasing. This consumption has a huge negative impact on the national economy. Sustainable development is not only the future direction of the construction industry but also a sustainable development direction to establish an energy-efficient construction industry. With advancements on the socioeconomic level, a contradiction emerges between building energy consumption and the indoor thermal adaptability of humans. In this regard, building energy requirements should be scientifically and reasonably reduced while meeting indoor

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comfort. On this basis, the energy-saving issues of buildings should be considered based on their inherent thermal behavior and through full use of pollution-free energy-saving and environmental protection measures such as solar energy and natural ventilation. In addition, it is indispensable to achieve energy savings and consumption reductions for air-conditioning, refrigeration, and heating. Building energy efficiency not only reduces energy consumption but also involves using local materials as energy-saving materials. This approach will reduce shipping and building costs, strengthen the performance of the enclosure structure, improve the efficiency of solar energy use, and achieve building energy conservation. When considering building energy efficiency, architects should reflect its effectiveness indicators in the overall planning and design of the building. These measures include the thermal indicators of the enclosure structure and the CO_2 emissions throughout the building's life cycle. Published literature demonstrates very well that choosing appropriate building materials can effectively reduce building energy consumption. At present, the energy-saving potential and impacts of buildings in China are not so good as those in developed countries. The indoor thermal comfort is also not satisfactory. Therefore, effectively implementing building energy conservation measures in China is imperative. Because genetic algorithms have better global search function and lower auxiliary information requirements, this study analyzes the optimization measures of building energy conservation through genetic analysis of algorithms.

In the experiment we conducted, the heat transfer coefficients of the exterior windows and exterior walls of the building envelope were taken as variables in the building energy conservation model. We then compiled the main optimization program and subprograms using MATLAB. We used a genetic algorithm to study the optimized building energy consumption, average number of votes predicted mean vote (PMV), and building envelope structure cost. In the process of building enclosures, the heat transfer coefficient of exterior walls in different areas is the lowest, and the absolute heat transfer coefficient of the enclosure structure is the lowest. In addition, the heat transfer coefficient of external windows and walls can provide some references and guidance for the optimal design of building energy conservation measures in cold regions and warm winter and hot summer regions. This information will also be beneficial for the research and implementation of building energy-saving models. Cao et al. (2017) studied and reported the corresponding meteorological parameters of different climatic regions; they researched meteorological factors that represent the foundation for the energy conservation design of buildings and the corresponding air-conditioning system operation. By investigating outdoor microclimate mitigation, Castaldo et al. (2018) designed a multiscale, microclimate improvement method and carried out microclimate simulations of the building's thermal behavior in local areas. Based on their obtained results, they reported that inter-building scale analysis can reduce the impact of microclimate on building energy consumption (Castaldo et al., 2018). Berardi et al. (2017) demonstrated that phase change materials can be applied to allow heat capacity enhancement for building envelopes to reduce the cooling needs of buildings and improve indoor thermal comfort. Kim et al. (2017) also found that efficient HVAC equipment and fluorescent lighting systems can effectively cut energy use in complex and large buildings.

In the rest of this paper we elaborate on the background and needs to scientifically and reasonably reduce building energy consumption, while meeting indoor comfort requirements; describe the research methods and achievements of the implemented genetic algorithms and building energy efficiency impacts; discuss our construction of energy-saving models for buildings and their surrounding structures; introduce the variation in various indicators as a result of optimizing building energy efficiency; and share our research results related to building envelope structures and building energy efficiency. We also summarize the shortcomings and added value of our research and provide prospects and perspectives for future development and examination.

The innovation of this study lies in improving the traditional building energy-efficiency models currently in use. In the construction of a building's energy-saving models in this study, we considered both human comfort and air-conditioning energy consumption. In this regard, building energy consumption and indoor human comfort were evaluated and discussed. This study takes the cost of building structure maintenance as the optimization goal of the building's energy-saving design. This optimization direction can be used as a reference for architects to aid in building energy-saving designs. Another innovation in the current research is the selection and implementation of the research methods. In this experiment we used the advantages of genetic algorithms in global search in addition to the genetic evolution characteristics of "survival of the fittest" to effectively analyze the indicators in building energy conservation.

RELATED WORK

According to the specific characteristics of different climatic regions in China, Ma et al. (2016) introduced practical, cost-efficient passive and active energy conservation strategies to aid the transformation of office building energy-saving technologies in cities; then after comparing the energy consumption and the operation cost before and after the transformation, these researchers notes a significant reduction in the building's energy consumption. Promoppatum et al. (2016) implemented staggered cross-flow heat exchangers containing phase change materials for building construction. These structures can absorb heat from the heating flow of the building HVAC and subsequently discharge it to the cold atmosphere of the building. Ma et al. (2016) considered a solar air collector implemented into the building wall and found that the collector achieved a reduction in the building heating load by preheating the air.

