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Research on the Reform of Carbon Neutral Education and Innovation of Talent Cultivation Mode in Construction Industry with the Help of Information Technology

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Abstract The development of information technology and the change of global ecological environment have put forward higher requirements for education teaching and talent cultivation in the construction industry. This paper constructs a building performance simulation system and an optimization system based on the multi-objective particle swarm optimization algorithm to optimize the design of green buildings, reduce the energy consumption and cost of the whole life cycle of green buildings, and thus enhance the carbon neutral benefits and economic benefits included in green buildings. Using the optimization scheme of green building design as a technical template, reform the existing architectural design education curriculum, and effectively integrate the optimization scheme into the teaching of architectural design curriculum. The evaluation system of the educational reform of the architectural design curriculum is constructed, and the reform effect is evaluated by using the optimized fuzzy comprehensive evaluation model and the analysis of teaching experiments. The green building optimization program proposed in this paper reduces carbon emissions by 106.2606 kgCO2e per cubic meter per year on average in the operation phase, and at the same time, it has significant economic benefits. The overall effectiveness of the teaching reform based on the green building design optimization scheme is excellent, with high student satisfaction and generally improved grades.

Index Terms green building, carbon neutral benefit, multi-objective particle swarm optimization, fuzzy comprehensive evaluation, talent cultivation

I. Introduction

The zero-carbon transition led by the goal of carbon neutrality will bring about extensive and profound social changes, covering new trends in policy orientation, industrial technology layout, investment and financing, and international governance in various countries. Carbon neutrality will promote green technology innovation, and the process of carbon neutrality will also bring industrial structure adjustment and transfer [1].

The adjustment of industrial pattern puts forward new requirements and challenges for the cultivation of engineering talents. In the current context of the rapid development of information technology such as big data, artificial intelligence and other information technologies and the promotion and implementation of the carbon peak carbon neutral target, the industrial changes and the emergence of new business forms have put forward new requirements for the cultivation of higher education talents [2], [3]. The whole industry has an increasing demand for high-quality technical and skilled talents who master intelligent construction technology, especially the talent gap in the specialized fields of intelligent construction design, intelligent assembly construction and decoration, and intelligent operation and maintenance and management of buildings has affected the transformation, upgrading and development of the construction industry [4]-[7]. Under the environment of aging population and green and intelligent development of buildings, higher education schools, as the training base for technical and skilled talents, need to cultivate construction digital craftsmen with digital thinking, intelligent construction, and intelligent operation and maintenance [8]-[10]. As a training base for compound skill talents, higher education institutions should strive to seize the opportunity for school-enterprise collaboration to cultivate more talents in the construction industry that meet the needs of society and satisfy the demand for the advancement of the modernization of the construction industry [11]-[13]. Efforts to promote the reform of professional education in the construction industry have embedded low-carbon genes for students, injected low-carbon elements into talent cultivation, integrated low-carbon concepts into higher engineering education, and provided talent guarantee and professional support for the development of low-carbon transformation and the realization of carbon-neutral goals [14]-[17].

The primary innovation of this paper is to propose a multi-objective particle swarm optimization algorithm to optimize and transform the green building design, which overcomes the defects of high carbon emissions and low economic benefits caused by the adoption of high-energy and high-cost materials in traditional building design. At the same time, the optimization scheme is applied to the educational reform of architectural design courses to build an innovative path of talent cultivation mode in the construction industry, forming the second major innovation point of this paper. Specifically, this paper is based on multi-objective particle swarm optimization algorithm to construct a simulation system containing building lighting simulation and building thermal environment performance simulation, and set parameters in the optimization system to optimize the design of the building's whole life cycle. The carbon emission factor method is used to measure the carbon emissions of the building, and according to the measurement results, the changes in the carbon emissions of the building before and after the optimal design of the green building are compared and analyzed, so as to check the carbon neutrality benefit of the optimization scheme in this paper. Taking into full consideration of the possible changes in energy prices, discount rates, actual energy efficiency and other factors affecting green buildings, we construct the annual net cash flow and cumulative net cash flow models of green buildings, and calculate the incremental payback period of green buildings based on them, so as to quantitatively measure the economic benefits of the optimized green building design in this paper. The green building design optimization scheme proposed in this paper is used as a technical template to carry out educational reform of the existing architectural design courses in terms of teaching content, site selection and setting, teaching methods and auxiliary means. Using the fuzzy comprehensive evaluation method and the analysis of teaching practice to assess the effect of educational reform in an all-round way, it aims to provide a theoretical basis for the innovation strategy of talent cultivation mode in the construction industry in the information technology era.

II. Green optimization programme for building design

II. A. Multi-objective particle swarm optimization algorithm

In this paper, the multi-objective particle swarm optimization algorithm is chosen for the optimal design of green buildings [18]. The velocity and position of the particles of this algorithm can be represented by the following model:

Assuming that the position and velocity of the i st particle in step t are expressed as x_i^i and v_t^i, then in the next step, its position x_{t+1}^i and velocity v_{t+1}^i can be expressed as:

$$v_{t+1}^i = wv_1^i + c_1 r_1 \left(p_1^i - x_1^i\right) + c_2 r_2 \left(g_1^i - x_1^i\right) \tag{1}$$

$$x_{t+1}^i = x_1^i + v_{t+1}^i \tag{2}$$

$$w = w_a - \left(w_a - w_i\right) \times iter / \max it \tag{3}$$

where $i = 1, 2, \cdots\cdots, S$, S is the size of the swarm, $t = 1, 2, \cdots\cdots$, N. N is the number of iterations, c_1 and c_2 are two constants, r_1 and r_2 are two random functions in the range $[0,1]$, p_i^i is the optimal position experienced by the i th particle up to step t, g^i is the current global optimum, w is the inertia weight coefficient, which serves as a balancing factor between the two searching capabilities, w_i is the minimum inertia weight, w_a is the maximum inertia weight, iter is the number of current iterations and maxit is the number of maximum iterations.

II. B. Optimization of green building design based on multi-objective particle swarm optimization algorithm

II. B. 1) Simulation systems

(1) Building lighting system simulation

The building selected in this paper is chosen to achieve the minimum illumination of 500lux as a measure. When the light is less than 500lux, auxiliary artificial light source is required. Therefore the lighting time of artificial light source in a year is:

$$T_{el-1} = \left(1 - DA_{500}\right) \times T_{day} \times T_{hour} \tag{4}$$

where, T_{el-1} denotes the hours of illumination by artificial light sources in a year. T_{day} denotes the number of working days per year. T_{hour} denotes the number of working hours per day.

