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Analysis and Evaluation of Holistic Energy Saving for Modern Buildings

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Abstract

The basic developing objects of modern society are low carbon and energy saving. We must change the traditional high energy consuming building ways into modern novel energy saving buildings. In this paper, the development of modern building energy saving technology was reviewed and concluded. On this basis, designing ways and methods for energy saving system was proposed from the points of walls, doors and windows, roofs, and grounds. The concept of evaluation index of energy saving building was put forward, and the objectives and principles of evaluation index of energy saving building were analyzed. Finally, take the modern energy saving residential housing as an example, we discussed in tail how to establish the evaluation index system for energy saving residential housing, and confirmed the weight and standard for evaluating the residential housing, and ensured the gray multi-hierarchy structure comprehensive method. We also proposed that in this modern situation, we should seize the opportunity, pay attention on energy saving, construct energy saving building, and establish the evaluation index system. In this way, building energy saving work can be further developed and it plays an important role in saving energy and protecting the environment.

Keywords: *energy saving, modern buildings, design method, evaluation index*

1. Introduction

Because of the continuous energy consumption since the last century, CO_2 concentration in the atmosphere is increasing year by year. Increase of global temperature results in the climatic anomaly and ecological destruction, endangering the basic human living environment [1]. Besides, with the continuous increasing price of energy such as petroleum, coal, and electricity, the problem of energy saving is located in front of every industry. The building industry is an important object for energy saving because its energy consumption reaches 30% of the social total energy consumption [2]. We must change our traditional building construction way into modern novel energy saving building under the restrain of source and environment to realize the social goal of low carbon and energy saving.

Energy saving building is defined as a new type of buildings. In their planning, design, and usage process, new type of materials are adopted, building energy standard is executed, operation and management of building device is enhanced, the thermal performance of enclosure structure of building is designed reasonable, the efficiency of heating, refrigeration, illumination, ventilate, water supply and drainage, and aisle system is improved, and take advantage of reproducible energy, in the premise of ensuring the using functional and indoor thermal environment quality in the building, the energy consumption is reduced, and the resource is utilized reasonably and efficiently. The significances of constructing modern energy

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saving building are as follows: (1) the situation of energy lack can be eased and the national economy demand can be increased; (2) ecology environment can be protected and the environment pollution can be reduced; (3) the thermal environment can be enhanced and can meet the need of human living environment; (4) social resource assignment result and the energy configuration can be improved, and the enterprise competitiveness can be enhanced [3]. Building energy saving is a giant project with the widest range, rich of meaning, complex situation, less investigation, quick efficiency, and huge development potential. It is an effective route to destroy the energy bottleneck constraint, and can remit the contradiction of energy short. It is also the most direct and cheapest way to realize better human living life, less environment pollution, improve the economy continuous development, and an easy choice for building a well-off society.

Since the first energy crisis break out in 1973, petroleum price have been soaring, and the energy saving problem has drawn people’s wide attention. The building energy consumption takes about 1/3 of global energy. Besides this, a lot of pollution is discharged into the atmosphere, such as total suspension particles (TSP), SO_2, NO_x, etc. Thus, some developed countries starts to pay great importance to building energy saving. In the developed countries, building energy saving has experienced three stages: (1) energy saving in buildings, that is to save energy in building process; (2) energy conservation in buildings, that is to conserve the energy and reduce the energy loss; (3) energy efficiency in buildings, that is to improve the building energy usage efficiency from a positive view. In our country, the meaning of building energy saving has been reached to the third stage. In the recent years, green buildings, ecological buildings, and sustainable development buildings have been carried out, however, building energy saving have always been their core and key. The first building energy saving design standard was carried out in 1986 in our country, indicating we have 20 years of history for building energy saving work [4]. Since then, a lot of works concerning of building energy saving have been done by our government. A series of projects, policies, plans, and standards have been formulated to push the development of building energy saving technology and building energy saving industry.

However, some plans and projects for building energy saving came to some difficulty. The present survey to the situation of building energy saving in northern buildings shows that, the energy saving buildings which reach their energy saving standard are only 6.4% of the total buildings. In the national house buildings up to 2000, the area of buildings which reach the urban building energy saving heating design standard is only 180 million square meter and this is only 0.6% of the total urban building area [5]. There are serious problems such as poor heat preservation, gas tightness, and low heat supplement efficiency exist in more than 27 billion square meter buildings. The result reveals that the good building energy saving environment of our country has not been formed, and the building energy saving work should be further improved.