Furthermore, Mahoney et al. (2019) used genetic algorithms to study the operation and environment of plants during restoration. Bhola et al. (2020) studied the optimization of wireless sensor networks and introduced an optimization genetic algorithm. They used the fitness function of the algorithm to find the optimal path (Bhola et al., 2020). In their work, Abbasi et al. (2020) introduced a multi-objective genetic algorithm into the propagation delay between fog equipment and cloud in the Internet of Things (IoT). They found that the load allocation algorithm in the fog cloud scenario improved energy consumption and reduced the delay of the IoT system (Abbasi et al., 2020). In another study, Sun et al. (2020) used a genetic algorithm to envisage the automatic architecture of a convolutional neural network in the process of studying and solving the problem of image classification. Examining the fossil energy-saving issue, Yokose et al. (2020) addressed the minimization problem of joint energy expenditure by employing a nonlinear friction robot based on the genetic algorithm. They combined a genetic algorithm with a gradient algorithm for fast seeking of the global optimal solution in a large range (Yokose et al., 2020).

In the process of studying the operation of HVAC systems, Nasrudin et al. (2019) investigated secondary water chiller optimization by combining a multi-objective genetic algorithm with an artificial neural network. They considered parameters related to the passive solar design, the chiller control system, and thermostat settings as decision variables. Moreover, they selected the dissatisfaction rate and the yearly building energy consumption as objective functions to optimize the HVAC system (Nasruddin et al., 2019). In another study, Almalaq et al. (2019) analyzed the specific variation in the building energy consumption under different algorithms, including load forecasting, energy mode analysis, regional energy consumption, and building energy saving scheme formulation. As demonstrated in different reports, in light of the modern trend for low-energy and net-zero energy buildings, the end user must take an active role in achieving high levels of efficiency without compromising comfort or productivity (Karatzas et al., 2021). End-user behavior is a determinant that indirectly or directly affects energy utilization (Menon, et al., 2019). This behavior includes window closing or opening; lighting deactivation, activation, or diminishment; and deactivation and activation of office facilities, heating systems, and air-conditioning systems.

Considering the research of different scholars all around the world, we note that there obviously are many studies on genetic algorithms, multi-objective optimization (MOP) algorithms, and building energy conservation measures. However, not enough experiments have been completed to be able to combine them into a coherent evaluation. Nevertheless, the genetic algorithm-based research of energy conservation model creation for buildings can aid in accurately finding out the parameters affecting the energy savings of buildings. In this regard, the energy conservation optimization model for buildings can be established according to the impact of every parameter optimization on the building's energy conservation.

BUILDING ENERGY-SAVING OPTIMIZATION MODEL

Analysis of Building Energy Consumption and Building Envelope

In general, the building shape coefficient and the actual building orientation, as well as the building envelope properties and specifications, influence actual building energy consumption. The building envelope expends about 57%–77% of heat, accounting for the largest proportion of the building's heat consumption. Table 1 details the breakdown of the heat consumption in buildings in three representative areas.

As shown in Table 1, consumption accounts for around 22% – 37% of the overall building heat consumption. In view of this information, attention should be paid to the design and function of the envelope in reducing energy consumption and sustaining comfortable indoor areas during the establishment of a building energy-saving optimization model. According to the PKPM software package, the heat consumption of buildings can be expressed as shown in equation (1).

$$q_H = q_{HT} + q_{INF} - q_{HI} = \frac{\left(t_i - t_0\right)\left(\sum_{i=1}^{m} \varepsilon_i k_i F_i\right)}{A_0} + \frac{\left(t_i - t_0\right)\left(c_p \rho N V\right)}{A_0} \tag{1}$$

Table 1. Composition analysis of building heat consumption in three representative areas

Region		Severe Cold Area	Cold Area	Hot Summer and Cold Winter		
Maintenance structure heat consumption/total building heat consumption (%)		71	63~78	/	Summer	Winter
					57.2	75.2
Component proportion of heat consumption of maintenance structure (%)	Exterior wall	27.9	23~34	/	18.5	35.4
	Window	29.5	23~25	/	38.7	39.8
	Ground	3.8	Stairs8	Heat consumption of ventilation/main-tenance structure (%)	74.8	33.0
	Roof	8.8	7~8			
	Door of household	1	2~3			
Heat consumption of air infiltration/ total heat consumption of buildings (%)		29	22~37	Heat transfer and heat transfer energy consumption of windows/total building energy consumption (%)	81.5	64.6
Heat consumption of windows and their air infiltration/total heat consumption of buildings (%)		58.5	45~62	Heat consumption for ventilation/total heat consump-tion of buildings (%)	42.8	24.8

In equation (1), q_H, A_0, N, V, and t_0 represent the building energy consumption index (W/m^2), building area (m^2), air exchange volume (m^3), and outdoor mean temperature in the course of heating (°C). In addition, the unit area consumption of air infiltration heat (W/m^2), building interior gain of heat (W/m^2), and heat consumption through the enclosure (W/m^2) are respectively represented by q_{INF}, q_{HI}, and q_{HT}. The enclosure area F_i (m^2) and the air exchange volume (m^3) are also respectively represented by bb, in addition to the heat transfer coefficient k_i (W/m^2 K), correction factor ε_i of the heat transfer coefficient, average indoor calculation temperature t_i (°C), air specific heat capacity c_p (J/(kg ·°C)), and air density ρ (kg/m^3). A functional relationship exists between the building heat consumption q_H and the thermal transfer coefficient K of the envelope structure. In this study we examine the optimal energy-saving building design by assessing the building envelope, such as exterior walls and windows. The expression of the building envelope cost calculation is given in equation (2).

