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Research on the New Path of Integration of Ecological and Intelligent Technologies in Housing Product Designs

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Abstract The rapid development of the economy brings the problem of environmental pollution. The ecological design of housing products is a response to the concept of sustainable development. It is an important means to build an environmentally friendly society. This paper proposes an intelligent control strategy based on deep reinforcement learning for ecological energy-saving control of housing products, and carries out energy-saving and energy-consumption verification simulation for its effectiveness. In order to further analyze the effect of ecological design of housing products, a comprehensive evaluation of ecological design of housing products is carried out through the evaluation index system combined with gray clustering model. The overshoot and static difference were 0.52°C and 0.14°C, respectively, when the intelligent control strategy for housing products was performed for indoor temperature control, and the average monthly energy consumption of housing products was reduced from 52,346 kWh to 36,222 kWh after applying the intelligent control strategy for 2 months. In the ecological design of housing products, the weight of ecological sustainability had the highest proportion of 0.2585, and the gray clustering composite evaluation score of 4.484 points. The integration of intelligent technology and ecological design of housing products can significantly improve the energy-saving efficiency of housing products and provide a new research direction for the sustainable development of ecological environment.

Index Terms sustainable development, housing products, ecological design, deep reinforcement learning, gray clustering model

I. Introduction

In modern society, with the increasing awareness of environmental protection and the rapid development of science and technology, the integration of ecological design and intelligent technology has become an important trend in the field of architecture and environment design. This combination can not only meet people's needs for comfortable and convenient life, but also effectively reduce the impact of the building on the environment and realize the goal of sustainable development [1]-[4].

Eco-designis a design concept based on ecological principles and methods. It emphasizes the full consideration of the natural environment, resource utilization and ecological balance in the design process to achieve maximum benefits with minimum environmental costs [5]-[8]. Intelligent technology is the use of modern information technology, automation control technology and intelligent systems, so that the building has high efficiency, energy saving, comfort, safety and other characteristics. When these two are integrated with each other, a brand new building and environment model is created, which brings many changes to our life [9]-[12]. The combination of eco-design and intelligent technology can significantly improve the efficiency of energy utilization. Through reasonable building layout, orientation and shading design, natural light and natural ventilation can be fully utilized, reducing the dependence on artificial lighting and air-conditioning systems [13]-[16]. Intelligent control system can adjust the operation status of lighting, air-conditioning, ventilation and other equipments in real time according to the changes of indoor and outdoor environments, so as to avoid the waste of energy. In addition, the integration of eco-design and intelligent technology is beneficial to save water resources, improve the quality of indoor environment, and reduce the generation of construction waste [17]-[20].

This paper establishes an intelligent control strategy for housing ecologization with deep reinforcement learning as a guide, and evaluates the effect of ecological design of housing products by combining entropy weight method and gray clustering model. Under the strong impetus of ecological civilization construction, the concept of ecological design has a non-negligible impact on the design method of housing products. The article takes the ecological design theory as the theoretical basis and combines green energy-saving technology and intelligent regulation technology to carry out ecological energy-saving control of housing. The DQN algorithm is used to construct an intelligent control strategy for housing ecologization, and the effectiveness of the intelligent control strategy is analyzed through energy-saving and energy consumption simulation and application. In addition, this paper establishes the evaluation index system of housing product ecological design from five dimensions of society, ecological environment, system, economy and operation and management, and evaluates it through entropy weight method and gray clustering model.

II. Eco-design of housing products and energy-saving controls

Designshoulders the mission of maintaining the sustainable development of mankind. In the history of modern civilization, green energy saving concept has been deeply rooted in people's hearts. Ecological design has become an important means of fully practicing the concept of ecological design. Sometimes design is a form of destruction, it cause resource waste, destroy the mutual integration of human habitat and nature. Therefore, in order to realize the higher value of design, the ecological design concept gradually evolves into the main goal of future housing design development. Supported by the theory of ecological design of housing and environment, it fully combines intelligent technology to realize the sustainable development of housing design.

II. A.Ecological design of housing products

II. A. 1) Ecological design theory

“Design” is primarily a process by which designers intentionally build and shape energy and matter to achieve desired goals and needs, forming natural bonds through the exchange and connection of matter and energy. Any form of design that harmonizes with ecological processes and minimizes its destructive impact on the environment is called eco-design. This means reducing the waste of resources, respecting the diversity of species, maintaining the natural circulation system, preserving the balance of natural ecosystems, and working to improve the harmony of landscape ecosystems in residential areas. Ecological principles are the core as well as the focus of ecological design. Deeply speaking, ecological design is based on the natural system, with the help of nature's own power, the least intervention in the design to create a green and sustainable landscape, ecological design is the way to green and ecological residential areas and must be the means.

II. A. 2) Housing design framework

Based on the theory of ecological design, the ecological design of housing products includes natural ecology and social ecology, natural ecology embodies the harmony between man and nature, while social ecology embodies the harmony between man and man. Therefore, the ecological design of housing products must also be considered from these two aspects. The spatial environment system that embodies the harmony between man and nature and the social environment system that embodies the harmony between human. In addition, with the development of intelligent technology, the influence of technology on the development of ecological settlements is becoming more and more significant. Therefore, The residential product ecosystem needs to be composed of three systems: spatial environment system, social environment system, and technical support system. And the three systems are divided into several subsystems. Its specific framework is shown in Figure 1, which supports the ecological design of housing products with intelligent technology, with the aim of further enhancing the energy-saving efficiency of housing products and reducing the pollution caused by design and construction.