Lighting by artificial light source consumes electricity, so the annual power consumption due to lighting is:

$$Q_{el-1} = \sum_{n-1}^{N} \left(T_{el-1} \times P_{lit}\right)_n \tag{5}$$

where, Q_{el-1} denotes the power consumption caused by artificial light source illumination in a year. P_{lit} denotes the power of each lamp. $n=1,2,\cdots\cdots$. N is the number of lamps in the test area, which is calculated by the formula:

$$N = E_{av} \times A/\left(u \times k \times \phi\right) \tag{6}$$

where, E_{av} denotes the true average illuminance of the measured work plane. A denotes the area of the measured working plane $\left(m^2\right)$. u denotes the utilization factor. k denotes the shading coefficient. ϕ denotes the luminous flux of artificial lighting.

(2) Building thermal environment performance simulation

In order to calculate the amount of cooling and heating energy consumption, COP coefficients are introduced to indicate the energy efficiency ratio, which refers to the ratio of the rated cooling or heating capacity to the rated power (electricity consumption):

$$Q_{el-t} = Q_{cool}/COP_{cool} + Q_{heat}/COP_{heat} \tag{7}$$

where, Q_{el-t} denotes the annual electricity consumption for maintaining the comfort performance of the thermal environment of the building. Q_{cool} indicates the annual cooling load. Q_{heas} indicates the annual heat load. COP_{cool} indicates the cooling energy efficiency ratio. COP_{heat} indicates the heating energy efficiency ratio.

After the building lighting system simulation and thermal environment performance simulation are completed, the total annual energy consumption can be output:

$$Q_{el-s} = Q_{el-1} + Q_{tl-t} = \sum_{n-1}^{N}\left(T_{tl-1} \times P_{lit}\right)_n \tag{8}$$

II. B. 2) Optimization system

All processes of the full life cycle of a building, including natural resource extraction, material production, construction, maintenance and demolition. Then the first objective function (LCC minimization) can be expressed as:

$$LCC = C_{con} + C_{op} \tag{9}$$

where, C_{con} denotes the building design program construction cost. C_{op} denotes the operating cost. Since the LCC considers both existing capital flows and future cash flows as well as the time value of money, all of the above parameters need to be converted to present value (PV), which is:

$$PV = C/\left(1+i\right)^t \tag{10}$$

where $t=1,2,\cdots\cdots$. i is the real interest rate for the compounding period. Since there is an inflation rate, i should be the real interest rate, calculated as:

$$i = \left(i_n + 1\right)/\left(f+1\right) - 1 \tag{11}$$

where i_n denotes the nominal interest rate. f denotes the inflation rate.

Thus, the actual LCC formula is:

$$LCC = C_{con} + \sum_{t-1}^{T}\left(C_{op}\right)t \times \left(i+1\right)^{-1} \tag{12}$$

where T denotes the building life cycle.

The second objective function LCCE can be expressed as:

$$LCCE = E_{con} + E_{op} \tag{13}$$

where E_{con} represents carbon emissions from the construction process. E_{op} represents the carbon emissions from the operation process.

Since the amount of CO_2 emitted by equal amounts of different materials is different, the carbon emission factor (CEF) is introduced to calculate the corresponding carbon emissions [19], which is calculated by the formula:

$$LCCE = \sum_{i-1}^{l} Q_i \times f_i + t \times Q_{el-s} \times f_{el} \tag{14}$$

where $i = 1, 2, \cdots\cdots$, is the number of building material types. Q_i is the number of type i materials. f_i is the CEF of the i th material. f_{el} is the corresponding power consumption of the CEF.

II. C. Optimization program benefit analysis

II. C. 1) Architectural overview

The building selected in this paper is located in Zhengzhou City, Henan Province, and its meteorological parameters are shown in Figure 1. From the meteorological parameters, it can be seen that the environment in which the building is located belongs to the cold B zone specified in the Thermal Design Code for Civil Buildings (GB50176-2016).

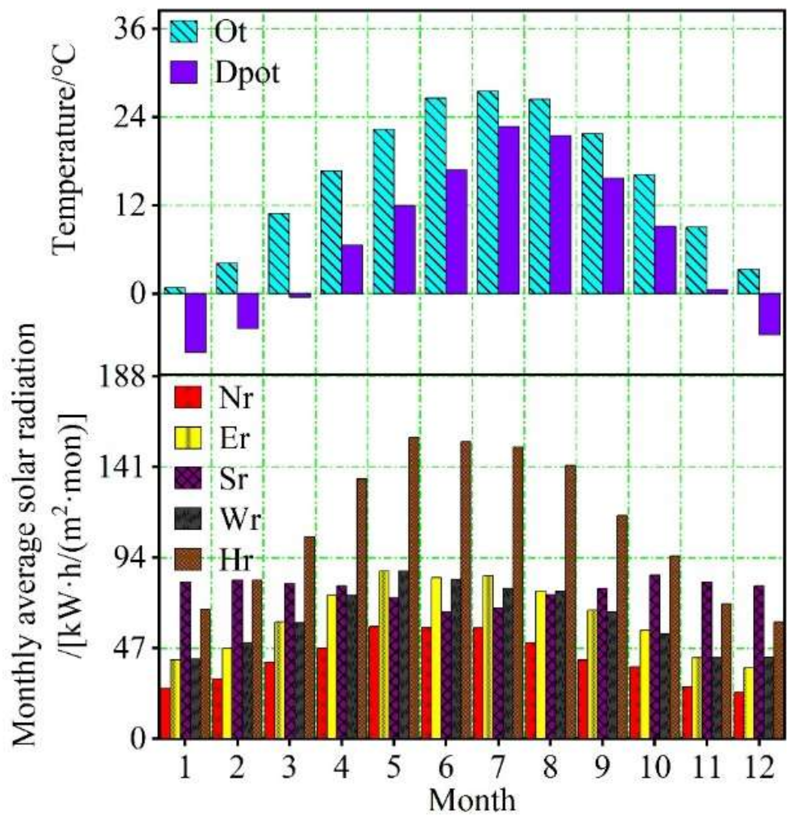

Figure 1: Meteorological parameters

The building has 1 floor underground and 5 floors above ground, and the structural form is frame structure with a body shape coefficient of 0.52, which was completed in August 2022. The total area of the building is 281.42m², the height of the building is 17.38m, the area of the external wall is 412.73m², the area of the roof is 313m², and the total area of the external window is 74.86m².The building is equipped with solar collectors on the south-facing roof, and adopts boiler heating method.

II. C. 2) Carbon neutral benefits

(1) Carbon emission measurement method

According to the relevant norms, this paper adopts the carbon emission factor method for the measurement of building carbon emissions, the principle of which can be expressed as “carbon emissions = activity data × carbon emission factor”.