$$\begin{aligned} E &= E_q F_q + E_c F_c + E_{wm} F_{wm} + E_{dm} F_{dm} = \sum\nolimits_{i=1}^{n} E_{qi} F_{qi} \delta_{qi} \sum\nolimits_{i=1}^{n} E_{ci} F_{ci} + E_{wm} F_{wm} + E_{dm} F_{dm} \\ K_i &= \frac{1}{0.908 + \delta_{qi} / 0.041} \end{aligned} \tag{2}$$

The project cost of external walls, the project cost of external windows, the area of external walls, the area of external windows, and the insulation layer thickness in the eastern, western, southern, and northern directions are represented by E_{qi}, E_{ci}, F_{qi}, and F_{ci}, respectively. The heat transfer coefficient of exterior walls is K_i, and the roof area and its engineering cost are respectively expressed by F_{wm} and E_{wm}. Similarly, the ground area and its engineering cost are F_{dm} and E_{dm}, respectively. Note that a functional relationship of fcost (k) exists between the cost of the envelope structure E and its thermal transfer coefficient K.

In addition, human thermal comfort is one of the foremost reasons for energy- saving measures in buildings at this stage. Several factors directly influence human thermal comfort, including the relative humidity, temperature, and velocity of air; mean temperature of radiation; human metabolic speed; and clothing. In addition, it is indirectly affected by the building envelope, room floor position, and room orientation. In this study, we assess the human thermal comfort by considering the PMV as an evaluation index. At a PMV value of 0, the interior thermal environment offers an optimal thermal comfort effect to the human body. When the PMV is in the range of - 0.5 ~ + 0.5, it is considered that a relative comfort is attained in the interior thermal environment.

$$\begin{aligned} & M\left(1-\eta\right) - 3.054\left(0.256 t_{sk} - 3.37 - p_a\right) - 0.0173 M\left(5.867 - p_a\right) \\ & -0.0014 M\left(34 - t_a\right) = \frac{t_{sk} - t_{cl}}{0.155 I_{cl}} = 3.9 \times 10^{-8} f_{cl}\left(T_{cl}^4 - T_{mrt}^4\right) + f_{cl} h_c \left(t_{cl} - t_a\right) \end{aligned} \tag{3}$$

Equation (3) provides the heat balance relationship of a human body, where M and t_{sk} refer to the metabolic rate (W/m^2) and the average skin temperature (°C). The average surface temperature (°C) and the clothing area coefficient (%) of a dressed human body are respectively represented by t_{cl} and f_{cl}. Also, the mechanical efficiency of the human body is represented by η (%), and the convection exchange coefficient is h_c (W / (m2 · °C)). The air temperature (°C) and the clothing's basic thermal resistance (CLO) are respectively expressed by t_a and I_{cl}.

$$\begin{aligned}
&t_{sk} = 35.7 - 0.0275H \\
&E_{sw} = 0.42\left(H - 58.15\right) \\
&M\left(1-\eta\right) - 3.054\left(5.765 - 0.07H - p_a\right) - 0.42\left(H - 58.15\right) \\
&\quad - 0.0173M\left(5.867 - P_a\right) - 0.0014M\left(34 - t_a\right) \\
&\quad = \left(35.7 - 0.0275H - t_{cl}\right)/0.155I_{cl} \\
&\quad = 3.9\times10^{-8} f_{cl}\left(T_{cl}^4 - T_{mrt}^4\right) + f_{cl}h_c\left(t_{cl} - t_a\right) = 0
\end{aligned} \tag{4}$$

Equation (4) is the thermal comfort formula in which the skin surface temperature is TSK, the sweat evaporation loss is ESW, and the net gain of heat by humans is h (W/m^2).

$$\begin{aligned}
PMV = &\left(0.303e^{-0.036M} + 0.0275\right)\left[M\left(1-\eta\right) - 3.054\left(5.765 - 0.007H - P_a\right)\right] \\
&- 0.42\left(H - 58.15\right) - 0.0173M\left(5.867 - P_a\right) - 0.0014M\left(34 - t_a\right) \\
&- 3.9\times10^{-8} f_{cl}\left(T_{cl}^4 - T_r^4\right) - h_c\left(t_{cl} - t_a\right)
\end{aligned} \tag{5}$$

Equation (5) shows the formula for forecasting the mean vote quantity PMV in which the average surface temperature of the dressed body $t_{cl} = T_{cl} - 273.15$ and the net heat gain H = m (1 - η). t_a is an environmental variable, and the atmospheric vapor's partial pressure is P_a. The mean radiation temperature T_r of the environment is expressed as shown in equation (6).

$$t_r = \frac{\sum_{j=1}^{k}\left(F_{nj}t_{nj}\right)}{\sum_{j=1}^{k}F_{nj}} \tag{6}$$

In Equation (6), the area and temperature of each surface of the surrounding structure are respectively expressed by F_{nj} and t_{nj}. The calculation expression of the temperature T at the envelope internal surface is then shown in equation (7).

$$t = t_a - k\left(t_a - t_w\right)/\alpha \tag{7}$$

In this equation, t_a and t_w respectively represent the indoor and outdoor temperatures. The thermal transfer coefficients (W/m^2) for the envelope are k and α, respectively. In addition, equation (7) assumes that there is a functional relationship of fheat (k) between the PMV and the envelope structure's thermal transfer coefficient K.