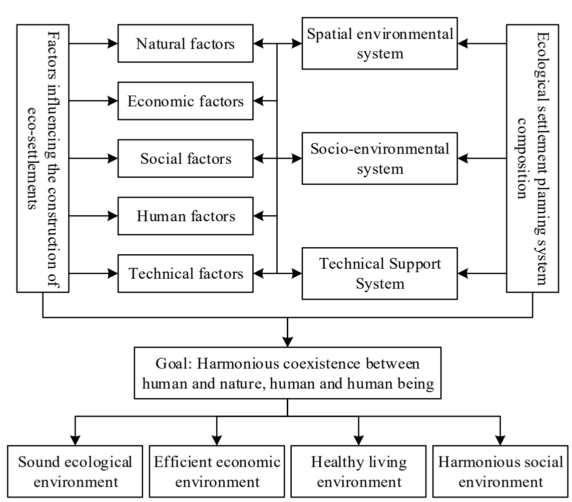

Figure 1: Ecological design framework for housing products

The ecological design and construction of housing products need the support of advanced science and technology, and various ecological technologies are also necessary to support the construction process, energy conservation, health and environmental protection. The technology system of ecological community includes energy, water, sound, light, heat, greening, waste management and treatment, green materials and other nine systems, and then add residential intelligent control management system, a total of ten systems. In the use of these ecological technologies, according to the different regions of the climate and natural conditions, the actual situation of the level of economic and technological development to take the most suitable technology. And through a reasonable combination to achieve the best ecological, economic and social effects, and then realize the ecological design and sustainable development of housing products.

II. B.Energy-saving controls for the ecologization of housing

II. B. 1) Green energy-saving technologies

Green energy-saving technology is an advanced technology based on the concept of sustainable development, promoting energy saving and emission reduction and environmental protection, with high application value. By means of modern intelligent technology, it can realize the reduction of building energy consumption and the improvement of energy utilization and reduce the damage to the natural environment in optimizing the design, operation and manufacturing. The application of green energy-saving technologies in the construction field mainly involves the areas of building facades, building design, electricity, lighting, building materials, air conditioning, ventilation and lighting.

The construction industry plays a pivotal role in social and economic development, but its construction can not be at the expense of the ecological environment, the traditional construction project construction will produce a large amount of noise pollution, light pollution and construction waste, causing great damage to the surrounding ecological environment. With the requirements of sustainable development put forward by the state for all walks of life, the construction industry should pay attention to the protection of the ecological environment when carrying out ecological design, and the application of green energy-saving technology should follow the standardized pollutant management system, which should be carried out in all aspects of the ecological design of housing products, to ensure that the practical application of the technology.

II. B. 2) Intelligent control technology

Intelligent regulation technology is in line with the main prospects of the current development of the big data era, through the use of intelligent equipment to effectively detect the power consumption information, according to the actual needs of the equipment to allocate power, to achieve scientific use. The design model and the research data should simplify the structure of living environment design and decrease the complexity of data analysis in application. [21] And at the same time, it can also build big data information according to the use of electricity, which can provide effective data reference in the future supply of electricity. Intelligent regulation and control technology is also constantly improving with the continuous development of the big data era, and is now deeply promoted in many areas [22].

With the support of intelligent control technology, energy saving and emission reduction can be better realized in the ecological design of housing products, laying a solid foundation for the sustainable development of housing construction. Combining intelligent technology and ecological design of housing products effectively reduces the waste of energy resources in housing products, effectively expands the economic and social benefits of housing products, and thus realizes the reasonable energy conservation and sustainable development of housing products.

III. Intelligent control strategies for the ecological design of housing

In order to meet the needs of group life, intelligent technology in the development of attempts to combine with the current stage of ecological design of housing products, in the development of a reasonable use of a variety of measures and technical means to carry out the overall optimization of the development process of housing products, so that more people can live a better, more comfortable life. Relying on intelligent control technology to give housing products more ecological benefits, so as to better realize the energy saving and emission reduction in the construction industry, and promote the ecological and sustainable development of housing products.

III. A. Intelligent control strategies for housing ecologization

III. A. 1) Deep reinforcement learning theory

Q-learning is the most representative of traditional reinforcement learning algorithms based on a value function, where the Q -value in the algorithm represents the cumulative reward estimate, denoted as $Q(s_t, a_t)$, for taking a given action in a given state of the environment [23]. Q The core process of learning is to continuously update the state-action value function to obtain the optimal strategy. When state s_t is acquired, an optimal action a_t^* will be selected based on the action value, after which it will be applied to the environment to obtain a new state s_{t+1} based on the state transfer probability and an immediate reward r_t. At this point, the value of Q contains an estimate of the future discounted reward, denoted as:

$$Q(s_t, a_t) = r_t + \gamma \max_{a \in A} Q(s_{t+1}, a) \tag{1}$$

Its Q worth updating in the following manner:

$$Q(s_t, a_t) \leftarrow Q(s_t, a_t) + \alpha \left(r + \gamma \max_{a_{t+1}} Q(s_{t+1}, a_{t+1}) - Q(s_t, a_t) \right) \tag{2}$$

where α is the learning rate, which controls the step size when the Q value is updated, when α is larger, it indicates that more attention is paid to the previous training results, and the convergence may be slower, but an effective control strategy can be obtained. γ is the discount factor, which indicates the importance of rewarding future moments.

The core of the Deep Reinforcement Learning (DQN) algorithm is the use of a convolutional neural network to fit the value function. The method inputs the environmental state s into the neural network and goes through the network to score the individual actions, which can be seen as recording the Q table using a neural network, and is more suitable for tasks with high-dimensional state spaces [24]. Then:

$$Q(s, a) = f(s, a; \theta) \tag{3}$$

where function f represents the function fitted by the neural network, θ is the parameter of function f, i.e., the weights of the network, and the training process of the network i.e., the updating of the parameters. Therefore the optimal Q value is expressed as:

$$Q(s, a; \theta) = E\left[r + Q(s', a'; \theta) \mid s, a \right] \tag{4}$$

Use the quadratic cost function to calculate the error for:

$$L(\theta) = E\left\{ \left[r + \gamma \max_{a'} Q(s', a'; \theta) - Q(s, a; \theta) \right]^2 \right\} \tag{5}$$

where $\max_{a'} Q(s', a'; \theta)$ is the value of making the optimal action in the next moment state.

