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The Economic Evaluation of Lighting Energy-saving Modification Program

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Abstract

Many lighting energy-saving modification programs have the embarrassment of uneconomical. This paper takes into account economic evaluation to solve the problem. According to illuminative equipments price, life span and power consumption, the optimal program will be found under the limited investment. Firstly, the benefit ratio will be used to evaluate on the equipments modification necessity, and get the modification sequence. If the biggest benefit ratio is in different equipment simultaneously, the better one will be selected in terms of relative investment recovery period. The relative remaining time is innovatively introduced into economic evaluation for determining the equipments modification locations. Then the system operation flowchart is to prove that the scheme is workable.

Index Terms: Lighting energy-saving modification; benefit ratio; relative investment recovery period; relative remaining time

1. Introduction

The Chinese government take "building an economic society and environment friendly society" as the basic national policy, marking our country entering the period of energy-saving society. Thus many users have opportunely modified their illuminative equipment in order to saving energy. According to investigation, many energy-saving modification programs have the embarrassment of uneconomical [1]. Why? The quality of lighting equipments is rather spotty in Chinese market. What's worse, users modify the illuminative light blindly, not according to the foundation of the electricity-saving benefit [1], [2].

Thus, the user has to evaluate the effect of energy-saving modification from economic view. The economic evaluation is calculated in economic effectiveness, which helps the user to choose the optimal energy-saving program [3]. According to statistics, the common methods are life cycle cost method, payback period method and net present value method, which are used to evaluate the economy of program [4], [5], [6]. (1) The life cycle cost method pursues the minimum discounted cost, which is suit to comparative evaluation of various programs.

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The target of life cycle cost method is minimum discounted cost, which is suitable to compare various programs. (2) The payback period method evaluates the recovery of investment, which uses the indicator of payback period to observe the recovery speed. The payback period method evaluates the effect of investment, and the speed of return is seen from the payback period directly. (3) The net present value method valuates short run and certain investment project, which is calculated by discount rate of the cost of capital [7]. However, the cost recovery speed can't be seen through life cycle method. The payback period method doesn't take the effective discount rate into account. In practical application, there's a great deviation between the anticipated investment and the reality because of the net present value [8], [9], [10]. Thus this paper combines the advantages of these major methods, and introduces these three indexes, which include benefit ratio, relative investment recovery period and relative remaining time to evaluate the economic benefit and get the optimal modification program.

2. The Principles of Modification

Illuminative light are classified into five types as follows: incandescent, fluorescent (T12/T8/T5/compact fluorescent lamps), high-pressure mercury lamp, high-pressure sodium (HPS), metal halide lamp (MH). Ballasts include electronic ballast and magnetic ballast [11]. Most of the user's power consumption is in the indoor fluorescent lighting. Thus this paper is mainly concerned about fluorescent lighting and cites four factors, which are price, power consumption, life span and running time, to establish the economic evaluation to get the best energy-saving modification program. These four factors are common features of lighting equipments. Therefore, based on economic evaluation of fluorescent lighting modification program can be applied to metal halide lamps, high pressure sodium and high pressure mercury lamps and other lighting equipment.

Generally, user can't carry out the modification of all illuminative lights due to limited fund. Therefore, the principle of corresponding modification is introduced in this paper to work out the best program of saving energy. The principles of corresponding illuminative equipment are as follows:

(i) Only when the benefit ratio of equipment is bigger than 0 can it be modified .The bigger the benefit ratio of the equipment is, the bigger the benefit of energy-saving is. There's no doubt that that equipment, which has the maximum benefit ratio, should be modified first. Thus, the principle should be followed for having sort of benefit ratios, which is the ranking from the largest down to the smallest. Based on the benefit ratios, the best brand of lighting equipments and their modification sequence can be obtained.

(ii) If the maximum benefit ratio exists in different equipment, the equipment with minimum relative investment recovery period should have priority to be modified. T When the relative payback period is smaller; its investment recover time is shorter. Thus, the principle should be followed for having sort of relative payback period, which is the ranking from the smallest to the largest.