2. Design Methods for Modern Building Energy Saving System

2.1 Content of Building Enclosure Structure Energy Saving

Building energy consumption is defined as the energy consumption during the building usage, including heating condition, air conditioning, hot water supplement, lighting, household applications, and elevators. The energy lost through building enclosure structure and consumed in heating and cooling system takes up a large part of total building energy consumption. So the worldwide building energy saving work is always around two aspects: the enhancement of heat insulation and preservation of building enclosure structures, and the improvement of efficiency of heating and cooling system. In recent years, some works has been carried out about the sub new resources such as solar energy and ground heat energy. Building energy saving is to utilize energy reasonably and improve the energy usage efficiency continuously under the conditions of ensure the building comfort.

Different parts in the building enclosure structure have different heat consumption index in different energy saving stages. With the increase of building energy saving demand, the variation of distribution proportion of every part of building enclosure is also becoming large, as shown in Table 1 [6]. Therefore, in different energy saving stages, the methods should be taken according to the heat consumption distribution of every part of building enclosure, in order to reduce its heat consumption and ensure the total heat consumption demand of the whole building.

Table 1. Heat Consumption Distributed Situation of Various Parts of Building Enclosure

	Outside wall /%	Outside window /%	House face /%	Other parts /%	Ari permeation /%	Total heat transfer and consumption /[(W/m^2)/%]	Heat consumption index /(W/m^2)
No energy saving	25.5	23.7	8.6	19.2	23.0	27.43/86.26	31.8
Saving 50% of energy	27.5	18.9	7.9	24.7	21.0	19.26/93.5	20.5
Saving 65% of energy	16.8	16.9	5.9	32.6	27.8	13.32/91.23	14.6

2.2 Outside Wall Energy Saving

The outside wall heat preservation is to put the heat preservation and insulation system outside the wall in order to realize the heat preservation effect. The heat preservation effect is enhanced obviously due to this layer, whose thermal resistance is larger than 1 m2K/W [7]. Because the heat is preserved from the outside, the structure must meet to demand of water tightness, wind resistance, and temperature and humidity adaption. It is not easy to produce cracks and can resist the impact effect from outside. The function of outside preservation layer should be noticed, that is the increase of heat preservation and the corresponding demands, as shown in Table 2. The heat preservation layer will not improve the stability of outside main wall. The main wall is the basis of heat preservation layer, which should meet the requirement of mechanical stability of buildings and can bear vertical load, wind load, and resist impact to ensure its safety usage, and the covered heat preservation and decorated layers can be fixed tightly.

Table 2. Heating Preservation System Requirement of Outside Wall

Examine Item	Property requirement
Resistance to wind load	System resistance to wind load value is not lower than wind load designed value
Resistance to impact	Safety index K of EPS plane and ESP particle heat preservation system should not smaller than 1.5. Safety index K of mechanical fixation EPS system should not smaller than 2.
Resistance to impact of building	Building first wall and doors, windows: 10J level. Building second wall: 3J level.
Water adsorption	After dipping in water for 1 h, the water adsorption is not larger than 1.0 kg/m^2.
Freeze-thaw resistance	After 30 times of freeze-thaw recycles, there are no hollow, falling off, and water seepage. The tensile adhesive strength should not smaller than 0.1 MPa, and the destroy part should in the protective layer.
Thermal resistance	Meet the design requirement.
Water tightness	Not permeable to water for 2 hours.
Vapor permeable of protective layer	Meet the design requirement.

The heat preservation system of outside walls should meet the quality demands as follows.

(1) Heat preservation effect. Key index such as enough thickness should be calculated according to the actual thermal property of raw materials and by thermal engineering, in order to meet the requirement of local building energy saving design standard.

(2) Stability. Combined tightly with the basis wall, which is the basic step to ensure the stability of heat preservation layer.

(3) Fireproof treatment. Fireproof treatment should be carried out according to the demands strictly.

(4) Resistance to humidity and thermal. Strict methods should be taken in the surface of outside wall, including the surface layer, junction point, around pores and doors and windows, etc. Proper measurements should be adopted to prevent the dew formation inside the wall. Finally, the outside wall should resist the local strict climate and its variation.

(5) Impact resistance.

(6) When the main building structure distorts, there is no cracks.

(7) Durability. The lifetime should be more than 25 years under normal usage and service condition.

