

Article

Economic Evaluation of Energy-Saving Retrofit of Existing Hotels

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Abstract: With the improvement of China's economic strength, the energy consumption of public buildings is continually increasing, notably for hotels. The energy consumption of a hotel accounts for more than 15% of its revenue, and the average energy consumption per floor area is more than 10 times that of urban residents. Therefore, the energy-saving retrofit of existing hotels is imperative. This study investigates the economic evaluation methods for existing hotel retrofit projects, and constructs an economic evaluation model using economic evaluation and cost-effectiveness ratio as the base. The energy-saving retrofit measures of 15 existing hotels in Jiangsu Province, China, are used as a case study to demonstrate the research framework. The results indicate that the heating, ventilation and air conditioning (HVAC) system, monitoring system, lighting system, domestic hot water system, and building envelope system are the five energy-saving retrofit technical measures with the highest application ratio. The average dynamic investment payback period of hotels in Jiangsu Province is 2.96 years, which meets the requirement of no more than 10 years specified in the energy-saving building standard. The cost-effectiveness ratio of different technologies differs significantly. Lighting and kitchen systems have the highest energy-saving efficiency, followed by monitoring systems, while HVAC and domestic hot water systems have the lowest. The research presented in this paper contributes to the economic evaluation of the energy-saving retrofit of hotels.

Keywords: existing hotels; post-occupancy evaluation; retrofit cost; energy savings; economic evaluation



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1. Introduction

The energy-saving retrofit of existing buildings refers to the activities of implementing energy-saving retrofit of heating, ventilation and air conditioning (HVAC) systems, monitoring systems, lighting systems, domestic hot water systems, and building envelope systems [1] of existing buildings that do not meet the mandatory standards for energy savings in civil buildings. In recent years, with the increasing energy consumption of buildings, the energy-saving retrofit of existing buildings has become an important part of energy-saving research for building. Currently, studies concerning the field of energy-saving retrofitting of existing buildings have been conducted worldwide, forming relevant markets, mature retrofit technologies, and post-evaluation methods [2–4]. In addition, various researchers have analyzed the optimization methods of energy-saving retrofitting by employing theoretical research, software simulations, and project evaluations [5,6]. Their findings have revealed that energy-saving retrofitting is very important for economic and environmentally friendly development and achieving a sustainable development strategy [7].

China's existing public buildings cover an area of about 4.5 billion m², accounting for 10.7% of the national urban housing construction area [8], but their annual electricity consumption has reached 22% of the total electricity consumption of the national cities

and towns. The annual power consumption per m^2 is 10~20 times that of ordinary houses in China and 1.5~2 times that of similar buildings in developed countries such as Japan and Europe [9]. According to statistics, the energy consumption per floor area of public buildings in Jiangsu Province of China is 5~10 times that of ordinary houses. Government office buildings and large public buildings account for about 6~10% of the total number of urban buildings, but the energy consumption accounts for 50% of the total building energy consumption, which is equivalent to that of all residential buildings [10]. As a large public building, the average annual power consumption per square meter of the hotel is $150 \text{ kWh}/\text{m}^2$, and the cost of annual energy consumption accounts for 10% of the total turnover, which is still increasing [11]. The main energy consumption systems of the hotel include the heating ventilation and air conditioning (HVAC) system, monitoring system, lighting system, domestic hot water system, and building envelope systems, etc. Due to the lack of operation energy consumption data, occupancy rate, and the impact of customer usage, there is great uncertainty in hotel operation, which makes it more difficult to retrofit the existing hotels [12]. In addition, the energy consumption of air conditioning system is the largest, followed by lighting system. The lack of effective operation management will also lead to more energy waste. Therefore, the retrofit of existing hotels plays a positive role in improving the energy efficiency of existing buildings.