Subsequently, the gradient of the objective function (5) is solved to obtain Eq. (6), and the back propagation algorithm is utilized to update the network parameters according to Eq. (7).

$$\frac{\partial L(\theta)}{\partial \theta} = E\left[r + \gamma \max_{a'} Q(s', a'; \theta) - Q(s, a; \theta) \frac{\partial Q(s, a; \theta)}{\partial \theta} \right] \tag{6}$$

$$\theta_{t+1} = \theta_{t+1} + \alpha \left[r + \gamma \max_{a'} Q(s', a'; \theta) - Q(s, a; \theta) \right] \nabla Q(s, a; \theta) \tag{7}$$

The training flow of the DQN algorithm is shown in Fig. 2.

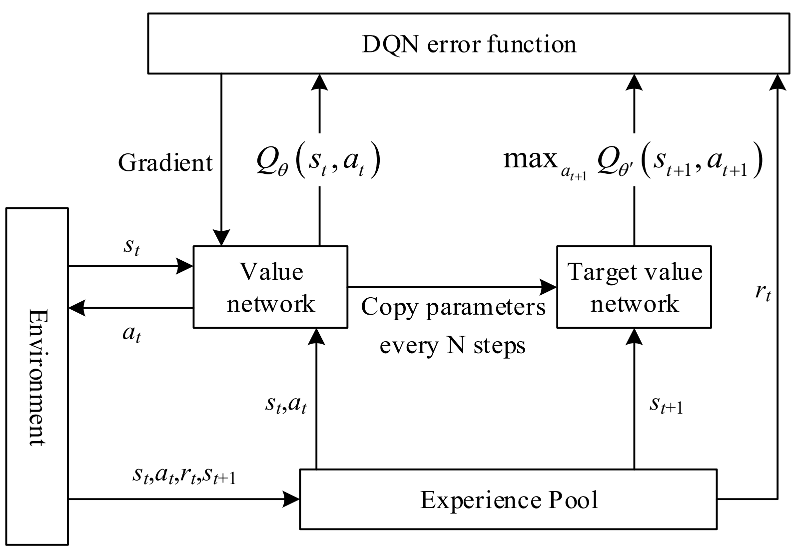

Figure 2: DQN algorithm training flow chart

The DQN algorithm optimizes the policy by "bootstrapping" and TD-Target is computed as:

$$y_t = r_t + \gamma \max_a Q\left(s_{t+1}, a; \theta\right) \tag{8}$$

In this case, the maximizing action leads to a higher value than the true action, and that overestimation keeps on accumulating. At the same time, due to the introduction of the empirical playback mechanism, the non-uniform samples lead to the overestimation is also not uniform. Subsequently, in order to alleviate the Q -value overestimation problem a DDQN algorithm is designed by introducing a dual network on the basis of DQN, which separates the Q -value computation of action selection from the Q -value computation of action evaluation, and establishes two action-value functions, one for selecting an action based on the current state, and the other for evaluating the value of the current state being an individual action, with the TD-target computed as:

$$y_t = r_t + \gamma Q\left(s_{t+1}, \arg\max_a Q\left(s_t, a_t; \theta\right); \theta^-\right) \tag{9}$$

where, θ is the parameter of action selection network and θ^- is the parameter of state evaluation network.

The TD-error is calculated according to the following equation, i.e:

$$L(\theta) = \frac{1}{batch}\sum_{i=1}^{batch}\left(r_i + \gamma Q\left(s_{t+1}, \arg\max_a Q\left(s_t, a_t; \theta\right); \theta^-\right) - Q\left(s_t, a_t; \theta\right)\right)^2 \tag{10}$$

The improvements of DQN over Q learning algorithms are mainly focused on the following 3 aspects:

(1) DQN introduces a neural network to approximate the action value function as a way to solve the dimensionality catastrophe problem, which allows DQN to cope with high-dimensional sensory inputs.

(2) A target network is introduced in DQN to deal with the TD error separately, so as to optimize the loss function and reduce the correlation between the target Q value and the estimated Q value, thus solving the training instability problem.

(3) The empirical playback mechanism is introduced to solve the problem that the algorithm is difficult to converge when the input data do not satisfy the independent homogeneous distribution, and at the same time, the correlation between the samples is broken, which improves the utilization efficiency of the data and the stability of the algorithm.

III. A. 2) Integrated housing energy control

In order to realize the ecological design of housing products, this paper introduces the DDQN algorithm for the integrated control of the energy integrated system of housing products. The heat pump and battery control of the energy system of housing products in this paper belongs to the continuous action space, to realize the cooperative control of the two, the ensemble space of the actions in the Markov process will be a multi-dimensional matrix, so the TD algorithm will have a greater advantage to deal with the high-dimensional space. At each time step, the TD model selects actions through the actor network, observes the rewards and new states fed back from the environment after executing the actions, and then evaluates these state-action pairs using the critic network, and updates the parameters of the actor and critic networks through the back-propagation algorithm, which allows the model to gradually learn the optimal control strategy.