(8) Construction deviation. It is difficult to avoid the deviation during work process. The deviation should be as small as possible.

(9) Repair. Regular checking and repairmen should be done.

(10) The product quality of raw materials used in outside wall, and project quality should be controlled in order to ensure the quality of heat preservation system.

2.3 Constitute of Doors and Windows Energy Saving System

Materials constituting for doors and windows includes: window frame materials (including the frame and sash materials forming the windows), hardware (hand fitting, driving medium), auxiliary materials (depression layer, sealing strip, and glass block), glass (usable flat and curve glass, transparent or non-transparent glass), and window caulking materials (such as rock wool, etc.) and so on. The principles of energy saving doors and windows are divided into heat obtained and heat loss.

Firstly, some factors will influence the quantity of heat obtained from sunshine.

(1) The position and direction of windows. In winter, the position of sun in the mid-day is relatively lower, so that sunlight can enter into the room from south windows, which can help to reduce the heating cost in the room in winter. In summer, the sun rise to a high position in high noon, there is little sun light shines directly to the southern window, which is reflected back in such a small angle.

(2) Window design. Windows which have wide and vertical window frame, or are composed by small windows, can obtain solar energy by very little glass area. If narrow window frame and big glass are used, more sunshine will enter into the room.

(3) Choice of glass. The area of glass is usually 70% of the total door and windows, which is the key part of energy saving design of doors and windows. Hollow glass should be used in aluminum alloy glass with an optimum gap between two glasses of 12 mm. Double layer hollow glass can reduce 20% of the total sunshine heat than single layer hollow glass in the same area. White glass can transfer more sunlight into the building than coating film and color glass.

(4) Sunlight shade problem. Curtain indoor and trees outdoor will influence the sunlight. For example, deciduous trees with fewer branches should be considered in the south of room, in order to shield the strong sunlight in summer and allow the sunlight to go through the room in autumn after the leaves fall down.

After considering these factors, we should take some steps to configure the doors and windows. A lot of energy passes through the windows in bidirectional flow obviously. In daytime, solar energy is obtained from south windows in radiation method. At night, the heat is lost by convection, radiation, and conduction methods. For the north windows, the heat is lost by convection and conduction. The heat seasons of east and west windows are unsure. In summer, the windows in four directions are all obtaining energy to cause hot temperature. If the directions of windows are not considered, the heat insulation and energy saving properties of windows can be improved by using these methods.

(1) Reduce the windows area as much as possible. Doors and windows are key parts of building enclosure to separate and communicate the environment in and out doors. It requires not only good heat insulation property, but also lighting and ventilating functions, becoming important parts for energy saving design. Under the conditions of ensure the sunshine, lighting, and ventilating, the area of outside door and windows can be reduced as much as possible. At the same time, the controlling of window and wall ratio is very important, which is better to lower than 25% in the north, not larger than 35% in the south, and not larger than 30% in the east and west [8].

(2) Choose an appropriate window type. The popular window type at present is casement window, sash window, fixed window, bright window, and suspended sash window, and so on. In these types, casement and sash windows are most produced. Casement window is advantaged at large ventilate area and good gas tightness,

which meets the requirements of this field, and its safety, easy, and low fabrication cost, which makes it popular in hot summer and cold winter area.

(3) Add thermal preservation and heat insulation layer in the doors and windows. Firstly, heat transfer resistance should be increased by using air layer between glasses of the window, since air has low heat conductivity coefficient (0.04 W/m^2K). Another method to insulate heat is to add inert gases or other heat insulating gases into the two glass layers. Secondly, heat insulating property of window frame should be considered. The heat insulating property is to increase its heat transfer resistance, which is benefit to reduce the heat transfer mass and energy consumption. Heat conductivity coefficient of window frame and heat insulating volume in the frame are two important factors to influence the heat transfer resistance of window frame. Wood and plastic frame should be the first choice. Steel and aluminum with high heat conductivity coefficient are not chosen for energy saving windows. They are required to be pre-treated by spraying plastics or other methods to improve their heat insulating property.

(4) Materials with good heat insulation property should be chosen as window frame. According to the heat insulation coefficients of different materials in Table 3, PVC has the lowest heat insulation coefficient, so it is the best one to be used as window frame material.