In recent years, the concept of sustainable development has become more established, and life-cycle costing (LCC), sometimes called life-cycle cost analysis (LCCA), is being increasingly favored by investors and cost management researchers. ISO 15686-5:2017 provides requirements and guidelines for performing life-cycle cost (LCC) analyses of buildings and constructed assets and their parts, whether new or existing. Life-cycle costing takes into account cost or cash flows, i.e., relevant costs (and income and externalities if included in the agreed scope) arising from acquisition through operation to disposal [13]. Salem et al. used building life-cycle cost (BLCC) software to carry out the global cost calculations. The identified cost-optimal PEC level and recommendations provided may be used in the appraisal of other purpose-built UK nZEB hotel retrofits [14]. Sharif and Hammad aimed to find the optimal scenario for the renovation of institutional buildings considering energy consumption and LCA. Different scenarios can be compared in a building renovation strategy to improve energy efficiency. Each scenario considers several methods including the improvement of the building envelopes, HVAC and lighting systems [15]. Filimonau et al. discussed the potential for life-cycle assessment (LCA) to be utilized for the environmental assessment of tourism accommodation facilities. To demonstrate the viability of employing LCA in the hotel sector, its simplified derivative, life-cycle energy analysis (LCEA), is applied to two tourism accommodation facilities in Poole, Dorset (UK) to quantify their CO_2 emissions [16]. Staniaszek et al. not only consider the whole life-cycle cost of retrofit schemes, but also emphasize the measurement of non-monetized benefits and expenses which are of great significance in the retrofit process. Its method of dealing with non-monetary benefits and expenses is to analyze multi-objective decisions with the help of AHP [17]. According to the specific situation of the whole process management of the construction project, Herrmann divides the life cycle of the construction project into four stages: (1) decision-making design stage, (2) construction stage, (3) operation stage, (4) and demolition stage. The costs of each stage are interrelated and influence one another, and the costs incurred in the previous stage often affect the costs incurred in the later stage. Under normal circumstances, there is a negative correlation between the construction cost and the operation cost of a construction project within a certain functional scope, and the construction cost increases while the operation cost decreases, and vice versa. However, the construction cost is often far greater than the operating cost. Therefore, after years of use, existing buildings should be rebuilt according to the changing operational needs rather than be demolished. This is the premise of the energy-saving retrofit of existing buildings [18,19]. The energy-saving retrofit of existing public buildings is essentially one of many forms of housing retrofit. Although some aspects are specific to the retrofit process, it also has many of the common characteristics of general construction projects. The purpose is to effectively

reduce the operating costs of buildings and prolong their functions and economic lifespan. Therefore, it is applicable to the whole life-cycle cost theory of construction projects. The life cycle of an energy-saving retrofit project for existing public buildings can also be divided into the four stages mentioned above [20]. In addition, the life-cycle method widely used in China in recent years evolved from the total cost method and LCCA observed abroad [21].

The importance of housing maintenance and retrofit in urban construction has received increasing attention. With the process of urban housing maintenance and retrofit, several economic evaluation methods for housing retrofit have emerged [22]. Two of the most representative are: comparative analysis method based on economic cost and evaluation method based on value engineering theory. About the former: the research of Needleman (1965) and others was more influential in the early stage [23]. Needleman was the first economist to establish the evaluation principle of housing retrofit, and put forward the prototype formula for retrofit and new construction. His research suggests that there are three main economic factors that affect housing retrofit: the interest rate, the service life of the renovated house, and the difference between the annual maintenance cost of the newly built and renovated house [24]. Sigsworth and Wilkinson (1967) pointed out that the original building value should be included in the retrofit cost, and suggested that the rising building cost should be included in the formula [25]. From this point of view, Schaaf (1969), Pugh (1990), and others modified and improved Needleman's original formula to some extent. Since Needleman put forward the evaluation method of reconstruction and retrofit, many evaluation methods such as total cost method, converted cost method, and input–output balance method have been developed. The basic ideas of total cost method and converted cost method are consistent with the above formula, which can be regarded as a development of early research. The total cost method involves discounting the expenses of each period in the construction stage, later use, and scrapping stage at the beginning or sharing them equally, and then comparing the present value at the beginning or the annual equivalent value; the smaller the expenses, the better the technical and economic benefits. The conversion cost rule is a rough comparison method, which means that the initial cost and the later operation and management cost are converted to each period according to a certain empirical coefficient, and then the annual cost is compared, and the economic scheme is that with the smallest conversion cost. Input–output balance rule is a set of evaluation methods for profitable projects. By estimating the cost and benefit of a retrofit project investment and determining whether it can be compensated by a rent increase within a certain period, the retrofit investment scheme that cannot be compensated is not desirable. Early research on the retrofit of existing buildings in China dates back to the late 1980s, when the Science and Technology Department of the Ministry of Construction, together with China Academy of Building Sciences and Shanghai Institute of Housing Sciences, launched relevant research on the retrofit of existing buildings. Compared with European and American research theories, Chinese scholars pay more attention to the application of the model in practice. In the past ten years, Chinese scholars have formed a series of technical and economic evaluation theories in the process of combining European and American evaluation theories with Chinese practice [26]. The most authoritative technical and economic evaluation method for existing building retrofit in China is cost–benefit incremental analysis. According to Economic Evaluation Methods and Parameters of Construction Projects (Third Edition) issued by the Ministry of Construction, retrofit and expansion projects can be evaluated by cost–benefit analysis, and its evaluation criteria follow the principle of “with or without comparison” [27]. This approach uses the benefits and costs of “with projects” and “without projects” to calculate incremental benefits and costs, which can be used to analyze the incremental profitability of projects and serve as one of the main bases for project decision-making.