The study modeled the building energy system, including components such as batteries and heat pumps, and the problem is transformed into a reinforcement learning task by designing the state space, action space, and reward function. In the state space, twelve states are considered such as the building load demand, PV power generation, and the electricity price, in which the PV, the temperature, and the irradiation intensity are exogenous to the model. In the action space, the relationship between the operation of the heat pump and the real-time electricity price is considered, and the start and stop of the heat pump is turned on intelligently, the heat pump operation time is reduced when the electricity price is too high, and the heat pump operation time and the frequency of turning on are increased when the electricity price is low. The battery action considers the charging and discharging behavior, and the reward function considers adding relevant expert experience knowledge, and the design of the reward function is consistent with the optimization objective of this paper, i.e., the minimization of the economic cost of the energy system and the enhancement of the local consumption of PV.

III. B. Validation of smart controls for housing ecology

III. B. 1) Experimental results of room temperature regulation

According to the projection of the Ministry of Housing and Construction, the electricity consumption of split air-conditioner operation in housing products in winter accounts for a large proportion. Therefore, the intelligent monitoring and management of split air conditioners is of great significance to energy saving and emission reduction of housing products. Usually common household split-type air conditioners mostly use simple manual control, often through the infrared remote control to control the operation mode of the air conditioner, it is difficult to automatically adjust the operation status of the air conditioner according to the indoor temperature and humidity status. As a result, split air conditioners operate at high loads most of the time, which not only makes it difficult to keep the indoor temperature within a reasonable range to ensure the comfort of the indoor personnel, but also creates an unnecessary waste of energy, which is not in line with the concept of ecological design.

In order to verify the effectiveness of the energy intelligent control system for housing products proposed in this paper, the indoor temperature intelligent regulation is verified under the winter working conditions from 8:00 to 17:00 on January 20, 2024, taking the example of the secured housing in S province. Firstly, the real-time monitoring of indoor temperature is completed by the indoor integrated sensor, and the data recording is realized in the form of log by the intelligent unit controller of building space. The data collection interval of the indoor integrated sensor is 3s. Considering the stability of the actual operation of the split air conditioner and saving energy consumption as much as possible, the air supply temperature and wind speed of the split air conditioner should be adjusted with priority to the air supply wind speed, and the air supply temperature of the split air conditioner should be adjusted appropriately when the indoor temperature still can't satisfy the indoor temperature demand after adjusting the wind speed. Split air conditioning air supply temperature and air supply gear control cycle are 2min/time, by the controller every 2 minutes at the same time to record the current cycle of indoor temperature, split air conditioning air supply temperature and fan gear. The specific experimental results are shown in Fig. 3, and the changes in the control targets and the actions of the actuators are analyzed as shown in Table 1.

The experimental results show that under winter conditions, for an office with an indoor temperature of 21℃, the room temperature can be maintained in a suitable range after using the room temperature regulation system based on split air conditioning, the transition time of indoor temperature change is about 3.2 hours, and the overshoot and static difference of indoor temperature are 0.52℃ and 0.14℃ respectively, which can meet the indoor personnel's demand for temperature. During the 9-hour experiment, the number of adjustments of the air supply gear and the air supply temperature were 18 and 15 times respectively, and their adjustments were more reasonable. The air supply temperature and air supply speed of the split air conditioner can be automatically adjusted according to the real-time monitoring value of the indoor temperature, which indicates that local control of the split air conditioner can be realized for the housing product unit to minimize the load on the grid system and reduce energy consumption. Therefore, by connecting the widely used split air conditioning system in housing products to the energy intelligent control system of housing products, the precise regulation of indoor temperature can be realized, and a better control effect can be achieved, which effectively meets the ecological design of housing products and provides new technical support for energy saving and emission reduction.

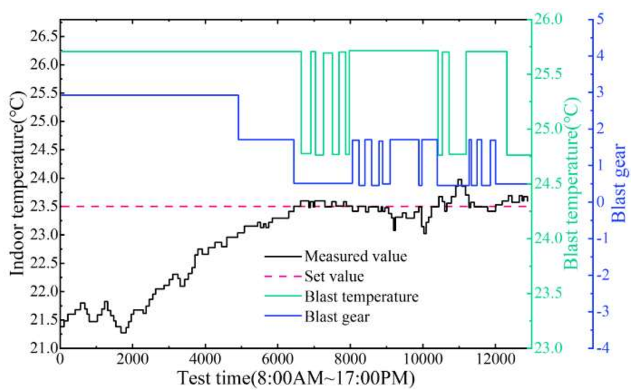

Figure 3: Experiment results of room temperature control

Table 1: Analysis of results

Indoor temperature measurement		Control number of actions	
Transition time	3.2h	Air blast gear adjustment	18
Overadjustment	0.52℃	Air blast temperature regulation	15
Static difference	0.14℃	-	-

III. B. 2) Power dispatch demand control

In order to further validate the effectiveness of the energy intelligent control system for housing products designed in this paper, a simulation analysis is performed. Assuming that there is a SBC park with a feeder capacity of 10 MW located in a hot summer area, there are a total of 2,000 domestic electric water heaters contracted for residential buildings. Unlike split air conditioners, electric water heaters are used in discrete time periods, so instead of grouping electric water heaters together, the first search is for water heaters that are in use to cut their loads each time they need to be dispatched, and the water heaters that are not activated are turned on when they need to be regulated upward. The SBC is equipped with a 600kW distributed wind power generation system and a 1000kW distributed photovoltaic power generation system. Assuming that this new energy generation is completely absorbed by the SBC load, the load curve after the actual load consumes the new energy is used as the original data for simulation, and the power purchase curve is obtained by subtracting the sum of the PV forecast and the wind forecast from the forecasted load.

The actual composite deviation curve after absorbing PV and wind power on July 7, 2024 is used for rolling decomposition, and then the absolute value of the raw demand value at different moments is obtained according to the lowest frequency IMF. If the deviation is positive at that second, the demand value takes a positive value, and vice versa, the demand value takes a negative value. After logical judgment of the above raw demand value as the scheduling order value, according to the previous section in the housing product energy intelligent control system to establish the aggregation model, and temperature control load action program formulation, and finally get the actual action value. Fig. 4 and Fig. 5 show the comparison results of the absolute value of the original demand of electricity and the scheduling order value with the actual action value, respectively.