Table 3. Heat Insulation Coefficient of Different Materials

Window frame materials	Alumina alloy	Insulated aluminum alloy	PVC
Heat insulation coefficient (W/m^2K)	4.49	3.63	2.78

2.4 Roof Energy Saving Design

Most of the roofs of our countries are flat, which is poor in heat preservation and insulation functions. The rooms in the top floor loss a lot of heat in cold winter, while their temperature in summer are always 2-3 °C higher than other rooms in the bottom. What's more, the flat roofs are difficult to ensure the water tightness property. Water leak and crack are always happening in rainy days. Therefore, some energy saving measurements should be taken for improving the heat preservation and insulation method of flat roofs [9].

(1) Put a heat preservation layer using materials with small heat capacity and high heat conductivity. Their water adsorption should also be very small, because large amount of water adsorption will reduce the heat preservation effects of the layer.

(2) Lay a kind of heat insulation materials on the top of roofs to fabricate a composite energy saving roofs. The materials could be chosen as polystyrene board and rock wool board. The thickness should be calculated and should be water tightness.

(3) Inversion type roof could be considered. The structure of inversion type of roof is "slope layer-flat layer-water tightness layer- combination layer- heat preservation layer- insulation layer (optional)-protection layer". This structure has a lot of advantages such as water tightness, climate resistance, aging process delay, and so on.

(4) Build temperature reflecting reduction roofs. The reflection of sun radiation will be increased by spray white or light color materials outside the roofs, and the indoor temperature could be reduced by 1-2 °C.

(5) Plants roofs. Shrub and grasses planted in the roofs can not only beautify the city and building, but also adjust the temperature, prevent the pollution, and increase the heat preservation property.

(6) Water store roof is also a good choice in summer to reduce the sunshine radiation and the high temperature in the room.

2.5 Ground Energy Saving Analysis

In most of the foreign buildings, there are basement and underground spaces in order to save energy and meet the space requirement for heater and water heater. Moreover, hot water with temperature of 40-50 °C flowing in high density polyethylene tube buried underground can heat the whole ground and reduce the heat consumption by approximately 15%, which is called low temperature floor heating system. The heat sink device of low temperature floor heating system is the whole floor. Heat can be adjusted by water system in the tubes under the floors, which improves the heat comfort by a large degree than traditional heating system. When the hot water of 60 °C is injected into the tubes, the floor temperature can usually reach 26 °C and the room temperature is about 16-20 °C. The floor temperature is higher than room temperature, making people more comfortable. There is no heater in the room space so that the usage area of room is increased. The tubes is made of aluminum plastic composite material and buried underground, which will not be corroded and incrusted. A heat preservation layer in the ground can improve the sound insulation property. The floor heat system using cables can also be adopted and the floor temperature can be heated to 20-28 °C.

3. Objective and Principles of Energy Saving Building Evaluation System

During the planning, design and building process, and final acceptance of construction process of energy saving houses, reasonable building design using energy saving materials and reproducible devices is realized by the energy saving technology. Under the conditions of house safety and heat comfort, energy usage efficiency is improved continuously; energy consumption is reduced after comprehensive consideration of economy, society, and environment benefit. In this work, we analysis the influence factors by comprehensive analysis method and qualify these factors to form an evaluation system for energy saving house. The principle for carrying out these energy saving evaluation system is as follows.

(1) They must meet the design criterion of national building codes, civil building energy saving standards, living performance evaluation technology standards, heating residential building energy saving inspection standards, and so on.

(2) Building of energy saving houses should comply with the national standards and local climate, and use new resource and reproducible energy as much as possible (solar energy, wind energy, and floor heat energy, etc.).

(3) Strict quality control should be carried out for energy saving houses in the early design and plan, work construction, and check stages to improve the executing quality of energy saving design standard and to enlarge the commitment range of energy saving house evaluating signs.

(4) Building energy saving houses should insist the principles of environment protection, and realize the transformation from energy saving houses to ecological houses and green houses.

4. A case Study-evaluation System of Energy Saving House

Energy saving house evaluation is carried out step by step according to its functional object and hierarchy evaluation index structure. The evaluation system is built up layer by layer after making the relationship of every factor clearly. After research and analysis of articles about energy saving house evaluation system at home and abroad, we discover that the present evaluation index system is mainly focused on the house building energy consumption, but lack of evaluation on building technology and economy. In our work, the evaluation system contains performance evaluation mode to indicate more information about energy saving house. The energy saving house evaluation index is shown in Figure 1. The layer structure of energy saving house evaluation index is shown in Figure 2.