The production and transportation stages of building materials are shown in equation (15):

$$C_{jc} = \frac{\sum_{i=1}^{n} M_i F_i + E_{cy3} F_{cy}}{A} \tag{15}$$

where, C_{jc} is the carbon emission of building materials, $kgCO_2e/m^2$, $\sum_{i=1}^{n} M_i F_i$ is the sum of carbon emissions of the i th building materials, $kgCO_2e$, $E_{cy3}F_{cy}$ is the carbon emission from transportation of building materials, $kgCO_2e$, A is the building area, m^2.

The building construction stage is shown in equation (16):

$$C_{jz} = \frac{\sum_{i=1}^{n} E_{jz,i} EF_i}{A} \tag{16}$$

where, C_{jz} is the carbon emissions per unit area during the construction phase of the building, $kgCO_2e/m^2$.

$E_{jz,i}$ is the total energy use of category i in the construction phase, $kW \cdot h$ or kg.

EF_i is the carbon emission factor of category i energy, $kgCO_2e/kg$.

The building operation stage is shown in equation (17):

$$C_M = \frac{[\sum_{i=1}^{n} (E_i EF_i) - C_p]y}{A} \tag{17}$$

where, C_M is the carbon emission per unit area of the building during the operation stage, $kgCO_2e/m^2$, E_i is the annual energy consumption of the building in category i, unit / a, C_p is the annual carbon reduction of the green space carbon sink system of the building, $kgCO_2e/e$, y is the building design life, a.

The demolition stage converts the demolition stage of the building into electricity and fuel consumption for calculation, and the calculation formula is shown in equation (18):

$$C_{CC} = \sum_{i=1}^{n} (E_i \times Q_i) \tag{18}$$

where, E_i is the amount of energy used for type i, $kW \cdot h$ or kg.

Q_i is the carbon emission factor of the i th energy source, $kgCO_2e/kg$.

(2) Explanation of the measurement scope

In the calculation of building carbon emissions, the design service life of each structural part is uniformly set according to the construction service life of 70 years. In order to better compare the carbon emissions in the operation phase before and after the optimization and renovation of the case building, the greening associated with the building is used as a carbon sink to offset the carbon emissions generated by the building operation, and the energy generated by the use of renewable energy such as solar energy and ground source heat pump is accounted for as a discounted amount of carbon emissions.

(3) Analysis of test results

Based on the previous green building optimization scheme, the carbon emission measurement results before and after the transformation can be obtained as shown in Table 1 and Table 2. From the measurement results, it can be seen that the whole life cycle energy saving rate after the retrofit is more than 85%. Since the carbon emission in the operation phase of the building accounts for the largest proportion in the whole life cycle of the building, the carbon emission in the operation phase is significantly reduced after energy-saving retrofit, which can reduce 3641.39 tCO2e in the whole life cycle, and 106.2606 kgCO2e per square meter per year on average in the operation phase.

Table 1: Results of the pre-transformation carbon emission measurement

Active stage	Carbon emission source	Total carbon emissions/ tCO2e	Annual carbon emissions/ [kgCO2e/a]	Carbon intensity/ [kgCO2e/(m²·a)]
Demolish	Stage total	4.27	83.64	0.1236
	Demolish	4.27	83.64	0.1236
Building operation	Stage total	4249.79	81741.05	119.1683
	Hot water	14.87	265.87	0.3859
	Illumination electricity	11.28	193.58	0.2983
	Heating and cooling	1643.79	31238.71	45.0364
	Elevator	2.38	3.27	0.1382
	Ventilation and exhaust fan	2573.82	50036.43	72.9781

	Photovoltaic	1.29	1.11	0.1568
	Carbon sink	2.36	2.08	0.1746
Total		4254.06	81824.69	119.2919

Table 2: Carbon emission measurement results after modification

Active stage	Carbon emission source	Total carbon emissions/tCO2e	Annual carbon emissions/[kgCO2e/a]	Carbon intensity/ [kgCO2e/(m²·a)]
Building materials production and transportation	Stage total	42.38	885.65	1.2557
	Building materials production	40.06	848.02	1.2186
	Building materials transport	2.32	37.63	0.0371
Construction and demolition	Stage total	1.57	30.99	0.0542
	Construction	0.84	16.38	0.0283
	Demolition	0.73	14.61	0.0259
Building operation	Stage total	608.40	11507.54	12.9077
	Hot water	-5.32	-89.64	-1.2364
	Illumination electricity	8.71	183.57	0.2673
	Heating and cooling	298.36	6035.11	8.5736
	Elevator	0.02	0.06	0.0258
	Ventilation and exhaust fan	502.83	9745.71	13.6974
	Photovoltaic	-122.39	-2582.88	-4.8371
	Carbon sink	-73.81	-1784.39	-3.5829
Total		652.35	12424.18	14.2176

Ecotece software was used for further analysis and simulation, the working hours were from 9:00 to 17:00 p.m., with working days from Monday to Friday, a water-cooled chiller was used with a COP of 4.6, the temperature of the interior design was 24°C, the lamps used were all 60W, the illumination in the building was less than 500lux, and artificial auxiliary lighting was used. The wall types used are 150mm concrete wall (W1), 150mm aerated block wall (W2) and lightweight brick wall (W3). Three types of glass were used: single transparent glass (G1), double transparent glass (G2) and double green glass (G3), the window-to-wall ratio was in the interval of 0.1-0.5, and the building orientation was 0°-360°. The width of external shading is 0m-1.2m, and the optimal scheme can be obtained through the optimization calculation, and the following ten Pareto-optimal schemes with the best energy consumption are selected for comparison, and the results are shown in Table 3, where LCC indicates the full life cycle cost (the sum of construction cost and operation cost), and LCCE indicates the objective function of carbon emission (the sum of the carbon emission in the process of construction and the carbon emission in the process of operation) The Through the calculation, it can be found that different optimization schemes can reduce the cost and building carbon emissions, and the decision makers can consider them comprehensively and choose the best scheme to optimize the design.