About the latter: An important innovation in the technical and economic evaluation method of existing building retrofit is to present an evaluation method based on value engineering theory. The previous evaluation theories and methods focus on the comparison of economic costs [28]. The value engineering method takes the cost of improving

the unit living value as the evaluation effect coefficient, and comprehensively considers the input cost and the improvement of building function [29]. Finally, the schemes are compared according to the technical and economic effect coefficient, and the larger one is best. Because of the different emphasis, it is difficult to compare these methods directly. The formula itself does not consider social costs and benefits, but focuses on private costs and benefits [30]. The total cost method and the converted cost method have no specific functional requirements, while the improvement degree of the use functions of the modified and newly built methods is clearly different [31]. The input–output balance method is mainly applicable to buildings with fixed income. Although the value engineering method is comprehensive, it is difficult to retrofit the function V from qualitative to quantitative. On the basis of comprehensive analysis and comparison of many evaluation methods of European and American old house retrofit, “Research on Technical Policy of Urban Old House Maintenance and Retrofit”, an early study on existing building retrofit in China, suggested “value engineering” as the basic method of technical and economic evaluation of old house utilization and retrofit in China [32]. According to the quality status of old houses in different regions in China, Wan Molin and others put forward two main aspects of functional evaluation: perfect building function and intact facilities. Later, some scholars believed that the impact of retrofit on society should also be regarded as an important aspect of retrofit evaluation. In general, the Chinese evaluation methods quoted European and American related theories, and combined with the actual situation in China, various methods have been improved to varying degrees [33], thus the applicable conditions of various methods are similar to those mentioned above, so they will not be repeated here.

Currently, there is a lack of research regarding retrofitting hotels, especially concerning economic analyses based on actual energy-saving benefits after retrofitting. By providing a reasonable energy-saving retrofit scheme, the energy-saving funds can be properly allocated and the effect of energy-saving retrofit can be optimized, which involves the economic evaluation of building energy-saving retrofit measures. Therefore, this study first examined the economic evaluation methods for existing hotel retrofit projects, and constructs an economic evaluation model using economic evaluation and cost-effectiveness ratio as the base. The energy-saving retrofit measures of 15 existing hotels in Jiangsu Province, China, are used as a case study to demonstrate the research framework.

2. Principle and Calculation Model of Economic Evaluation

The economic evaluation of energy-saving retrofit projects carried out on existing public buildings mainly considers the profitability of project investment, and makes economic comparison with the operational cost and energy efficiency of similar buildings before retrofit. Economic indicators such as retrofit cost and energy-saving benefits are not only represented in the one-time investment during the initial construction stage, but are also present in the energy consumption during the construction operation period [34]. Relevant research indicates that the cost per floor area of existing buildings can be increased by 5~7% because of the adoption of advanced energy-saving materials and measures, but the analysis of energy utilization efficiency over the whole life cycle will produce considerable economic benefits [35]. For example, VA institutions in the United States use a 40-year calculation period and a 5% discount rate to analyze the life-cycle costs of 2000 buildings, and the results indicate that the operating and maintenance costs of public buildings are 7.7 times that of their construction costs [36]. The initial cost of existing buildings retrofit has increased, but over decades of operation and the development of more efficient equipment, due to the reduction of energy consumption such as air conditioning and heating, the operating costs have been greatly reduced. Not only can the retrofit costs be recovered within a certain period, but also the energy-saving benefits and retrofit costs will reach a pure income period after reaching a balance, thus greatly reducing the total cost over the whole life cycle [37].

Therefore, in the economic evaluation of energy-saving retrofit of existing buildings, the relationship between retrofit costs and energy-saving benefits should be considered

in order to balance the comprehensive benefits of energy-saving standards and economy. According to the system and method of project economic evaluation [38], the research presented in this paper comprehensively adopts two methods of economic evaluation and cost-benefit analysis to evaluate the economy of existing building energy-saving retrofit projects. The main economic evaluation indexes include financial net present value, investment payback period, cost-benefit ratio, and so on. The principle of economic evaluation refers to analyzing the retrofit cost and energy-saving benefits on the basis of energy-saving retrofit of existing buildings, compiling the project net present value table, and considering the profitability of energy-saving retrofit projects in combination with economic evaluation indicators, so as to judge the economic feasibility of energy-saving retrofit [39].

2.1. Economic Evaluation

2.1.1. Energy-Saving Retrofit Cost

The cost of energy-saving retrofit includes the cost of manpower, material resources, and financial resources consumed in the retrofit process. Compared with before the energy-saving retrofit, the material cost is the main difference factor in the direct engineering cost, which makes the investment cost for energy-saving retrofit approximately 5~10% higher [40]. Therefore, the calculation of the energy-saving retrofit cost (I_0) for existing buildings mainly focuses on the cost of energy-saving materials. The calculation is expressed as Formula (1):

$$I_0 = \sum_{i=0}^k (m_i + c_i) n_i \quad (1)$$

where m_i and c_i represent the unit price and unit construction cost of the i -th energy-saving material used in energy-saving retrofit, respectively; n_i indicates the number of the i -th energy-saving material; and k denotes the type of energy-saving material.