From the figure, it can be seen that the actual action value is basically able to track the curve of the dispatching ordered value, and its relative error is around ±1.27%. In some places where the ordered values are too close to each other, it is not appropriate to change the action program frequently considering the life of temperature-controlled loads, and it is sufficient to maintain the previous action.

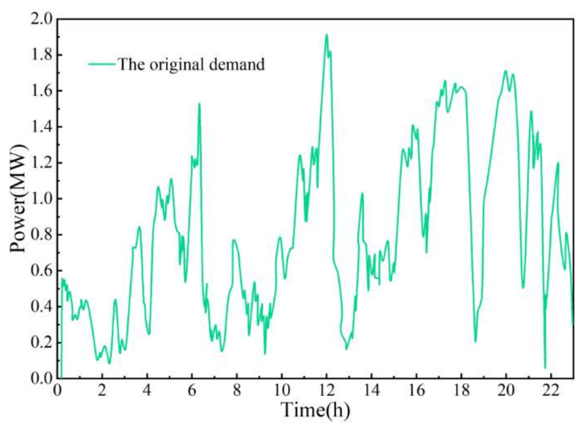

Figure 4: Absolute value of the original demand

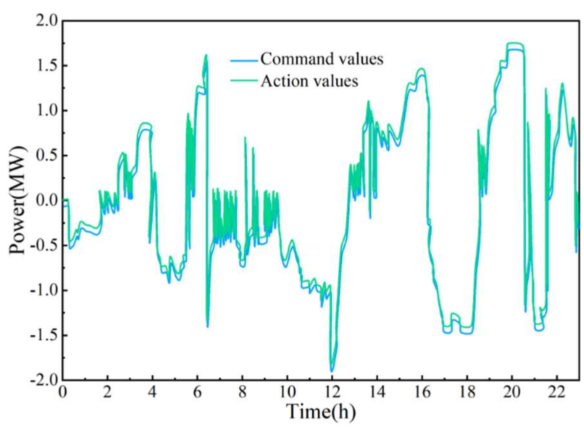

Figure 5: Comparison between command values and action values

After simulating the real-time simulation control, the power dispatch control effect of the housing product energy intelligent control strategy is obtained as shown in Figure 6. As can be seen from the figure, the maximum power of the load profile before the intelligent control compensation is 4.81MW, while its maximum power after compensation is 4.32MW, the maximum power is reduced by 10.19%, and the all-day RMSE is reduced from 29.35% to 6.84%. It can be seen that this strategy can effectively compensate the power load deviation of the housing product and realize the tracking of the real-time load curve to the day-ahead forecast curve. And the IMF power with higher center frequency is used as a small fluctuation area, which significantly reduces the number of ordered actions, thus the comfort of users is guaranteed, and it is also an effective embodiment of the ecological design of the housing product, which can more reasonably realize the effective planning of power resources.

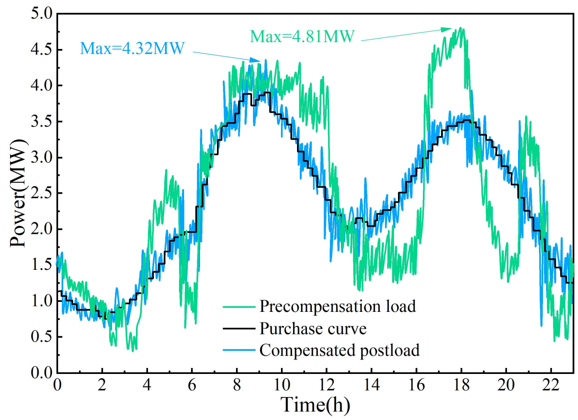

Figure 6: The overall control effect of Electric dispatching

III. B. 3) Energy consumption before and after energy-saving controls

The intelligent control strategy for housing products designed in this paper is applied to the energy-saving renovation of Y district in T province, and the effect of energy-saving renovation is compared after the system has been running for 2 months as a way to verify the role of intelligent technology in facilitating the ecological design of housing products. Table 2 shows the energy consumption comparison results before and after the energy-saving transformation of housing products.

As can be seen from the table, in the two months before the ecological energy-saving intelligent control of housing products, its average monthly energy consumption reached 52,346kWh, while after the trial operation of the ecological energy-saving intelligent control system for two months, the average monthly energy consumption of housing products was reduced to 36,222kWh, an overall reduction of 30.8%. Among them, the average monthly energy consumption of air-conditioning system, water supply and drainage system, lighting system, compartment elevator and escalator has been saved by 32.88%, 27.12%, 30.99%, 18.05% and 52.18%, and the escalator has the biggest effect of reducing energy consumption. This is due to the fact that before the transformation, the escalator needs personnel to manually control the elevator switch every day, and the control method is backward, and the elevator has been running at industrial frequency after it is turned on, which consumes a lot of energy. After the transformation of energy-saving intelligent control, the elevator switching time will be controlled regularly by the intelligent control system, which does not require personnel to manipulate all the time. And through the infrared sensor signal control to adjust the running state and speed of the elevator, no one ride the building automation elevator monitoring system automatically stops the elevator running. In conclusion, through the combination of intelligent technology and ecological design of housing products, the energy loss in the design process of housing products can be significantly reduced, providing assistance for the sustainable development and energy efficient application of housing products.