Table 3: Pareto optimal solution

Scheme	Wall	Window to wall ratio			External shading width(m)			Glass type	Orientation (°)	LCC	LCCE
1	W1	0.38	0.49	0.16	0.99	0.27	0.74	G3	265	16.4	328.3
2	W1	0.25	0.27	0.34	0.10	0.54	0.88	G1	290	17.1	341.5
3	W3	0.25	0.43	0.13	0.28	0.28	0.32	G3	240	16.4	322.6
4	W2	0.44	0.25	0.19	0.29	1.06	0.05	G3	35	16.6	317.4
5	W1	0.43	0.30	0.31	0.18	0.54	0.43	G2	309	15.8	308.8
6	W3	0.28	0.45	0.26	1.17	0.38	0.44	G1	84	16.3	320.5
7	W3	0.38	0.43	0.37	0.21	1.04	0.8	G1	68	17.5	313.7
8	W3	0.14	0.36	0.17	0.95	0.04	0.59	G2	342	21.2	319.2
9	W2	0.45	0.3	0.47	0.42	0.79	0.67	G1	188	22.4	306.1
10	W1	0.38	0.49	0.16	0.99	0.27	0.74	G3	112	18.9	303.8

Original	W1	0.25	0.27	0.34	0.10	0.54	0.88	G1	181	28.8	549.6

II. C. 3) Analysis of economic benefits

(1) Economic benefit analysis model

The economic benefit analysis of green building optimization design is to construct the annual net cash flow and cumulative net cash flow models of green building with full consideration of possible changes in energy price, discount rate, actual energy saving efficiency and other factors affecting the green building, as a basis for calculating the incremental payback period of the green building, and further clarifying the economic benefits generated during the whole life of the green building. The annual energy cost savings of a green building can be expressed by the annual net cash flow (NCFt), which is calculated as equation (19). The energy-saving benefits due to the reduction of energy consumption during the whole life of the green building minus the input cost of the construction period relative to the ordinary building can be expressed by the accumulated net cash flow (ANCFt), which is calculated as equation (20). The practice required for the energy efficiency gains during the use of the green building to offset the increased investment in the construction period relative to an ordinary building is expressed in terms of the incremental payback period Pd, which is calculated as equation (21):

$$NCF_t = \alpha * (Q_t - Q_t') * p * (F/P, \eta, t) * (P/F, i, t) \tag{19}$$

$$ANCF_t = \sum_{t=1}^{n-1} \alpha * (Q_t - Q_t') * p * (F/P, \eta, t) * (P/F, i, t) - \gamma * (C_0' - C_0) \tag{20}$$

$$P_d = n - 1 + \frac{|ANCF_t|}{NCF_t} \tag{21}$$

where, α is the actual energy saving efficiency, η is the growth rate of energy prices, i is the discount rate, $Q_t - Q_t'$ is the difference in electricity consumption between green buildings and ordinary buildings under the same operation mode, p is the annual energy price, γ is the rate of change of the cost during the construction period of the green building, C_0 is the cost of constructing the green building without energy-saving measures, C_0' is the cost of constructing the green building with energy-saving measures, and n is the year of the cumulative net cash flow with a positive value.

(2) Economic Benefit Analysis

The cost comparison between the building after adopting green energy-saving optimization and ordinary building is shown in Figure 2, where M1, M² and M3 represent the components of external walls, roofs, external windows and doors, respectively. The cost increases are all calculated on the basis of the total area in use. From the figure, it can be seen that after carrying out the green building optimization design, the cost of each component rises compared with the ordinary building, in which the cost of external windows and doors rises by 48,364 yuan compared with the ordinary building.

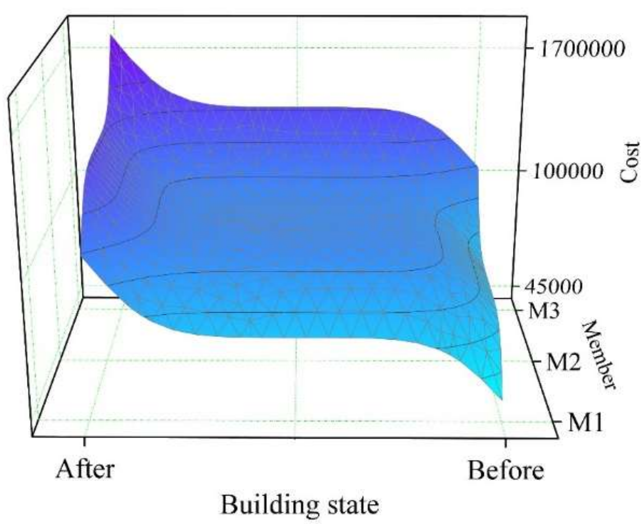

Figure 2: Cost contrast

According to the shape of the green building and the building construction size, the use of energy simulation software Doe-2 to simulate its annual energy consumption simulation calculations simulation calculations according to the actual energy use of the heating and air conditioning to take the adjustment mode to calculate the level of energy consumption, the results are shown in Figure 3, where H, A, T represent heating, air conditioning, and the total, respectively. Figure 3 data show that after the use of green building optimization design, the annual power consumption of heating and air conditioning decreased significantly, green building heating and air conditioning summary annual power consumption compared to ordinary buildings by 40.89%.

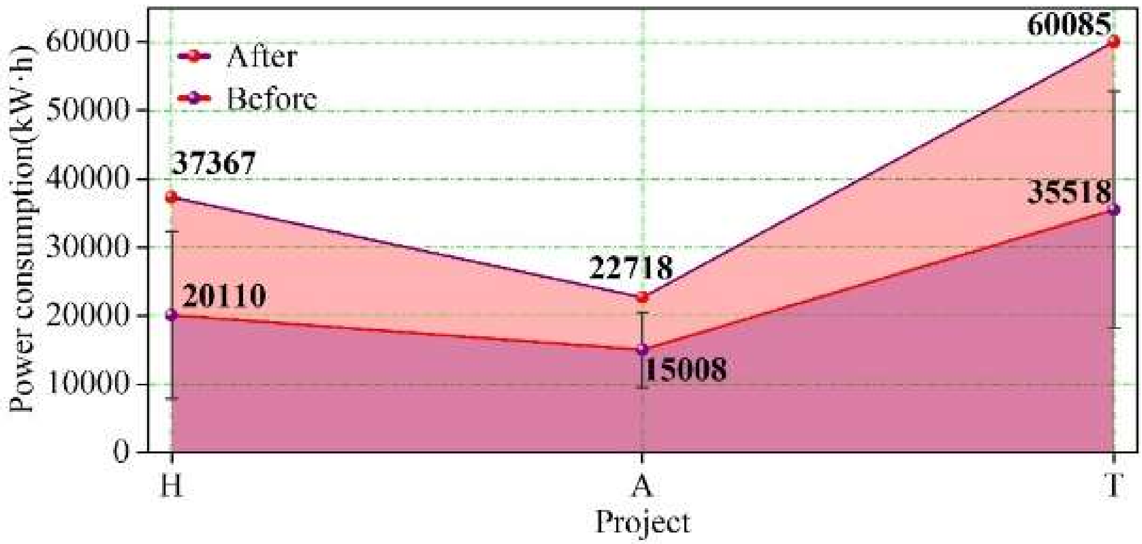

Figure 3: Energy consumption level before and after transformation

According to the data in Fig. 2 and Fig. 3, energy saving economic benefit analysis can be carried out. The energy price is taken as the average electricity price of 0.56 yuan/degree in Zhengzhou, and is calculated in two states of no change in energy price and 10% increase in the current energy price respectively. Due to the construction period of green building relative to its operation period time period, the cost changes are small, so take the construction period cost change rate γ for 90%, discount rate i according to the social discount rate of 4.3%. According to the different states of energy-saving efficiency that may exist in the actual use of green buildings, they are calculated according to their fluctuation ±10% respectively. Substituting the above data into the formula respectively, the annual net cash flow, cumulative net cash flow and incremental payback period under various states can be calculated, and the results are shown in Figure 4. It can be seen from the calculations and images that the initial cost of the green building increases due to energy saving measures, but the energy cost in the operation period decreases dramatically, so that the incremental investment can be recovered in 6-12 years in all states, and the incremental investment of the green building can also be recovered in 9 years when the energy price rises. Based on a building design life of 70 years, the last 60 years or so of its full life cycle are in a state of net gain from energy savings, indicating that the green building has significant economic benefits.