(iii) When the biggest benefit ratio and shortest relative investment recovery period is found in different equipment, those will enjoy the same right to be modified. On the basis of it, the specific location of modification will be decided in terms of relative remaining time. If the time is shorter, it means that its life span is shorter, and its chance to be abandoned is bigger. Thus it should be modified first.

What must be emphasized here is that the relationship among these three indexes including benefit ratio, relative investment recovery period and relative remaining time are subordinate. The relative investment recovery period is subordinate to the benefit ratio, and the relative remaining time is subordinate to the relative investment recovery period. If the benefit ratio of equipment A is larger than that of equipment B, then even the relative investment recovery period of B is much longer than A, A still has priority in modification. In the same way, if the relative investment recovery period of equipment A is longer than that of equipment B on the condition that they has the same benefit ratio, then even the relative remaining time of B is much longer than that of A, A should be considered firstly to be modified.

3. Based on Economic Evaluation of Lighting Modification Program

3.1. Energy-saving benefit

In this paper, in terms of the same luminous flux, the equipment which has less power consumption can be called energy-saving illuminative equipment. The energy saving can be calculated by the power conversion relation of lighting equipments, and then obtain their energy-saving benefit.

1) The relation of power conversion among illuminative light [11]

According to the relation of power conversion, the power consumption can be obtained in terms of the same luminous flux.

Table 1 The relationship of power conversion

Equipment		Alternative Product
T8	18W	T12/20W
	30W	T12/30W
	36W	T12/40W
T5	14W	T12/20W or T8/18W
	21W	T12/30W or T8/30W
	28W	T12/40W or T8/36W
CFL	9W	Incandescent 40W
	11W	Incandescent 60W
	15W	Incandescent 75W
	30W	Incandescent 100W
MH	Replace HPS /HPM of the same power	
Electronic ballast	Replace magnetic ballast of the same Power	

Note: T12 stands for coarse diameter fluorescent, T8 and T5 stand for two different types of small diameter fluorescent lamps, CFL stands for compact fluorescent lamp, MH stands for metal-halide lamp, HPS stands for high-pressure sodium lamp, HPM stands for high-pressure mercury lamp.

According to power conversion relation, the energy saving of energy-saving equipment can be obtained in terms of the same luminous flux.

2) The energy saving [7]

$$\Delta A_i^{'} = a_i^{'} - a_i \quad (i = 1, 2, 3, \cdots, m) \tag{1}$$

Where, $\Delta A_i^{'}$ stands for quantity of unit-hour energy saving of the i kind after replacing current-used illuminative equipment, hour/kilowatt; a_i stands for unit-hour power consumption of current-used illuminative equipment i; $a_i^{'}$ is unit-hour power consumption of energy-saving illuminative equipment that replaces current-used illuminative equipment i in terms of the same luminous flux; m stands for the amount of illuminative light which are replaced.

After the quantity energy saving is obtained, energy-saving benefit is calculated according to the price of electricity, cost of investment, discount rate and life span, and there will be a conclusion whether to modify the equipment in terms of the quantity.

3) The energy-saving benefit of per energy-saving illuminative equipment

The present value of energy-saving benefit of the illuminative equipment i in t year is the result energy-saving benefit in t year minus the cost of total investment in t year:

$$M_i^{'} = \sum_{t=1}^{n_i} M_{it}^{'} \tag{2}$$

$$\begin{cases} M_{it}^{'} = (P_t \cdot \Delta A_i^{'} \cdot T_{it}^{'} - c_{it}^{'}) \cdot (1+i_s)^{-t} \\ c_{it}^{'} = \dfrac{p_i^{'} + \sum_{t=1}^{n_i} m_{it}^{'}}{T_i^{'}}, T_i^{'} = \sum_{t=1}^{n_i} T_{it}^{'} \end{cases} \quad (t = 1, 2, 3, \cdots, n_{ij})$$