Table 2: Energy consumption contrast before and after energy saving

Name	Before 2 months (kWh)			After 2 months (kWh)		
	1	2	Means	1	2	Means
Air-conditioning	58924	61276	60100	40127	40553	40340
Water supply	16517	17231	16874	12315	12279	12297
Lighting system	10948	10814	10881	7593	7425	7509
Wing elevator	12547	12339	12443	10157	10237	10197
Escalator	4327	4461	4394	2124	2078	2101
Total Means	52346			36222		

IV. Evaluative analysis of eco-design of housing products

In the modern society where people's living standard is increasing, the proportion of construction investment in housing products is getting higher and higher, and higher requirements have been put forward for the living environment, which leads to the continuous increase in the consumption of financial resources, manpower and material resources, resulting in the unavoidable waste of resources, and causing certain damage to the environment, and the use of some substandard construction materials will also have an impact on the health of the human body. In this regard, housing product ang environment designers should actively learn ecological concepts, ecological concepts into the housing product design, break the cage of design concepts, and enter a broader world of design concepts. To study the environmental superiority of the ecological concept, scientific and rational and healthy green space design, in order to create a comfortable, healthy, environmentally friendly and safe living environment.

IV. A. Evaluation model for ecological design of housing

IV. A. 1) Construction of the evaluation indicator system

Evaluation of ecological design of housing products is a process that involves many complex factors, and its evaluation includes technology, environment, greening, environmental protection, users' feelings and so on, and all the indicators are not a simple combination, but an organic whole. In order to ensure the scientific and rational selection of evaluation indicators, it must be based on the principles of independence, operability, science, flexibility and the combination of qualitative and quantitative indicators. Based on this, the research combines the existing relevant research to construct an ecological design evaluation index system for housing products as shown in Table 3, which mainly includes five sustainability dimensions: social development, ecological environment, economic development, institutional development and operation and maintenance management.

Table 3: The evaluation index system of housing ecological design

Dimension layer	Index layer	Code
Social development (SD)	Environmental facilities	SD1
	Regional coordination	SD2
	Social adaptability	SD3
	Building energy saving service	SD4
	Regional cultural value	SD5
	Social satisfaction	SD6
Ecological environment (EE)	Design planning	EE1
	Environmental bearing capacity	EE2
	Regional ecology	EE3
	Resource optimization configuration	EE4
	Green construction	EE5
Economic development (ED)	The total life cycle cost of the building	ED1
	Net present value	ED2
	Investment recovery period	ED3
	Affordability	ED4
	Green performance	ED5
Institutional development (ID)	Policy guidance	ID1
	Technical support	ID2
	Economic preference	ID3
	Sound management system	ID4
	Public interest	ID5
Operational management (OM)	Intelligent building	OM1
	Equipment operation	OM2
	Property management	OM3

IV. A. 2) Entropy weighting method for determining indicator weights

The theory of determining weights through entropy weighting uses computational concepts and methods as an alternative to data theory. Relatively intense competition means that these weights represent the number of indicators that provide valid information, and the entropy weighting method is reported to decision makers [25]. The specific steps are as follows:

(1) The matrix consists of initial data consisting of estimated m -item and n -indicator values. Enter the indicator values for the j indicators to be evaluated online. If the decision matrix of the evaluation indicator is X and X_{ij} is the jth indicator value for the ith object. Then the initial matrix X is:

$$X=\begin{bmatrix} x_{11} & x_{12} & x_{13} & \dots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \dots & x_{2n} \\ x_{31} & x_{32} & x_{33} & \dots & x_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & x_{n3} & \dots & x_{nn} \end{bmatrix} \tag{11}$$

(2) It is important to confirm the proximity between indicators, as indicators include both positive and negative indicators, all of which are normalized. The normalization formula for each indicator is:

$$P_{ij}=\frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{12}$$

(3) Determination of the entropy value of j indicator, viz:

$$E_j=-n\sum_{i=1}^{m}\left(p_{ij}\ln p_{ij}\right) \tag{13}$$

(4) Normalize the entropy values. This normalization requires the use of the maximum value of entropy that matches all indices $E_{\max}=\ln\frac{1}{n}$. Second, the entropy weights of all indices are:

$$e_j=-\ln\frac{1}{n}\sum_{i=1}^{m}\left(p_{ij}\ln p_{ij}\right) \tag{14}$$

(5) The coefficient of variation of the evaluation indicators is:

$$h_j=1-e_j \tag{15}$$

(6) Calculate the entropy weights of the evaluation indicators based on the coefficient of variability as:

$$w_j=\frac{h_j}{\sum_{j=1}^{n} h_j} \tag{16}$$

It is clear that the higher the conversion factor for each indicator, the more information the entropy weights contain and the less information they contain. The entropy weights are particularly important. In terms of information, when determining the required evaluation object, the entropy weights are used to correct the evaluation indicators to make them more scientific, rational and reliable.

IV. A. 3) Gray clustering evaluation model

The basic principle of the gray clustering method is to use the gray correlation matrix to construct the gray whitening weight function, and the evaluation indexes are analyzed by clustering. When evaluating the indicators, the comprehensive factors of all aspects should be considered, and the observable indicators should be categorized based on the objectively obtained information [26].

Let there be n object to be studied, p evaluation indicators and s different grades, then the eigenvalue of the evaluation indicator $j\left(j=1,2,\cdots,p\right)$ of the first object to be studied $i(i=1,2,\cdots,n)$ is $x_{ij}\left(i=1,2,\cdots,n;\, j=1,2,\cdots,p\right)$, then the sample space consisting of the evaluation indicators of each object to be studied can be expressed as follows:

$$X=\begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix}=\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{p} \\ x_{21} & x_{22} & \cdots & x_{p} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{np} \end{bmatrix} \tag{17}$$

In the formula, X_i represents the object to be studied i, x_{ij} represents the eigenvalues of the evaluation index j of the object to be studied i; if the object to be studied i is attributed to the $k\left(k\in\{1,2,\cdots,s\}\right)$th class, let

$f_j^*(\cdot)$ be the degree of x_{ij} belonging to the kth gray class, and from this, the j index k subclass whitening weight function is constructed, and noted $f_j^k\left[x_j^k(1), x_j^k(2), x_j^k(3), x_j^k(4)\right]$.