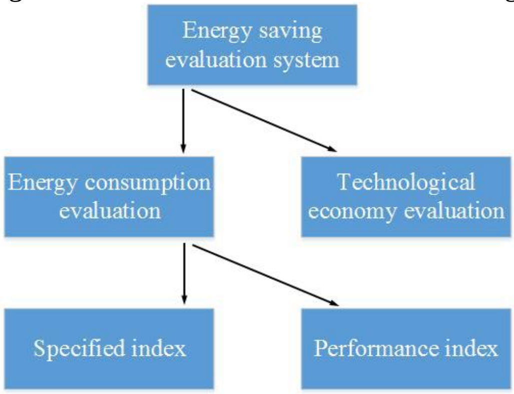

Figure 1. Evaluation System Structure of Energy Saving Houses in this Work

The objective layer is the first level index: energy saving evaluation of energy saving house. The second level index is the component parts of energy saving house evaluation system, including building comprehensive energy consumption evaluation index, building design and evaluation index, building enclosure structure evaluation index, building heating air conditioning system evaluation index, and building technological economy evaluation index. The third level of index of energy saving house is the influence and judgment factors about energy saving house evaluation, which is the refining of the principles and the basic elements of the whole evaluation system [10].

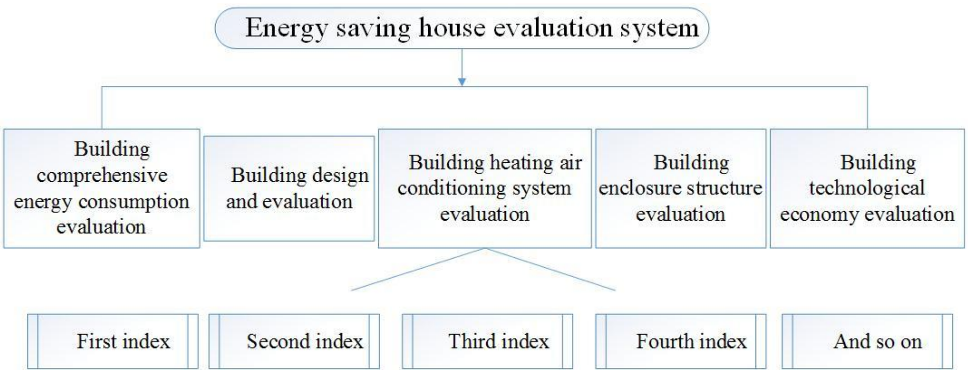

Figure 2. Layer Structure of Energy Saving House Evaluation Index

There are many kinds of evaluation methods for energy saving house. Different results will be caused by different evaluation methods, so it is demanded to choose a proper method for ensuring the scientific and reasonable meaning of energy saving house evaluation. In this work, the gray multi-hierarchy comprehensive estimating method is used to evaluate the energy saving house. The basic thinking of gray multi-hierarchy comprehensive estimating method is estimate the base layer index from single layer, and take this result as the initial index of nest layer. Then the single layer comprehensive estimating model is established and the multi-hierarchy estimating model is further built gradually. The evaluation system in this work contains three layers, that means the third index of system is estimated firstly, and then the total objective estimation result is realized for the second index.

It is assumed that "criterion-index layers" estimation system is a single layer system containing *m* indexes and *n* plans (every single house building corresponding to a plan). Then the plan *i* with *m* indexes can constitute a series $X_{ik} = [X_{i1}, X_{i2}, \ldots, X_{im}]$, ($i = 1, 2, \ldots, n$; $k = 1, 2, \ldots, m$). The initial data of *n* plans constitute the following matrix:

$$X = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1m} \\ X_{21} & X_{22} & \cdots & X_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ X_{n1} & X_{n2} & \cdots & X_{nm} \end{bmatrix} \tag{1}$$

The steps for examining the plans uasing gray multi-hierarchy comprehensive estimating method is as follows:

(1) Confirm the optimum index X_{0k}.

$$X_{0k} = [X_{01}, X_{02}, \ldots, X_{0k}] \tag{2}$$

Where X_{0k} ($k = 1, 2, \ldots, m$) is the optimum value of index *k* in the *m* plan. For many evaluation standards, the optimim development direction should consider the actual situation in the areas. The best index can ensure the energy saving house to reach the optimum property in whole.

(2) Normative approach of index value.