2.1.2. Energy-Saving Income

After the energy-saving retrofit of the HVAC system, monitoring system, lighting system, domestic hot water system, and building envelope system, the energy consumption of buildings during the operation period can be clearly reduced, thus achieving the purpose of savings in energy consumption. The energy consumption cost reduction after the energy-saving retrofit of a building is called energy-saving income (I'_0). Generally, heating energy is the primary form of energy consumption in North China, while air conditioning and lighting energy consumption are the primary forms of energy consumption in South China. Therefore, in hot summer and warm winter areas, the energy-saving income (I'_0) can be calculated by using the annual power consumption index, and its calculation can be derived from Formula (2):

$$I'_0 = (Q_t - Q'_t) p \quad (2)$$

where p represents the local energy price; $(Q_t - Q'_t)$ indicates the power consumption difference before and after building energy-saving retrofit under the same operation mode; and subscript t represents the year.

2.1.3. Economic Evaluation Analysis Model

The economic evaluation of energy-saving retrofit of existing buildings follows three steps: (1) Construct the annual net cash flow (NCF_t) and cumulative net cash flow ($ANCF_t$) model of energy-saving retrofit, (2) calculate the static investment payback period (P_t) and dynamic investment payback period (P'_t) of energy-saving retrofit, and (3) further clarify the economic benefits generated during the operation period after energy-saving retrofit, taking full account of the possible changes of energy price growth rate (η), discount rate (i), and actual energy-saving efficiency (α) [41].

The annual energy consumption cost saved after the completion of energy-saving retrofit of existing buildings is expressed by annual net cash flow (NCF_t), and its calculation

is expressed as Formula (3). From an economic point of view, the most reasonable service life of construction investment projects is determined by tangible and intangible wear, thus, the economic life is 50 years. During the economic life of an energy-saving building, the energy-saving gains obtained due to the reduction of energy consumption minus the energy-saving retrofit costs are expressed by the cumulative net cash flow ($ANCF_t$), and the calculation is represented by Formula (4). The static payback period (P_t) is calculated using Formula (5). The time required for the energy-saving income of an energy-saving building to offset its energy-saving retrofit cost during the operation period is expressed by the dynamic investment payback period (P'_t), and its calculation is presented as Formula (6).

$$NCF_t = \alpha p(Q_t - Q'_t)(F/P, \eta, t)(P/F, i, t) \quad (3)$$

$$ANCF_t = \sum_{t=1}^{n-1} \alpha p(Q_t - Q'_t)(F/P, \eta, t)(P/F, i, t) - \gamma I_0 \quad (4)$$

$$P_t = (CI - CO)_t = 0 \quad (5)$$

$$P'_t = m - 1 + \frac{|ANCF_{m-1}|}{NCF_m} \quad (6)$$

where $(F/P, \eta, t)$ represents the final value coefficient of one-time payment $(1 + \eta)^t$; $(P/F, i, t)$ indicates the discount coefficient $(1 + i)^{-t}$; n denotes the number of economic life periods of the building; α represents the actual energy saving efficiency; η denotes the energy price growth rate; i represents the discount rate [42]; γ indicates the cost change rate during the energy-saving retrofit period; I_0 represents the cost of energy-saving retrofit; m represents the year when the cumulative net present value begins to appear positive; the subscript t indicates the year; CI represents cash inflow, that is, the energy consumption cost saved by the building throughout the year; and CO denotes the cash outflow, that is, the cost of energy-saving retrofit.

China's "Civil Building Energy Efficiency Design Standard" stipulates that the payback period of energy-saving investment shall not exceed 10 years. The smaller the P'_t , the shorter the payback period of investment is, and the shorter the time for this technology to make up the increased investment cost with the income from energy savings and has good economic benefits and superior market potential. However, the payback periods of different products should be studied and determined separately to achieve reasonable evaluation and measurement.

2.2. Cost–Benefit Analysis

Based on economic evaluation, the technical and economic comparison of different retrofit measures is conducted, and the scheme to reach the maximum energy-saving benefit with the least investment is sought. To further verify the feasibility of the above economic analysis, this study introduces the concept of cost-effectiveness ratio, and conducts a more in-depth analysis of the economic benefits of energy-saving retrofit measures of existing public buildings [43]. The concept of cost-effectiveness ratio is a derivative application of value engineering theory in energy-saving retrofit [44]. Cost-effectiveness ratio refers to the ratio of input cost and output benefit, which is extended to the ratio of the cost of energy-saving retrofit of existing buildings, that is, the cost of a single energy-saving retrofit to the annual energy-saving income generated by the retrofit. Notably, energy-saving measures with low cost-effectiveness ratios are favorable to those with high cost-effectiveness ratios.

3. Case Study

During the "Thirteenth Five-Year Plan" period, Jiangsu Province vigorously developed green buildings and further promoted energy-efficient buildings, and carried out the energy-saving retrofit of 27.65 million m^2 of existing buildings, including 15.86 million m^2 of public buildings. At the same time, Jiangsu Province vigorously demonstrated energy-saving retrofit of existing buildings in both urban (3) and engineering (39) settings [7]. The

demonstration projects of existing building retrofit projects include 6 residential buildings and 33 public buildings, with a demonstration area of 793,800 m². There are six types of building retrofits in public construction projects, including office buildings, general office buildings, campus buildings, hotels, hospital buildings, and shopping malls. Due to the relatively developed tourism service industry in Jiangsu Province, there are several hotels with large energy consumption, which is the focus of energy-saving retrofit [45]. The retrofit includes HVAC system, monitoring system, lighting system, domestic hot water system, building envelope system [46], etc.