Where, $M_i^{'}$ is the present value of energy-saving benefit after replacing current-used illuminative equipment i, RMB; $M_{it}^{'}$ is the present value of energy-saving benefit in t year after replacing current-used illuminative equipment i, RMB; P_t is the price of electricity in t year, RMB/(kW·h); $c_{it}^{'}$ is the assessed cost of total investment in t year, RMB/year; $T_{it}^{'}$ is the running time in t year, and the total running time of each year based on past data, hours/year; p_i is the purchase price of current-used illuminative equipment i; $p_i^{'}$ is the purchase cost of energy-saving illuminative equipment; $m_{it}^{'}$ is the maintenance cost in t year and treated as a fixed value; T_i is the life span of current-used illuminative equipment i; $T_i^{'}$ is life span of energy-saving illuminative equipment; i_s stands for discount rate, %; n_i is the total running years of energy-saving illuminative equipment.

In order to simplify process, the investment cost just includes purchase cost of energy-saving illuminative equipment, and the maintenance cost of energy-saving illuminative equipment is out of consideration. Supposing annual running time of illuminative equipment is fixed and the price of electricity of per kilowatt-hour is always one Yuan. And overall discount rate is 10%.

a) When the replacement occurs to illuminative equipment with different power, energy-saving benefit is : $M_i^{'} = (P_t \cdot \Delta A_i^{'} \cdot T_i^{'}) / (1+10\%) - pc_i^{'}$.

For example, the life span of T8/18W is 10,000 hours, and its purchase price is 10 RMB. After T8/18W replaces T12/20W, energy-saving benefit is :
$(20-18) \times 8500 / (1000 \cdot (1+10\%)) - 10 = 6.3$ RMB

b) When the replacement occurs to the illuminative light in the same power, energy-saving benefit is: $M_i^{'} = (p_i / T_i \cdot T_i^{'}) / (1+10\%) - p_i^{'}$.

3.2. The economic evaluation of energy-saving benefit

The benefit ratio can be calculated by energy-saving benefit of per energy-saving illuminative equipment, and then put the equipment for modification in order. Benefit ratio is the ratio of total benefit divided by total investment. The energy-saving equipment that has the maximum benefit ratio would get priority to be modified.

$$B_i^{'} = O_i^{'} / C_i^{'} = M_i^{'} / p_i^{'} \tag{3}$$

$$\begin{cases} N_i^{'} = C_i^{'} / p_i^{'} \\ O_i^{'} = N_i^{'} \cdot M_i^{'} \end{cases}, \text{and } I_i^{'} \geq p_i^{'}$$

Where, $B_i^{'}$ is the benefit ratio; $O_i^{'}$ is the overall effectiveness; $C_i^{'}$ is the overall cost that just including purchase cost of energy-saving illuminative equipment, and its maintenance cost is not considered; $N_i^{'}$ is the amount of energy-saving illuminative equipments.

After the benefit ratio is obtained, in order to solve the problem that the maximum benefit ratio occurs to different energy-saving equipments, the relative investment recovery period is introduced. The relative investment recovery period can be calculated by annual running time and life span.

$$R_i^{'} = I_i^{'} / A_i^{'} \tag{4}$$

$$\begin{cases} I_i^{'} = p_i^{'} / (\Delta A_i^{'} \cdot P_t) \\ A_i^{'} = T_i^{'} / n_i \end{cases}$$

Where, $I_i^{'}$ is investment recovery period, hours; $R_i^{'}$ is relative investment recovery period, year; $A_i^{'}$ is annual running time, hours/year. As the annual running time is the same, so $T_{it}^{'} = A_i = A_i^{'}$.

After the benefit ratio and relative investment recovery period are obtained, in order to solve the problem that how to make sure the specific location in modification, relative remaining time is introduced. Relative remaining time is the ratio of annual running time divided by remaining life span.

$$R_{ij} = (T_i - T_{ij}) / a_{ij} \qquad (j = 1, \cdots, n) \tag{5}$$

Where, R_{ij} is the relative remaining time of illuminative equipment i in location j; T_i is the service life of illuminative equipment i; T_{ij} is the total running time of illuminative equipment i in location j; a_{ij} is the annual running time of illuminative equipment i in location j, hours/year.