Construction of the Building Energy-Saving Optimization Model

To build a reasonable optimization model for building energy conservation, we adopted the genetic algorithm and the MOP algorithm. In the implementation, the genetic algorithm involves the coding method, generation of the first-generation population, fitness function, crossover and mutation, termination principle of the algorithm, and other stages. In turn, the fitness function includes a direct transformation method and a boundary construction method. In the direct transformation method, $Fit\left(f\left(x\right)\right) = -f\left(x\right)$ is established in the boundary construction approach in case the objective function is a minimization problem. On the other hand, $Fit\left(f\left(x\right)\right)=f\left(x\right)$ is established in cases where the objective function is a maximization problem. When the objective function for the optimization problem is a maximization problem, there is $Fit\left(f\left(x\right)\right)=\begin{cases}f\left(x\right)-c_{\min}\ ,\ f\left(x\right)>c_{\min}\\ 0\end{cases}$.

When the function is a minimization problem, there is $Fit\left(f\left(x\right)\right)=\begin{cases}c_{\max}-f\left(x\right),\ f\left(x\right)<c_{\max}\\ 0\end{cases}$.

Cmax and Cmin denote the maximum and minimum values of the estimation, respectively.

$$\begin{aligned}&\min F\left(x\right)=\left(f_1\left(x\right),f_2\left(x\right),\ldots,f_k\left(x\right)\right)\\&s.t.gi\left(x\right)=0;i=1,2,..,m;x\in\Omega\end{aligned}\tag{8}$$

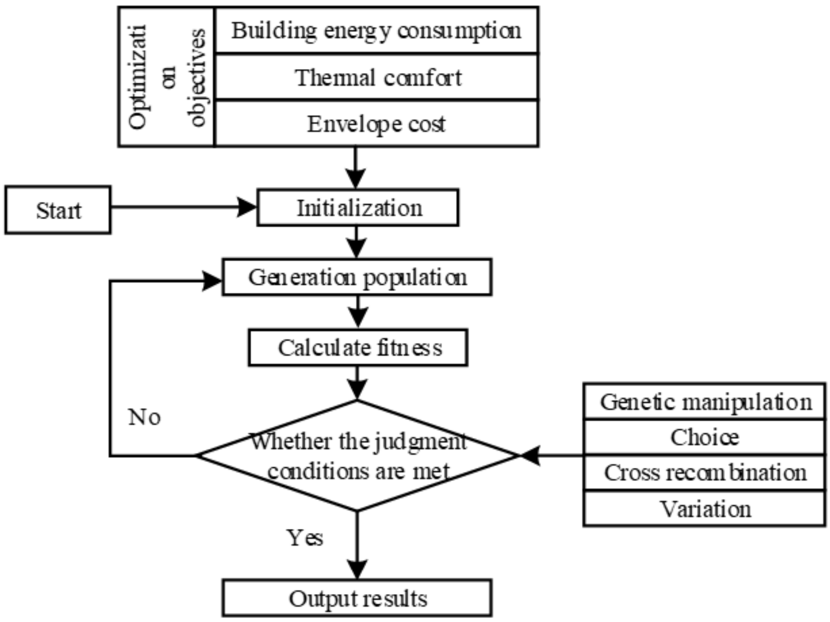
Equation (8) defines the MOP algorithm. The objective function $F\left(x\right)\in R^k$ and X in the decision space belong to the n-dimensional decision variables of Rn, m constraints, and K objective functions. When $x^*\in X$ does not exist $x\in X$, $f\left(x\right)\le f\left(x^*\right)$ or $f\left(x\right)<f\left(x^*\right)$. x^* is the valid solution for the MOP, as well as the Pareto optimal solution. According to the equations (1), (2), (5), (6), and (7), the sub-objective functions of the thermal transfer coefficients of external walls and windows corresponding to the building energy consumption qH, PMV, and building envelope cost e, are respectively established. The sub-objective functions of the three are ferengy (K), fheat (k), and fcost (k). On this basis, the expression of the building energy efficiency model, serving as the main objective function, is shown in equation (9).

$$F\left(K\right)=1/3\,F_{Erengy}\left(K\right)+1/3\,F_{heat}\left(K\right)+1/3\,F_{cost}\left(K\right)\tag{9}$$

Combining the building energy-saving model shown in equation (9) with the genetic and MOP algorithms, we obtained the flow diagram for the building energy conservation optimization model, as shown in Figure 1. In the early stages of architectural design, this article conducts further research on the comprehensive design of building energy efficiency, targeting specific building research objects. The subcomponents of building energy efficiency consisted of building energy consumption, natural lighting, and natural ventilation. We selected the building energy consumption temperature frequency BIN method model. In addition, we chose the natural lighting average daylighting coefficient ADF model and the natural ventilation natural pressure difference time PDPH model as the integrated optimization design prediction models and evaluation indicators. We then combined the NSGA II multi-objective genetic algorithm with the prediction model to characterize and determine the optimization variables and constraints. We adopted the real number encoding strategy and determining selection, cross recombination, mutation strategy, and the maximum evolution algebra as termination conditions in this study.