3.1. Post-Evaluation Object Analysis

The post-evaluation objects of this study include 15 energy-saving retrofit projects of existing hotel buildings, such as Jinhai Wujin Hotel, with a total construction area of 514,000 m². With the exception of the Jinhai International Hotel funding, which was self-financed by the owner, the other 14 hotels adopt the mode of contract energy management. The basic information of each project is presented in Table 1.

Table 1. Basic information of energy-saving retrofit projects of existing hotels.

Project Number	Project Name	Retrofit Area (10,000 m ²)	Retrofit Time	Retrofit Content
1	Contract energy management project of Jinhai Wujin Hotel	1.2	2018.5–2019.3	HVAC, monitoring, lighting, domestic hot water, and building envelope
2	Contract energy management project of Jinhai Business Hotel	1.5	2018.4–2019.4	HVAC, monitoring, lighting, and domestic hot water
3	Contract energy management project of Hantang International Hotel	1.7	2018.4–2019.3	HVAC, monitoring, lighting, domestic hot water, and building envelope
4	Contract energy management project of Yangzi International Hotel	1.8	2018.3–2019.5	HVAC, monitoring, lighting, and domestic hot water
5	Jinhai International Hotel (self-funded by the owner)	2.0	2018.4–2019.5	HVAC, monitoring, lighting, domestic hot water, and building envelope
6	Contract energy management project of Olympic Mingdu International Hotel	2.3	2018.4–2019.3	HVAC, monitoring, lighting, and domestic hot water
7	Contract energy management project of Songling Restaurant	2.5	2018.3–2019.5	HVAC, monitoring, lighting, domestic hot water, and kitchen
8	Contract energy management project of Jinjiang International Hotel	2.9	2018.4–2019.3	HVAC, monitoring, lighting, domestic hot water, power, and kitchen
9	Contract energy management project of Tianmuhu Hotel	3.0	2018.4–2019.5	HVAC, monitoring, building envelope, and power
10	Contract energy management project of Grand Metropark Hotel	3.4	2018.5–2019.3	HVAC, monitoring, lighting, building envelope, and kitchen
11	Contract energy management project of Zhongtian Phoenix Hotel	3.7	2018.4–2019.3	HVAC, monitoring, domestic hot water, building envelope, and power
12	Contract energy management project of Fuji Hotel	5.1	2018.4–2019.5	HVAC, monitoring, lighting, domestic hot water, building envelope, and kitchen

Table 1. *Cont.*

Project Number	Project Name	Retrofit Area (10,000 m ²)	Retrofit Time	Retrofit Content
13	Contract energy management project of Howard Johnson Jingsi Garden Resort	6.8	2018.3–2019.3	Heating, ventilation and air conditioning, monitoring, lighting, and power
14	Contract energy management project of Donghengsheng International Hotel	7.0	2018.4–2019.5	HVAC, monitoring, lighting, domestic hot water, and building envelope
15	Contract energy management project of Tongli Lakeview Hotel	7.7	2018.5–2019.3	HVAC, monitoring, lighting, building envelope, and kitchen

3.2. Post-Evaluation of Technology Application

The energy-saving retrofit projects of existing hotels in Jiangsu Province are all comprehensive energy-saving retrofits, and the retrofit measures involve the HVAC system, lighting system, kitchen system, power system, domestic hot water system, building envelope structure, and monitoring system. Among them, the retrofit of the HVAC system mainly includes frequency conversion retrofit of central air conditioning, intelligent fuzzy control of central air conditioning, renewal of high-efficiency energy-saving water pump, high-efficiency multi-connected air conditioning system, addition of intelligent start-stop control device of cooling tower, variable flow control system of circulating water pump, energy-saving property management service of central air conditioning system, etc. The retrofit of the lighting system is mainly to replace existing equipment with high-efficiency and energy-saving lamps and intelligent control of green lighting; the kitchen system is retrofitted into an energy-saving range; the power system retrofit is mainly to add an elevator power feedback device and passenger elevator frequency conversion start system; the reform of the domestic hot water system is mainly the adoption of a renewable energy system with a solar hot water system and air source heat pump; the building envelope is retrofitted into Low-E double-layer glass and glass windows with energy-saving film; the monitoring system is retrofitted into an additional itemized meter, energy consumption monitoring system, and energy-saving property management. The application information table of different system retrofit technologies of existing hotels in Jiangsu Province is presented in Table 2, and the application ratio is shown in Figure 1.

Table 2. Application information of energy-saving retrofit technology of existing hotels.