In the evaluation index system, normative approach of initial index should be done for comparison between different indexes because different dimension and order of magnitude of every index. The approach equation is as follows:

$$\lambda_{ik} = \frac{X_{ik} - X_i^{\min}}{X_i^{\max} - X_i^{\min}} \tag{3}$$

Where λ_{ik} represents the normative value of index *k* X_{ik} of plan *i*, X_i^{min} means the minimum value of index *k* in all of the plans, and X_i^{max} is minimum value of index *k* in all of the plans. After normative approach, the index matrix is as follows:

$$X = \begin{bmatrix} \lambda_{01} & \lambda_{02} & \cdots & \lambda_{0m} \\ \lambda_{11} & \lambda_{12} & \cdots & \lambda_{1m} \\ \lambda_{21} & \lambda_{22} & \cdots & \lambda_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ \lambda_{n1} & \lambda_{n2} & \cdots & \lambda_{nm} \end{bmatrix} \tag{4}$$

(3) Coefficient of association degree calculation

The index series after normative approach {λ_{0k}} = {λ_{01}, λ_{02}, …, λ_{0k}} is the basic evaluation standard series. The other index series after normative approach {λ_{ik}} = {λ_{i1}, λ_{i2}, …, λ_{ik}} is the comparable series. The coefficient of association degree between the k index of plan i and the k index of basic evaluation standard series is $\xi_i(k)$, (i = 1, 2, …, n; k = 1, 2, …, m). The equation for calculating coefficient of association degree is as follows.

$$\xi(k) = \frac{\min_i \min_k |\lambda_{0k} - \lambda_{ik}| + \rho \max_i \max_k |\lambda_{0k} - \lambda_{ik}|}{|\lambda_{0k} - \lambda_{ik}| + \rho \max_i \max_k |\lambda_{0k} - \lambda_{ik}|} \tag{5}$$

Where ρ is the resolution ratio range from 0 to 1, which is usually 0.5.

The coefficient matrix of association degree E is:

$$E = \begin{bmatrix} \xi_1(1) & \xi_2(1) & \dots & \xi_n(1) \\ \xi_1(2) & \xi_2(2) & \dots & \xi_n(2) \\ \dots & \dots & \dots & \dots \\ \xi_1(m) & \xi_2(m) & \dots & \xi_n(m) \end{bmatrix} \tag{6}$$

Where $\xi(k)$ (i = 1, 2, …, n; k = 1, 2, …, m) is the association coefficient between index k of plan i and the index k of basic index series.

(4) Building gray single layer estimating model

Formula of model R is as follows:

$$R = P \times E \tag{7}$$

R = [r_1, r_2, …, r_n], which is the comprehensive estimating results matrix of n plans. r_i is the comprehensive estimating results matrix of plan i. P = [p_1, p_2, …, p_n], which is the weight allocation matrix of the corresponding estimating index. So, the gray comprehensive estimating results matrix is as follows.

$$r_i = (p_{i1}, p_{i2}, \dots, p_{im}) \bullet \begin{bmatrix} \xi_i(1) \\ \xi_i(2) \\ \dots \\ \xi_i(n) \end{bmatrix} \tag{8}$$

(5) Building gray multi-layer comprehensive estimating model

Table 4. Level Signs of Energy Saving House Comprehensive Evaluation

Level of energy saving comprehensive evaluation	Gray multi-hierarchy comprehensive evaluation result
Excellent	[85, 100]
Fine	[75, 85]
Middle	[65, 75]
Qualified	[60, 65]
Below standard	[0, 60]

According to the basic thinking of gray multi-layer comprehensive estimating method, the estimating result of "standard-index layers" style is formed finally. Then, a comprehensive evaluation can be realized combining the weight assignment of standard layer in the whole objectives.

The model R can be multiplied by 100 as a level of energy saving house evaluation sign, which is shown in Table 4.

As discussed above, the evaluation system of energy saving living house has been built and established. In this situation, it is urgent to seize the opportunity, pay much attention to energy saving work, construct energy saving building, and establish the evaluation index system. In this way, building energy saving work can be further developed and it will play an important role in saving energy and protecting the environment.

5. Conclusions

The limit of resource and environment in our country requires us to change the traditional building ways to modern building methods. The modern building must contain necessary energy saving approaches. In this work, the design ways and construction methods were analyzed taking modern building as the research objective. The energy saving building evaluation index was proposed and its typical method was analyzed as well. Finally, a case study about energy saving living house evaluation is put up and gray multi-layer comprehensive estimating method is established. Our country should pay attention to energy saving building and evaluation index system, which will play an important role on environment protection and energy saving work.

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