As shown in Figure 1, the primary optimization targets of the building energy-saving model are energy consumption, thermal comfort, and building cost. In the process of genetic operation selection employing the random ergodic selection method, the crossover recombination rate Px, mutation rate PM, and maximum evolution algebra of the genetic algorithm are determined before starting the optimization. In the cross-recombination step of the main program of the genetic algorithm, the parameters to be optimized are coded by a real number, and individual genes are randomly selected and reorganized discretely. Moreover, in the mutation link, the accurate ranges of different optimization variables are determined. When the maximum evolution algebra is attained by the algorithm, the

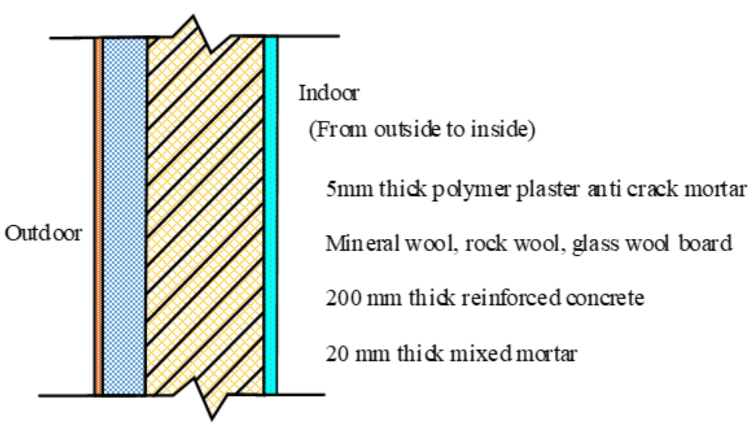
Figure 1. Flow chart of the building energy saving optimization model



calculation is then stopped. To study the application effect and optimization mode of the building energy-saving optimization model in various regions with different temperatures, we conducted an experiment to perform the optimization of the energy conservation model of buildings by assessing external wall thermal insulation materials in the envelope structure in the case of cold regions and regions with warm winters and hot summers. In the optimization process, we took into account the important position of the maintenance structure in the building's energy consumption.

Figure 2 shows the thermal insulation materials of the exterior walls in cold areas, which are often made of mineral wool, rock wool, glass wool board, and other materials. In the selected construction projects in cold regions, the building structure is a shear wall structure with a shape coefficient of 0.36. The building area and volume are 9,903.41 m^2 and 28,719.90 m^3, respectively. The building's surface

Figure 2. Construction composition of the exterior wall in cold areas



area is 10,376.14 m^2 and the building's height is 84.10 m. From indoor to outdoor, the construction levels of the building exterior wall are 5-mm-thick polymer plastering anti-cracking mortar, mineral wool, rock wool, glass wool board, 200 mm-thick reinforced concrete, and 20 mm-thick mixed mortar. The dry density of glass wool board is around 80-100.

Furthermore, Figure 3 depicts the construction composition of exterior walls in a region with hot summers and warm winters. In general, the thermal insulation material in this area is made of glazed bead thermal insulation mortar. In the selected construction project in an area with warm winters and hot summers, the building structure is a shear wall structure with a shape coefficient of 0.36. The building area and volume are 14,831 m^2 and 42,902.63 m^3, respectively. The building's surface area is 17,745.08 m^2 and the building's height is 97.10 m. From indoor to outdoor, the construction layers of the building exterior wall are 20-mm-thick waterproof mortar, 10-mm-thick cement mortar, 200-mm-thick reinforced concrete, 10-mm-thick cement mortar, vitrified micro bead thermal insulation fire mortar, and 12-mm-thick cement mortar.

EXPERIMENTAL DESIGN AND ANALYSIS

According to the function relationships presented above, we compiled three subprograms as a basis for the energy conservation model of buildings: the building energy consumption, thermal comfort, and cost of envelope structure. These three subprograms have similar weight coefficients of 1/3 in the overall model (main program). In other words, the sum of the weights of the three subprograms is the objective function of the genetic algorithm. For the genetic algorithm, its fundamental steps are realized by a code developed in MATLAB. At the beginning of the calculation, the variables of the actual problem are encoded to form the chromosomes. A certain number of individuals are then randomly generated; that is, a population is generated. The fitness values of each individual are then evaluated. After that, the algorithm examines whether the initial solution is the optimal solution through the termination condition, and if so, the calculation of the output result is stopped. If not, a new generation of population is generated through the genetic operator's operation. The fitness values of each individual in the population are then calculated. Afterward, the termination condition judgment is realized again. This process is executed iteratively until the optimization criteria are met, ultimately resulting in the optimal solution to the problem.