3.3. The determination of program

According to the principles, the benefit ratio can select the best brand of energy-saving illuminative light, and get the modification order of current-used equipments. When the maximum benefit ratio exists in different equipment, the relative investment recovery period is taken consideration for finding out the faster one. On this basis, the relative remaining time is taken into consideration to make sure the specific location for modification. Therefore, the optimal energy-saving program can be obtained from these three indexes when the fund and the specific modification are clear.

The determination of energy-saving modification program has four key factors: investment, objects, time and location. The investment in real life is often limited. Even if a plan can produce the greatest benefit ratio, if the cost is greater than the investment, it had to be abandoned. Therefore, this paper studies how to produce the best modification program from the angle of limited investment and makes users timely adjust the best program under the limited fund. This paper only modifies the current-used lighting equipments by assuming that the modification time is current. After such a simplification, the determination of program has only two key factors: the modification objects and the locations.

When only comparing the total value of energy-saving benefit, the maximum benefit of modification program can only be obtained on the condition of rich fund. Thus the energy-saving benefit of unit lighting equipment can be obtained through the benefit ratio. The relative value's real advantage over total value is that it pursues the optimization benefit of unit investment. Therefore, when comparing the benefit ratios of different equipments, it can directly reflect each equipment benefit under limited investment, which helps us to choose the best one; when comparing the relative investment-recovery periods of different equipments with their annual-running time, it can help us to choose the fastest one. By using relative remaining time to reflect the modification urgency of various regions' equipments, the modification locations can be obtained.

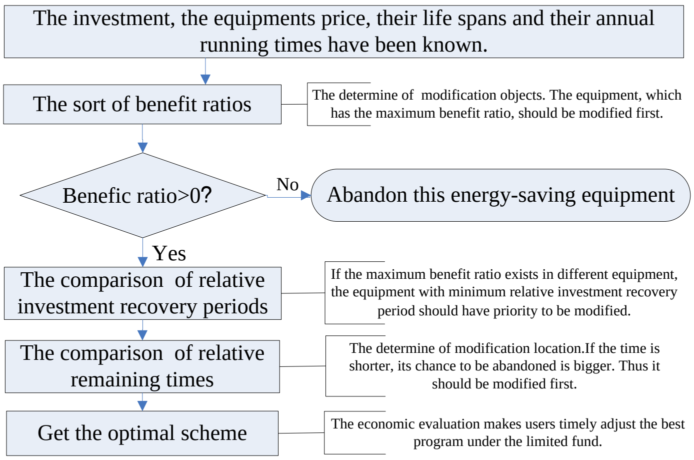

Fig 1. The system operation flowchart

From Fig. 1, the optimal program process is as follows: Firstly, the number of energy saving is calculated by power conversion and the benefit of power save will be showed by the price of electricity, the cost of investment, discount rate, and life span. Secondly, the benefit ratio of equipment of various brands is seen in terms of unit price of equipment, energy-saving benefit and life span. Thirdly, according to life span, price and annual running time, relative investment recovery period can be worked out. Last of all, the relative remaining time will be acquired in accordance with life span, time of operation of different location in the equipment. According to the principles of modification and these three indexes, the optimal energy-saving program is worked out by economic evaluation.

4. Conclusions

This paper sets up the economic evaluation in terms of three major indexes including benefit ratio, relative investment recovery period and relative remaining time. The constraint condition economic evaluation is investment fund, and the objective is to get biggest energy-saving benefits after modification. Thus, the best program can be selected according to investment fund and object for modification. Because the lighting equipments have general character, so this method can be applied to other lighting equipment. Of course, a good energy-saving program only has the basis on saving energy, when it has good performance indexes on economic evaluation. The key to save energy depends is on the daily users. When the people are aware of saving energy well, the energy-saving effect is much better than that of the modification of the illuminative lights.

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