III. Green building design education reform

In order to cultivate architectural design students' way of thinking of green building design, enhance the ability of innovative design, cultivate students' independent thinking ability and research-oriented design thinking with problem research as the basic starting point, this paper takes the optimization plan of green building design in the previous article as the technical template, and carries out a series of specific educational reform exploration and practice in four aspects, such as the teaching content, site selection and setting, the teaching method and the auxiliary means, aiming to provide theoretical support for the innovative training mode of talents in the construction industry under the background of carbon neutrality.

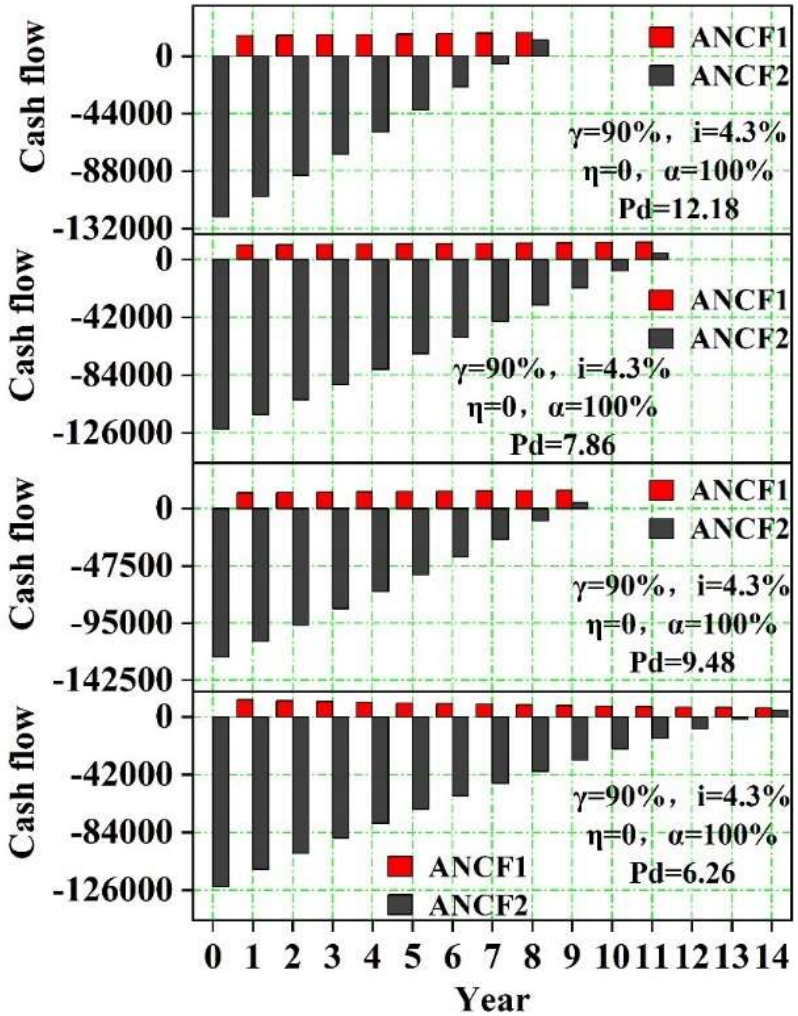

Figure 4: Incremental investment payback period

III. A. Teaching content

Green building design should start from the building itself, through passive design techniques, rationally arrange the building orientation and surrounding environment, skillfully handle the internal space and external form, and appropriately select building materials, structures and constructions. On this basis, appropriate design parameters are added in order to obtain a comfortable thermal environment with the lowest energy consumption and the least harm to the environment. Traditional professional learning in architecture disciplines focuses on the design of the building itself and lacks the thinking of integrating design and technology. Therefore, in order to improve the green building design thinking ability of architectural students, the reform of this course not only increases the systematic technical topics based on the original teaching content, but also adds the on-site measurement of building thermal environment and building comfort.

III. B. Site setup

In traditional design courses, the site selection and design content of design topics are usually unified, which has the advantage of easy control of the teaching content and progress of the classroom, and easy comparison between students' various design proposals. However, green building design is closely related to local climatic conditions, natural environment and other factors, and the restriction of site selection will largely limit the cultivation of students' independent innovation ability and the learning of green building design under different thermal design zoning conditions. In view of this, the site selection is not limited to specific thermal design zones and cities, and students can choose the project site independently according to the parameters in the optimization scheme, and at the same time, they must carry out a detailed demonstration of the area where the site is located.

III. C. Teaching methods

Traditional design courses or theory courses mainly adopt the one-way teaching method of one-to-one or move-many between teachers and students. In this way, the teacher is the output and the students are the input, and the students' thinking is easily limited to the teacher's personal thinking and lacks the subjective initiative of independent learning. Therefore, the reform practice of this course adopts a combination of one-way and multi-directional teaching methods, guiding students to explore in depth the various technological techniques of the green building optimization scheme proposed in this paper, to master the simulation and analysis methods, and to make appropriate choices and use of technology.

III. D. Auxiliary means

The use of building performance simulation technology can provide designers with data support at all stages of design, and promote the scientific and rationalization of design. There are many building performance simulation software developed, but most of them are difficult to be mastered by students in a short period of time. The optimization scheme designed in this paper only requires students to learn how to use basic and easy-to-learn software and analysis tools, which not only can play the role of assisting in verifying the expected effects of green building design solutions, but also inspires students to analyze from a scientific perspective, which has a significant role in promoting the reform of architecture teaching.