[illegible]

Table 2. Cont.

Project Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Lighting systems	Installation of high-efficiency energy-saving lamps	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓
	Intelligent control of green lighting	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓
Kitchen system	Energy-saving range installation							✓	✓		✓		✓			✓
Power system	Add elevator electric energy feedback device								✓	✓				✓		
	Frequency conversion start of passenger elevator											✓				
Domestic hot water system	Add solar water heating system	✓	✓		✓	✓		✓					✓		✓	
	Add air source heat pump	✓		✓	✓		✓	✓	✓			✓				
	Add steam generator								✓							
Building envelope system	Low-E double-layer glass	✓		✓		✓						✓	✓			
	Energy-saving film on glass windows									✓	✓				✓	✓
Monitoring system	Add itemized meters and energy consumption monitoring system	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Energy-saving property management	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

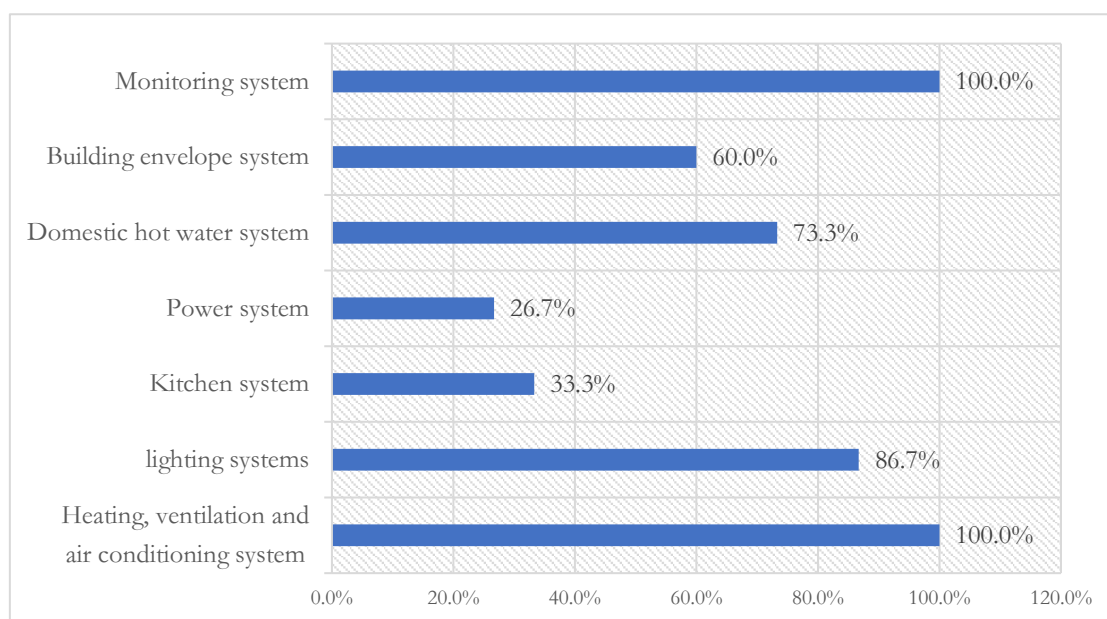


Figure 1. Application scale diagram of energy-saving retrofit technology of existing hotels.

It can be observed from Figure 1 that the application proportion of energy-saving retrofit technology is from high to low: HVAC system and monitoring system, lighting system, domestic hot water system, building envelope system, kitchen system, and power system. HVAC and lighting are major energy users in hotels, so the application rate is high; the scientific optimization of building operation management by monitoring system has become an effective measure to reduce building energy consumption. The domestic hot water system is widely used because of its renewable energy. In the retrofit of the building envelope system, due to the large volume of public buildings and large investment required for energy-saving retrofit, its application ratio is clearly lower than that of residential buildings. Overall, there are many types of retrofit technologies for existing hotels in Jiangsu Province, so it is necessary to comprehensively consider retrofit costs,

energy-saving benefits, time costs, and other factors to make the most suitable technology choice.

4. Economic Analysis of Energy-Saving Retrofit Based on Post-Evaluation

4.1. Calculation and Analysis of Energy-Saving Retrofit Cost and Energy-Saving Benefit

4.1.1. Calculation of Energy-Saving Retrofit Cost and Energy-Saving Benefit

The energy-saving retrofit cost, I_0 , is calculated according to Formula (1), in which the unit price and unit construction cost price of energy-saving materials refer to the comprehensive unit price in May 2018 in Jiangsu Province [47], and the types and quantities of energy-saving materials are derived from the post-evaluation report. The calculation results are presented in Table 3. Energy saving income, I'_0 , is calculated using Formula (2): $I'_0 = (Q_t - Q'_t)p$, and energy price, p , is 0.90 yuan/kWh with reference to the current commercial electricity price in Jiangsu province. The calculation results are presented in Table 3.

Table 3. Economic indicators of energy-saving retrofit of existing hotels.