Figure 3. Construction composition of exterior walls in hot summer and warm winter areas

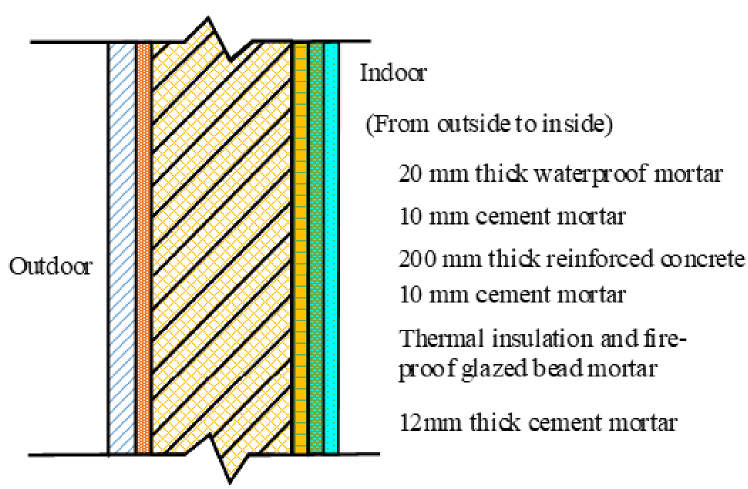


Table 2 lists the optimization parameters in addition to other parameters of the external walls in cold regions. The table highlights that the constraint conditions of K1, the external walls heat transfer coefficient, at gene site 1 is ≤ 0.7. Table 2 also shows that the constraint condition of the heat transfer coefficient K2 for exterior windows at gene site 2 is ≤ 2.8. The data for optimization parameters are adopted from the energy conservation design criteria JGJ 26-2010 for dwelling buildings in cold and severely cold areas. Other external wall parameters considered include wall area, window area, correction factor for wall heat transfer coefficient, outdoor and indoor temperatures, human metabolism rate, water vapor partial pressure in air, air density, heat transfer coefficient for enclosure internal surface, specific heat capacity of air, and the correction factor for exterior window heat transfer coefficient.

Figure 4 shows the variation of various indexes related to building energy efficiency in addition to the optimal solution with iteration times in cold regions. The results include the average value variation for the objective function and the variation of the optimal model solution after 100 iterations. In addition, Figure 4 highlights the average value variation of the building energy consumption, the model solution variation, the absolute value variation for the predicted average vote number PMV and the change of the solution, the average value variation for the cost of the envelope construction, and the solution variation. Note that when the main program carries out 100 iterations, with a K1 coefficient for exterior walls of 0.4459 and a K2 coefficient for the exterior windows of the enclosure structure of 2.7875, a minimum building energy consumption is attained. In this case, the cost of constructing the envelope structure is minimal, and the absolute value of the predicted average vote number PMV attains the minimum. At this time, the building's interior comfort is at its best. According to the iterative results, the appropriate thermal insulation materials and window glass types can be selected. Moreover, the average value of the PMV is 0.702, indicating that the indoor environment is in a relatively comfortable state. After carrying out the parameter optimization, the cost of materials for exterior walls thermal insulation and external windows is found to be 1.095 million yuan. In regions with warm winters and hot summers, to realize building energy savings, reducing the energy consumption of air-conditioning through reasonable architectural design should be considered.

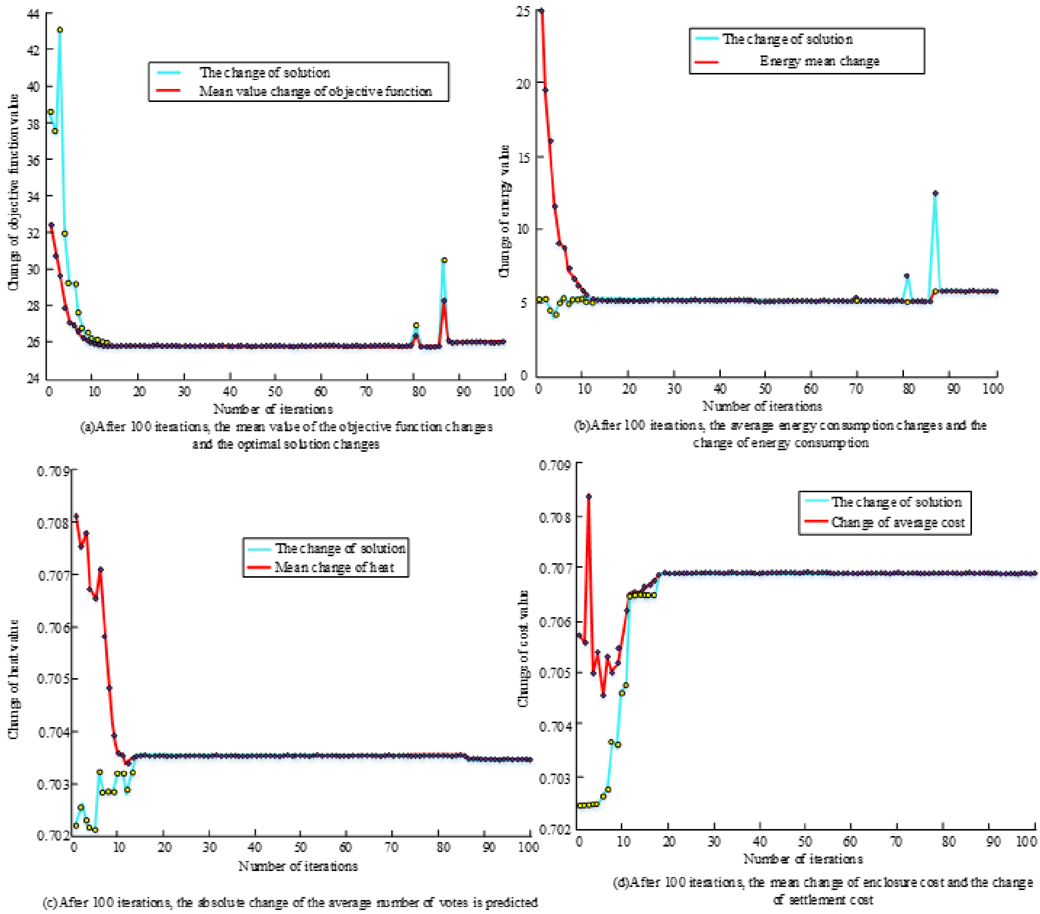
$$\begin{aligned}
BCF_c &= \left[\frac{\left(ECF_{C\cdot R} + ECF_{C\cdot WL} + ECF_{C\cdot WD}\right)}{A} + C_{C\cdot N} \bullet h \bullet N + C_{c\cdot 0}\right] \bullet C_C \\
ECF_{C\cdot WL} &= C_{C.WL.E}\sum_i K_i F_i \rho_i + C_{C.WL.S}\sum_i K_i F_i \rho_i + C_{C.WL.W}\sum_i K_i F_i \rho_i + C_{C.WL.N}\sum_i K_i F_i \rho_i \\
ECF_{C\cdot WD} &= C_{C.WD.E}\sum_i F_i SC_i SD_{c.i} + C_{C.WD.S}\sum_i F_i SC_i SD_{c.i} + C_{C.WD.W}\sum_i F_i SC_i SD_{c.i} \\
&\quad + C_{C.WL.N}\sum_i F_i SC_i SD_{c.i} + C_{C.SK}\sum_i F_i SC_i \\
C_C &= C_{qc} \bullet C_{FA}^{-0.147} \\
ECF_{C\cdot R} &= C_{C\cdot R}\sum_i K_i F_i \rho_i
\end{aligned} \tag{10}$$