IV. Evaluation of the impact of educational reforms

IV. A. Evaluation of the effect of architectural design education reform based on the fuzzy synthesis method

IV. A. 1) Optimization of the fuzzy integrated evaluation model

Hierarchical analysis method in the use of nine-scale method of the importance of indicators in the ordering step, due to the existence of human subjectivity, or because of a certain evaluation set within the indicator is too much, the degree of importance between the indicators of the degree of ambiguity is very large, resulting in the judgment matrix is difficult to pass the consistency test, you need to go through a number of adjustments, the test procedure in order to make the judgment matrix has consistency. Based on this, this paper proposes a fuzzy hierarchical analysis method by changing the nine-scaled matrix into a three-scaled matrix [20], which effectively makes up for the defects of the traditional hierarchical analysis method, and the specific process is as follows:

In the first step, the importance of n indicator within an evaluation set is compared two-by-two to construct a n nd-order three-scaled complementary fuzzy judgment matrix:

$$A=(a_{ij})_{n\times n} \tag{22}$$

where $a_{ij}=\begin{cases}1, i>j\\ 0.5, i=j\\ 0, i<j\end{cases}$.

In the second step, the fuzzy judgment matrix A is transformed into the fuzzy consistency judgment matrix $B=(b_{ij})_{n\times n}$ by using Equations $r_i=\sum_{j=1}^{n}a_{ij}$ and $b_{ij}=\frac{r_i-r_j}{2n}+0.5, i=1,2,3,\ldots,n$, where r_i denotes the sum of the elements of row i in the fuzzy judgment matrix A.

In the third step, the sorting vector W is found, and the methods are row sum normalization and square root method, and here the row sum normalization method is chosen, and its calculation method is determined by the following equation:

$$\begin{aligned}W^{(0)}&=(w_1,w_2,\cdots,w_n)^T\\&=\left[\frac{\sum_{j=1}^{n}b_{1j}}{\sum_{i=1}^{n}\sum_{j=1}^{n}b_{ij}},\frac{\sum_{j=1}^{n}b_{2j}}{\sum_{i=1}^{n}\sum_{j=1}^{n}b_{ij}},\cdots,\frac{\sum_{j=1}^{n}b_{nj}}{\sum_{i=1}^{n}\sum_{j=1}^{n}b_{ij}}\right]\end{aligned} \tag{23}$$

In the fourth step, the fuzzy consistency judgment matrix B is converted into a reciprocal matrix $U=(u_{ij})_{n\times n}$ by Eq. $u_{ij}=\frac{b_{ij}}{b_{ji}}$.

In the fifth step, the sorting vector $W^{(k)}$ with higher accuracy is calculated by the eigenvalue method, where the iterative initial value W_0 is the sorting vector $W^{(0)}$.

IV. A. 2) Establishment of a fuzzy integrated evaluation model

First, the establishment of factor sets. Let the evaluation object has n first-level indicator, then we can establish the first-level factor set $Y=\{Y_1,Y_2,\cdots,Y_n\}$. Similarly, we can establish the factor set $Yi=\{Y_{i1},Y_{i2},\cdots,Y_{ik}\},i=1,2,3,\cdots,n$ for the second-level indicators, and k indicates the number of second-level indicators contained in the i th sub-factor.

Second, to establish the evaluation set, let the evaluation system of architectural design course $R_{ij}=\{r_{i1},r_{i2},\cdots,r_{im}\}$ second-level indicators have m evaluation levels then the evaluation set is $D=\{d_1,d_2,\cdots,d_m\}$, which is divided into five levels in this study, respectively, indicating excellent, good, average, poor and poor, and construct the corresponding evaluation matrix.

Thirdly, determine the factor weight matrix of the first and second level indicator layer as $W=\{w_1,w_2,\cdots,w_n\}$, $Wi=\{w_{i1},w_{i2},\cdots,w_{in}\},i=1,2,\cdots,n$ by using three scale matrix fuzzy hierarchical analysis.

Fourth, the comprehensive evaluation model is constructed, in which the first level comprehensive evaluation model is $P_{ij}=W_{ij}\circ R_{ij}$, and the second level comprehensive evaluation model is $P_i=W_i\circ P_{ij}$. Where, "$\circ$" is the Zadeh operator operator. Generally, there are five types of synthesis operators in fuzzy mathematics, and since the indicators in the evaluation index system of this study are indispensable, the weighted average type $M(\square,\oplus)$ operator is selected.

IV. A. 3) Results and analysis

(1) Evaluation system establishment

This study adopts the questionnaire survey method and literature analysis method to obtain the evaluation indexes of educational reform of architectural design courses in a university, and the results are shown in Table 4. Finally, we get 5 first-level indicators such as teacher security, technical environment, teaching content, teaching method, teaching effect and 16 second-level indicators such as the number of teachers allocated to specialized courses.

Table 4: Education reform effectiveness evaluation system

Primary indicator	Secondary indicator
Teacher assurance (A1)	Number of course teachers allocated (B1)
	Number of associate senior teachers in course configuration (B2)
	Number of personnel with a master's degree or above (B3)
Technical environment (A2)	Technical teaching site area (B4)
	Fixed assets of technical teaching equipment (B5)
	Number of technical equipment (B6)
Teaching content (A3)	Meet the demand of the industry (B7)
	Operational strength (B8)
	Articulate (B9)
Teaching method (A4)	Suitable course capacity (B10)
	Suitable course difficulty (B11)
	Clear course logic (B12)
	Appropriate course schedule (B13)
Teaching effect (A5)	Big data analysis (B14)
	Experimental operation evaluation (B15)
	Theoretical evaluation (B16)

(2) Weight calculation

The study follows the calculation steps described in the previous section to get the first-level indicator eigenvector is $W=\{0.27,0.18,0.25,0.10,0.21\}$, the largest eigenroot is 5.37, and the consistency test result is 0.099, which meets the requirements. Therefore, the weights of teacher security, technical environment, teaching content, teaching methods, teaching effect are 0.27, 0.18, 0.25, 0.10, 0.21. According to this method, we also get the weights of the secondary indicators, and the results are shown in Figure 5, where the size of the circle area indicates the size of the indicator weights. As can be seen from the figure, the primary indicator of teacher security has the greatest impact on education reform, and its weight value reaches 0.27. Followed by the content of teaching and learning. Its weight is 0.25. The weights of the number of master's degree and above, clarity of expression, and the number of technical instruments and equipments in the second-level indicators are ranked in the top three, with the weights of 0.67, 0.57, and 0.48, respectively.