The calculation steps of the gray clustering evaluation model are as follows:

(1) Construct j indicator k subclass whitening weight function $f_{i,j}^k(\cdot)(j=1,2,\cdots,p;k=1,2,\cdots,s)$.

(2) Calculate the gray whitening weight coefficient of each indicator.

A unit under evaluation belongs to the gray number interval, then p bid evaluation experts to advocate the kth category of gray evaluation of the whitening weight coefficients were recorded as $f_{ij}^k\left(v_{ij1}\right), f_{ij}^k\left(v_{ij2}\right), \cdots, f_{ij}^k\left(v_{iq}\right), \cdots, f_{ij}^k\left(v_{ijp}\right)$, of which v_{ijq} refers to all p bid evaluation experts to select the qth expert to give the score.

(3) Determine the gray evaluation weight matrix.

Each evaluator's evaluation indicator x_{ij} corresponding to the rating v_{ij} is a gray number, let the trd expert's rating is recorded as v_{ijt}, then p evaluators corresponding to the ratings are $v_{ij1}, v_{ij2}, \cdots, v_{ijp}$, respectively, then the evaluation indicator rating v_{ij} belongs to the kth evaluation of the gray category of the whitening weight function is:

$$x_{ijk}=\sum_{t=1}^{p} f_{ij}^k\left(v_{ijt}\right)(t=1,2,\cdots,p) \tag{18}$$

The evaluation factor x_{ij} is then:

$$x_{ij}=\sum_{k=1}^{g}\sum_{i=1}^{p} f_{ij}^k\left(v_{ijt}\right)=\sum_{k=1}^{g} x_{ijk} \tag{19}$$

The ratio of the two, r_{ije}, is called the gray evaluation weight for each gray category:

$$r_{ijk}=\frac{x_{ijk}}{x_{ij}} \tag{20}$$

The gray evaluation weight matrix r_i is obtained from the vectors consisting of gray evaluation weights as $r_{ij}=\left(r_{ij1}, r_{ij2}, \cdots, r_{ijs}\right)$, $i=1,2,\cdots,m$, $j=1,2,\cdots,p$ as:

$$r_i=\begin{pmatrix} r_{i1} \\ r_{i2} \\ \vdots \\ r_{i3} \end{pmatrix}=\begin{pmatrix} r_{i1}^1 & r_{i1}^2 & \cdots & r_{in}^s \\ r_{12}^1 & r_{i2}^2 & \cdots & r_{12}^s \\ \vdots & \vdots & \ddots & \vdots \\ r_{in}^1 & r_{in}^2 & \cdots & r_{in}^s \end{pmatrix} \tag{21}$$

(4) Determine the comprehensive evaluation matrix

Using the above equation $R_i=w_{ig}\times r_{ij}$ can get the affiliation degree of each evaluation index of the guideline layer, and then determine the gray evaluation matrix of the guideline layer R_i, then there are:

$$R_i=\begin{pmatrix} R_1 \\ R_2 \\ \vdots \end{pmatrix}=\begin{pmatrix} R_1^1 & R_1^2 & \cdots & R_1^s \\ R_2^1 & R_2^2 & \cdots & R_2^s \\ \vdots & \vdots & \cdots & \vdots \end{pmatrix} \tag{22}$$

Then, the comprehensive evaluation matrix for the target level is calculated, such that R_t^k indicates the degree to which the evaluation object j belongs to the krd C_k evaluation level, then there is:

$$R_t^k=\sum_{i=1}^{m} w_i R_{ti}^k \tag{23}$$

In the formula, m represents the number of evaluation indicators in the criterion layer of the evaluation object: from this, the evaluation vector of multi-indicator comprehensive measurement is $R_t^k=\left(R_r^1, R_r^2, \cdots, R_r^s\right)$.

(5) Maximum affiliation identification criterion

The evaluation vector of multi-indicator comprehensive measurement of R_t is known, so the maximum affiliation identification criterion can be used, then it is concluded that the object t belongs to the gray category k^*, then there are:

$$k_t^* = \max\left\{k : R_t^k, k = 1, 2, \cdots, s\right\} \quad (24)$$

IV. B. Evaluation and analysis of ecological design of housing

IV. B. 1) Determination of evaluation indicator weights

The Y district of T province selected in the previous section as the research object, the housing ecological design evaluation index system is made as a questionnaire, and the Likert five-level scale is used to quantify the data, 200 questionnaires were distributed in the district, and 187 valid questionnaires were recovered. The data obtained were counted, and the entropy weight method given before was used to solve the entropy value and entropy weight of the housing ecological design evaluation indexes using SPSS software, and the weight distribution of the housing ecological design evaluation indexes is shown in Figure 7.

As can be seen from the figure, the entropy values of the evaluation indicators of the ecological design of housing products are all over 0.95, and the weights of social development, ecological environment, economic development, institutional development and operation and maintenance management are 0.1854, 0.2585, 0.1758, 0.1579, 0.2224, respectively, in which the weight of ecological sustainability is the highest, and the weight of institutional development sustainability is the lowest. This indicates that the ecological design of housing products focuses more on the sustainable development of the ecological environment, while the corresponding institutional development is less considered, but the whole will have an impact on the ecological design of housing products. Among the secondary indicators, building intelligence (OM1) has the highest weight (0.0918), which indicates that the introduction of intelligent technology into the ecological design of housing products can help the operation and maintenance management of housing products, and can also effectively improve the efficiency of the ecological intelligent control of housing products, fully realize the energy saving and emission reduction of housing products, and provide reliable technical support for the realization of the ecological design of housing products. Public interest (ID5) has the lowest weight (0.0244), which belongs to the dimension of sustainability of institutional development, and the public interest needs to be paid full attention to, and the ecological design of housing products needs public participation, so as to realize the ecological good development of housing products.