Equation (10) provides an expression of the air-conditioning power consumption index, where a, N, and H represent the total building area (m^2), air change frequency (times/h), and floor height weighted average according to the building area (m). The annual power consumption index of air-conditioning is related to roofs, walls, doors, and windows in addition to the air exchange frequency

Table 2. List of exterior walls parameters in cold areas

Gene Locus	1	2
Optimization parameter name	K1 External wall heat transfer coefficient	K2 Heat transfer coefficient of external window
Company	$W/(m^2 \cdot K)$	$W/(m^2 \cdot K)$
Constraint condition	≤0.7	≤2.8

Figure 4. Changes in the enclosure cost, PMV, building energy consumption, objective function, and optimal solution in cold areas



(a)After 100 iterations, the mean value of the objective function changes and the optimal solution changes

(b)After 100 iterations, the average energy consumption changes and the change of energy consumption

(c)After 100 iterations, the absolute change of the average number of votes is predicted

(d)After 100 iterations, the mean change of enclosure cost and the change of settlement cost

and area, indicated by $ECF_{C\cdot R}$, $ECF_{C\cdot WL}$, $ECF_{C\cdot WD}$, $C_{C\cdot N}$, C_{qc}, with $C_{C\cdot N}$ is 4.16. Also, $C_{c\cdot 0}$ and C_C is the relevant coefficient of annual power consumption index, with $C_{c\cdot 0}$ value of - 4.47. The area and heat transfer coefficient (W/(m^2·K)) of each enclosure are given by F_i and K_i. The solar radiation absorption coefficient of each wall surface is ρ_i and the ratio of the total area product of the peripheral protective structure to the total area of the building corresponding to the enclosure is represented by C_{FA}. In addition, the shading coefficient of different exterior doors and windows is given by SC_i, where $SC_{c.i}$ represents the external shading coefficient of different windows in summer.

Table 3 shows the corresponding $C_{C.WL}$ (heavy), $C_{C.WL}$ (light), and $C_{C.WD}$ in the four orientations of south, east, north, and west. Overall, it is shown that $C_{C.WD}$ (heavy), $C_{C.R}$ (light), and $C_{C.SK}$ of all orientations are consistent. According to the correlation coefficient calculated by each air-conditioning power consumption index presented in Table 3, the power consumption by the air-conditioning system, the absolute PMV value, and the building envelope cost structure are considered as three subobjective functions. The corresponding subroutines are compiled to ensure that each subobjective function has a 1/3 weight coefficient. Thus, the sum of the weights of the subprograms