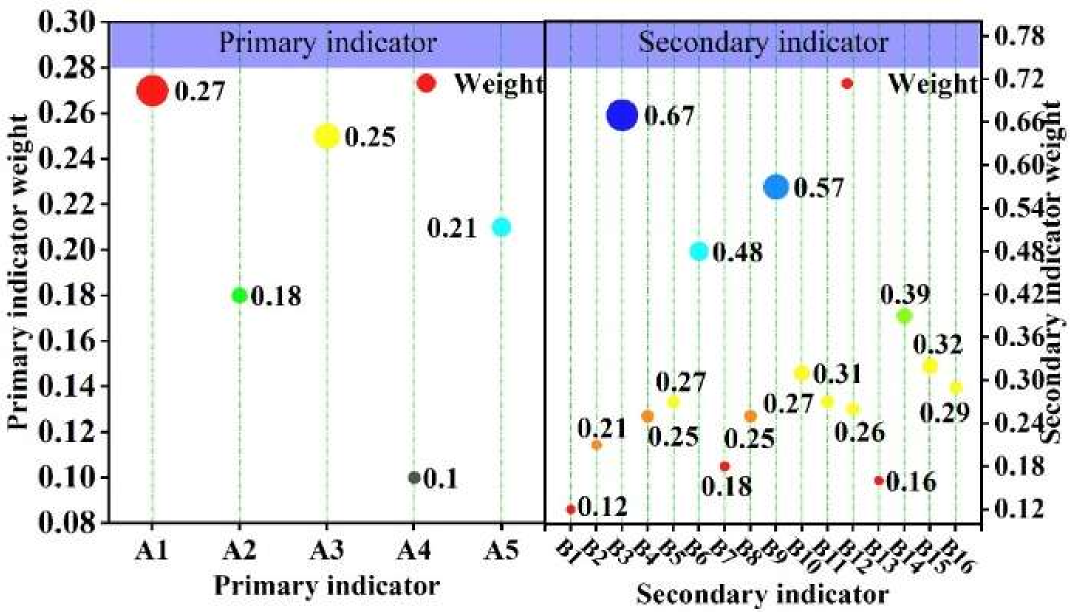

Figure 5: Weight of evaluation indicators

(3) Fuzzy comprehensive evaluation

In order to evaluate the effect of educational reform in architectural design, this study launched a questionnaire survey with 20 educational experts, and finally obtained the subordination degree of the secondary index of the effect of educational reform, and calculated that the evaluation results of the teacher guarantee, technical environment, teaching content, teaching method, and teaching effect were 0.57, 0.66, 0.78, 0.83, and 0.89, respectively.Therefore, the evaluation results of the teacher guarantee, technical environment, evaluation results of teaching content, teaching method, and teaching effect are average, good, good, excellent, and excellent respectively. The comprehensive evaluation result is 0.81. This indicates that the overall effect of this paper on the reform of architectural design education is excellent.

IV. B. Evaluation of the Effectiveness of Educational Reform Based on Teaching Practices

IV. B. 1) Analysis of course satisfaction

Before the end of the course, a questionnaire survey was done for 128 students in the architecture program of the class of 2022. The survey included four aspects: content satisfaction, class time satisfaction, modality satisfaction and technology satisfaction, and the results of the survey are shown in Fig. 6, where A, B, C, and D denote very satisfied, satisfied, fair and dissatisfied, respectively, and P1, P2, P3, and P4 denote content satisfaction, class time satisfaction, modality satisfaction, and technology satisfaction, respectively. The results showed that 71.09% of the students were satisfied with the content, 65.63% were satisfied with the class time, 64.84% were satisfied with the teaching method and 69.53% were satisfied with the technology. The above data indicate that this educational reform is more successful and the students' satisfaction is high.

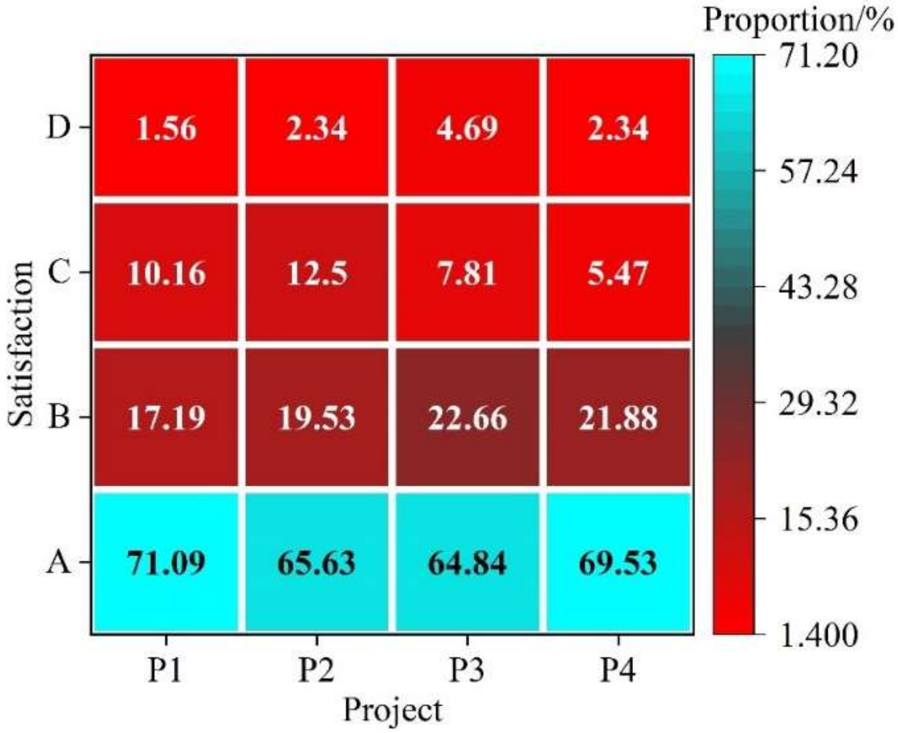

Figure 6: Teaching satisfaction survey statistics

IV. B. 2) Course experience analysis

Through the educational reform, students' motivation in class has improved, teacher-student interaction has increased, and the classroom atmosphere is more active. Students' subjective initiative in learning the architectural design course has increased, and the class status has improved significantly. Through the communication between teachers and students, it is found that students are more satisfied with the course content after the teaching reform. Compared with the teaching method before the reform, students are more likely to accept the teaching method after the reform. Some students put forward some suggestions on the course content and project tasks in the process of course implementation in the light of their future employment situation and development, such as increasing the diversity of project tasks and simulating work scenarios. For the course experience, the overall satisfaction of students has improved.

IV. B. 3) Analysis of course performance

Figure 7 shows the distribution of student achievement before and after the teaching reform, and the area of the shaded part in the figure indicates the degree of change in the percentage of student achievement levels before and after the teaching reform, with 1-5 indicating the scores of 60 points or less, 60-70 points, 70-80 points, 80-90 points, and 90-100 points, respectively. The analysis of students' performance before and after the architectural design teaching reform shows that the proportion of students' performance ranges in the 70-80, 80-90, and 90-100 points have increased after the implementation of the teaching reform, and the failure rate has decreased. Among them, the proportion of 70-80 points increased from 22.38% to 32.64%, the proportion of 80-90 points increased from 11.49% to 38.56%, and the proportion of 90-100 points increased from 1.33% to 11.65%. The student achievement data can reflect the good effect of the educational reform of the architectural design course to a certain extent.