Project Number	Floor Area (10,000 m ²)	Cost per Floor Area (yuan/m ²)	Energy-Saving Retrofit Cost I_0 (yuan)	Energy-Saving Amount ($Q_t - Q'_t$) (kWh)	Energy-Saving per Floor Area (kWh/m ²)	Energy-Saving Income I'_0 (yuan)
1	1.2	162.7	1,952,400.0	543,564.4	14.9	489,208.0
2	1.5	187.5	2,812,000.0	806,000.0	17.7	725,400.0
3	1.7	233.4	3,968,000.0	1,406,000.0	27.3	1,265,400.0
4	1.8	127.4	2,293,200.0	806,435.6	14.8	725,792.0
5	2.0	112.5	2,250,000.0	751,000.0	12.4	675,900.0
6	2.3	96.7	2,225,000.0	747,000.0	10.7	672,300.0
7	2.5	126.9	3,173,000.0	1,122,000.0	14.8	1,009,800.0
8	2.9	106.1	3,077,000.0	1,289,000.0	14.7	1,160,100.0
9	3.0	108.8	3,264,000.0	1,269,802.0	14.0	1,142,821.8
10	3.4	97.8	3,325,200.0	1,329,703.0	12.9	1,196,732.7
11	3.7	70.5	2,610,000.0	1,155,000.0	10.3	1,039,500.0
12	5.1	80.8	4,120,800.0	1,577,970.3	10.2	1,420,173.3
13	6.8	70.4	4,788,000.0	1,862,000.0	9.0	1,675,800.0
14	7.0	82.3	5,758,000.0	2,660,000.0	12.5	2,394,000.0
15	7.7	90.6	6,978,000.0	3,286,000.0	14.1	2,957,400.0

4.1.2. Analysis of Incremental Cost per Floor Area and Energy Savings per Floor Area

(1) Analysis of incremental cost per floor area

The comparison of incremental cost per floor area of different building scales is illustrated in Figure 2. Fifteen existing hotels are classified according to the building scale: Jinhai Wujin Hotel (12,000 m², Hotel No. 1), Jinhai Business Hotel (15,000 m², Hotel No. 2), and Hantang International Hotel (17,000 m², Hotel No. 3) are classified as economy, while the other 12 hotels (Hotel Nos. 4–15) are classified as luxury [48].

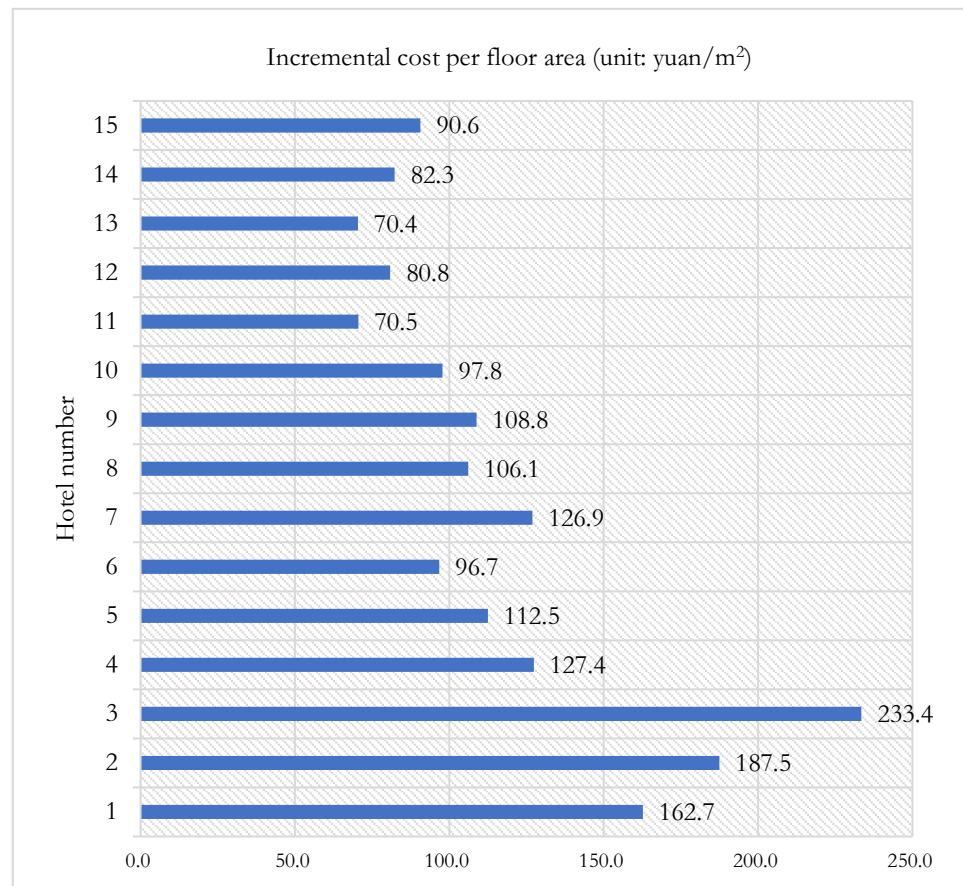


Figure 2. Comparison of incremental cost per floor area.