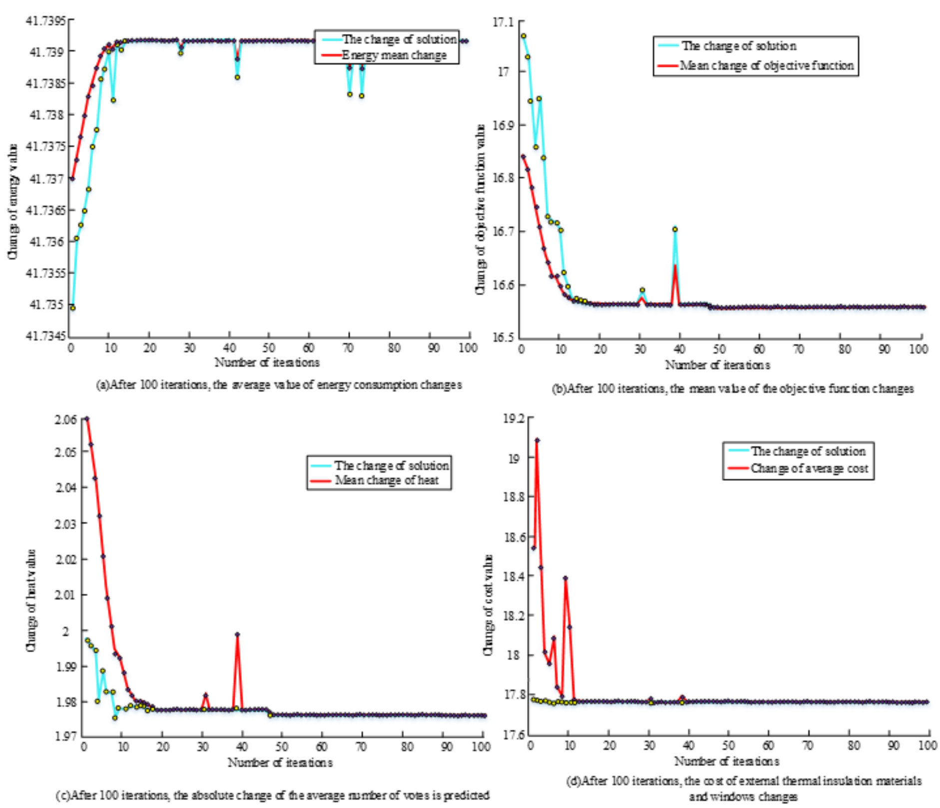
Table 3. Relevant coefficients of air-conditioning power consumption index calculations

Coefficient		$C_{C.WL}$ (Emphasis on Quality)	$C_{C.WL}$ (Light)	$C_{C.W.D}$	$C_{C.R}$ (Emphasis on Quality)	$C_{C.R}$ (Light)	$C_{C.S.K}$
The orientation of the wall	East	18.6	29.2	137	35.2	70.4	363
	South	16.6	33.2	173			
	West	20.4	40.8	215			
	North	12.0	24.0	131			

is the objective function of the genetic algorithm. The main program is compiled to simulate the building's energy-saving optimization. Figure 5 displays the simulation outcomes.

As shown in Figure 5, the heat transfer coefficients corresponding to the four exterior walls with different orientations are as follows: east-facing exterior walls (K1 = 0.66), south-facing exterior walls (K2 = 1.98), west-facing exterior walls (K3 = 1.026), and north-facing exterior walls (K4 = 1.59). The data reported aid in choosing external wall insulation materials suitable for zones where summer is hot and winter is warm. Using such a heat transfer coefficient for the exterior wall, the power consumption of the building hollow regulation is 29.7348W/m^2. In addition, the absolute value of the corresponding predicted average vote number is 1.9, and the aggregate cost of the external wall and window materials in the building envelope is 177,600 yuan.

Figure 5. The change of each index after 100 iterations in hot summer and warm winter regions



CONCLUSION

Energy conservation in buildings is the scientific utilization of building structure, services, systems, and materials to reasonably reduce building energy consumption and operational costs while fulfilling the demand for indoor comfort (Perea-Moreno et al., 2020). With regard to building energy consumption, the heat consumption by the envelope structure occupies the greatest proportion of overall heat consumption in buildings, where heat is mainly consumed on the external walls and windows. In view of this fact, we explored the performance optimization of exterior walls and windows in the envelope structure employing a genetic algorithm. We constructed an energy conservation optimization model for buildings. In the research process, we considered the heat transfer coefficients for exterior windows and walls as the optimization parameters in the created model, and we compiled the optimization program using MATLAB. The results demonstrated that in the cold region, the heat transfer coefficient K1 of the envelope walls is evaluated at 0.4459, while that for external windows is 2.7875. In addition, in regions with a warm winter and a hot summer, the heat transfer coefficient for the building envelope exterior wall is affected by the external wall orientation. In this regard, the external wall coefficient K1 for the east-facing building is 0.66, the external wall coefficient K2 for the south-facing building is 1.98, the external wall coefficient K3 for the west-facing building is 1.026, and that of the north-facing building is 1.59. The obtained data can provide some references for supporting the energy conservation scheme for buildings in different regions. Furthermore, the thermal conductivity of building wall materials represents the heat transfer per unit area and thickness of the wall for every 1-degree difference in temperature between the two sides of the wall. Most of our buildings have a more comfortable indoor environment than the outdoor environment owing to the action of the energy supply systems. Therefore, the more heat that is transferred inside and outside the building, the higher the energy consumption. In this case, the smaller the heat transfer, the smaller the energy supply consumed, and therefore, the more energy savings attained.

Although this study has reported some interesting results and achievements, the discussion about the parameters affecting the energy use and indoor comfort of buildings is still not comprehensive enough. We hope that with the further understanding of knowledge on energy saving and thermal engineering, the creation of more scientific and reasonable energy conservation models for buildings will be possible in the future. Many factors affect the overall goal in the engineering construction domain, including social, environmental, and economic factors. Large and complex projects that require consideration of many complex factors will often not meet the requirements of the users. In the future, other more advanced, robust genetic algorithms may be available that can be applied to address the problems of our old model.

DATA AVAILABILITY

The data used to support the findings of this study are included within the article.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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