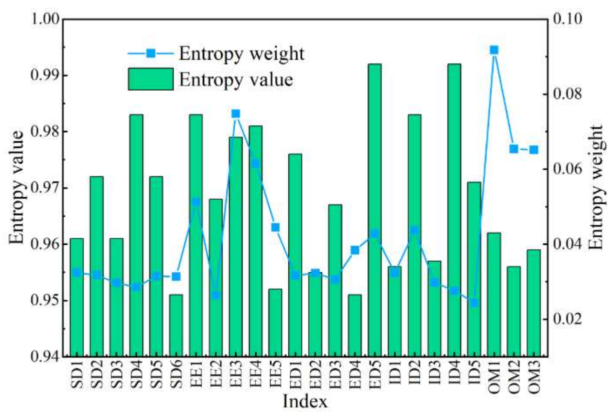

Figure 7: The weight distribution of the evaluation index

IV. B. 2) Comprehensive gray clustering evaluation

After clarifying the weights of the evaluation indicators of ecological design of housing products, the gray clustering evaluation model given in the previous section is used to carry out a comprehensive evaluation of ecological design of housing products. According to the quantitative range of the evaluation criteria, the set of linguistic descriptions of the secondary indicators is categorized into general, good, very good and excellent, and divided into four levels of [0~2], (2~4], (4~7], (7~10]. The higher the score of each evaluation indicator, the higher the indicator level. Then 10 experts in the field of ecological design of housing buildings were selected for scoring and their results were used to construct a gray sample matrix.

On this basis, based on the gray theory, the hybrid center point whitening weight function is used to construct the gray category grading, and it is set that there are four gray categories, and the four evaluation gray category intervals from one to four stars are indicated by 1, 2, 3 and 4 respectively, and the inflection point of each gray category corresponds to 1, 3, 5.5, 8.5, so as to derive the whitening weight function of each gray category. Then based on the gray class whitening weight function formula, combined with the scoring gray matrix of the second-level indicators, the gray weight matrix of each second-level indicator is calculated to determine the gray weight matrix of each second-level indicator. Based on the above steps, the comprehensive evaluation results of each level of indicators are obtained as follows:

$$\begin{cases} SD = W_{SD} * R_{SD} = [0.058, 0.479, 0.431, 0.032] \\ EE = W_{EE} * R_{EE} = [0.043, 0.468, 0.483, 0.006] \\ ED = W_{ED} * R_{ED} = [0.032, 0.384, 0.538, 0.046] \\ ID = W_{ID} * R_{ID} = [0.029, 0.435, 0.498, 0.038] \\ OM = W_{OM} * R_{OM} = [0.044, 0.485, 0.457, 0.014] \end{cases} \tag{25}$$

According to the principle of maximum affiliation, it is known that the grades of social development, ecological environment, economic development, institutional development and operation and maintenance management are Grade 2, Grade 3, Grade 3, Grade 3 and Grade 2 respectively. Then according to Equation $B = W \times R$, the comprehensive evaluation result of ecological design of housing products is obtained as:

$$\begin{aligned} B &= W \times R \\ &= [0.1854, 0.2585, 0.1758, 0.1579, 0.2224] \\ &\times \begin{bmatrix} 0.058 & 0.479 & 0.431 & 0.032 \\ 0.043 & 0.468 & 0.483 & 0.006 \\ 0.032 & 0.384 & 0.538 & 0.046 \\ 0.029 & 0.435 & 0.498 & 0.038 \\ 0.044 & 0.485 & 0.457 & 0.014 \end{bmatrix} \\ &= [0.042, 0.454, 0.480, 0.025] \end{aligned} \tag{26}$$

According to the principle of maximum affiliation, it can be seen that the comprehensive evaluation grade of ecological design of housing products in Y neighborhoods in T province is three levels. In order to further analyze its score, the evaluation set set combined vector set in the previous section is used to calculate its final score:

$$K = B \times V^T = [0.042, 0.454, 0.480, 0.025] \times [1, 3, 5.5, 8.5] = 4.484 \tag{27}$$

In summary, the comprehensive evaluation score of ecological design of housing products in Y neighborhood of T province is 4.484.

From the results of the evaluation, the degree of development of ecological design of housing products has been significantly improved in the process, in which the most important indexes are social, ecological environment, system and operation and management indexes. And based on these five indexes, the evaluation method of ecological design of housing products for sustainable development is constructed and tested with relevant examples, which can provide reference for promoting the ecological construction of housing products.

V. Conclusion

The research constructs an intelligent control strategy for ecological housing products with deep reinforcement learning, and evaluates the ecological design effect of housing products through a gray clustering model. Using the intelligent control strategy of housing products can maintain the temperature of housing in a suitable range, the transition time of indoor temperature change is about 3.2 hours, and the overshoot and static difference of indoor temperature are 0.52℃ and 0.14℃ respectively, which can satisfy the indoor personnel's demand for temperature. And 2 months after using the intelligent control strategy, the average monthly energy consumption of the housing product is reduced from 52,346kWh to 36,222kWh. In the ecological design of the housing product, the weight of building intelligence is the highest (0.0918), and the comprehensive evaluation score obtained through the gray clustering evaluation model is 4.484, which is more consistent with the actual situation of the ecological design of the housing product. Therefore, combining intelligent technology with the ecological design of housing products can help to improve the sustainability of housing products and provide assistance in reducing energy consumption to maintain the ecological environment.

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