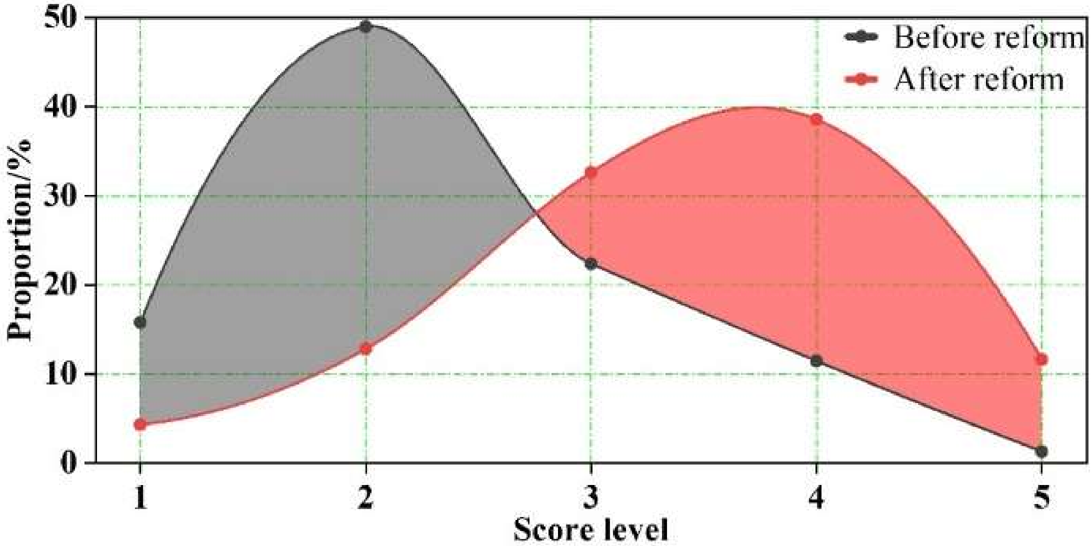

Figure 7: Analysis of student achievement before and after the reform of teaching

V. Innovative Strategies for Talent Training Models

This paper proposes a green building design optimization scheme with significant carbon neutral benefits and economic benefits, and takes this scheme as a technical template for educational reform of architectural design courses, aiming to innovate the talent cultivation mode in the construction industry. However, talent cultivation is not something that can be accomplished overnight, nor can a little bit of one side fully achieve the desired effect, but requires an all-round and three-dimensional multi-initiatives in parallel. In this section, we will further explore the new mode of talent cultivation in the construction industry in the era of informationization from the digital platform, school-enterprise cooperation, and evaluation mechanism [21].

V. A. Accelerating the construction of a digital platform for "three-dimensional synergy"

As a learning platform for talent development, it supports the construction, implementation, and practice activities of academic programs and is a key core for reaching the goal of three-dimensional synergy in teaching and learning. Information technology can be appropriately integrated into the architectural teaching curriculum, which defines the path of talent cultivation in the discipline of architectural education.

Schools should rely on information technology to accelerate the process of building and applying digital teaching resources. In the process of creating digital teaching resources, information technology should be used to establish a resource library of architecture courses that meets its own teaching needs, and set up a unified specification so as to create a digital course teaching resource library. In order to make full use of digital teaching content, colleges and universities must follow the actual teaching needs and operational regulations, and appropriately supplement and update the existing resources.

V. B. In-depth school-enterprise cooperation

The application of information technology must span multiple disciplines and involve complex processes, and it needs to be fully integrated into the teaching process to ensure that it matches the actual needs of enterprises, thus effectively connecting education and industrial practice. In the process of cooperation between institutions and enterprises, schools and enterprises need to enhance the frequency and depth of dialogues, comprehensively train construction students, ensure the integration of theoretical teaching and practical operation, and especially focus on improving students' practical operation ability. Schools should consider the future career development of students, and through cooperation with enterprises, integrate real enterprise cases into the curriculum, so as to effectively enhance students' theoretical knowledge and improve their practical operation ability. School-enterprise cooperation makes full use of enterprise resources and educational advantages to jointly promote talent cultivation and meet industrial needs.

V. C. Improvement of educational evaluation methods

In the education of architecture courses, it is necessary to reconstruct the evaluation mode led by teachers and passively accepted by students, and to promote the change of teaching evaluation from result-oriented to process-oriented through a perfect evaluation system. In the process of educational assessment, the use of information technology to integrate the teaching of construction projects, assess students' professional knowledge of construction, and assess their ability to apply information technology in project practice. Reshape the education and evaluation mechanism of “information technology +” architecture, and guide the focus of evaluation from result-oriented to process-oriented. Teachers can assess the projects completed by students to understand their actual ability and level of technical application, so as to judge whether the learning outcomes of students have reached the preset goals, so as to achieve the purpose of scientific and rational training of architectural talents.

VI. Conclusion

This paper is based on the multi-objective particle swarm optimization algorithm to improve the green optimization of the existing building design, and the optimization scheme is used as the basis for the educational reform of the architectural design course.

(1) The whole life cycle energy saving rate of the renovated green building reaches more than 85%, and the carbon emission is significantly reduced in the operation phase, which can reduce 3641.39 tCO2e in the whole life cycle, and 106.2606 kgCO2e per square meter per year on average in the operation phase. 10 Pareto-optimal solutions can be derived through calculation, and different optimization solutions can reduce the cost and building carbon emissions. After calculation, the optimized green building in this paper has an increase in the initial cost due to energy saving measures, and a significant reduction in the energy consumption cost during the operation period. The increased investment can be recovered in 6-12 years in all states. Calculated according to the building design life of 70 years, the last 60 years of the whole life cycle are in the state of energy-saving net income, indicating that the green building designed in accordance with the program of this paper has significant economic benefits.

(2) The fuzzy comprehensive evaluation model calculates that the evaluation results of teachers' security, technical environment, teaching content, teaching program and teaching effect are 0.57, 0.66, 0.78, 0.83, 0.89, respectively, and the comprehensive evaluation result is 0.81, which indicates that this paper is excellent for the overall effect of the reform of architectural design education. At the same time, the students' satisfaction with the content, class time, method and technology of the educational reform is 71.09%, 65.63%, 64.84% and 69.53% respectively, through the educational reform, the students' performance has a significant improvement, which indicates that this educational reform is more successful, and the overall satisfaction of the students is high.

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