It can be observed from Figure 2 that the incremental cost per floor area of energy-saving retrofit technology of luxury hotels is at least 70.4 yuan/m², the maximum is 127.4 yuan/m², and the average value is 97.6 yuan/m²; the minimum incremental cost per floor area of energy-saving retrofit technology for economy hotels is 162.7 yuan/m², the maximum is 233.4 yuan/m², and the average value is 194.5 yuan/m². Luxury hotels are significantly lower than economic hotels, and the difference is large. From the analysis, it can be observed that the scale of a hotel building will have a great influence on the incremental cost of per floor area [49].

(2) Analysis of energy savings per floor area

In order to measure the energy-saving benefits of energy-saving retrofit projects, and considering the influence of hotel scale [50], this research analyzes the energy-saving efficiency based on “energy savings per floor area”. The comparison of energy savings per floor area of different buildings is presented in Figure 3.

It can be observed from Figure 3 that Hantang International Hotel (Hotel No. 3) is the project with the most energy savings per year after retrofit, and the energy savings per floor area is 27.3 kgce /m². Howard Johnson Jingsi Garden Resort (Hotel No. 13) is the project with the least annual energy savings after retrofit, and the energy savings per floor area is 9.0 kgce /m². The difference between them is nearly three times, and there is a large gap in energy savings per floor area among the different hotels. The reasons for this are related to the technical measures used in the project, capital investment, hotel scale, and other factors.

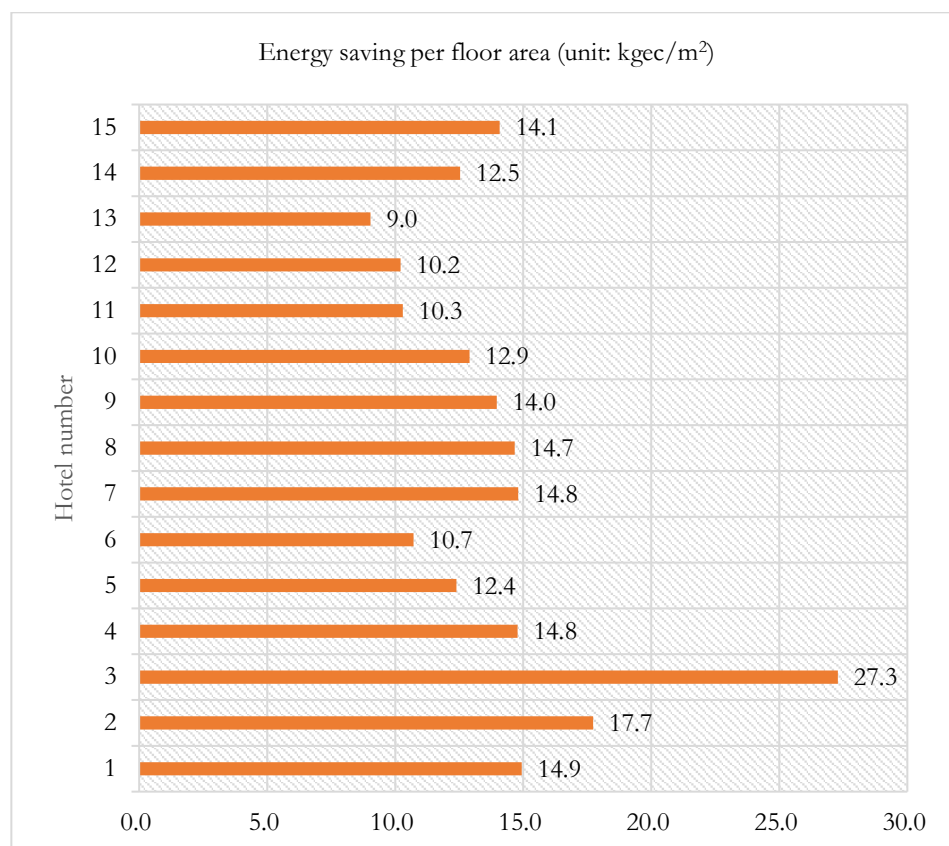


Figure 3. Comparison of energy savings per floor area.

4.2. Economic Evaluation of Energy-Saving Retrofit Projects

On the basis of calculating the cost and benefit of energy-saving retrofit, further economic evaluation is conducted. Assuming that the actual energy-saving efficiency, α , of the existing building after energy-saving retrofit is 100%, with the increase of the service life of the building, its energy-saving efficiency will decline, which is calculated as 100% and 80%, respectively. Due to the energy shortage and the increase of transportation cost, the growth rate of energy price, η , takes the predicted value of the coal industry research report of the National Bureau of Statistics, which is 7%. In this research, the calculation is made in two states: the energy price does not change and the current energy price increases by 7%. Discount rate i , the consumer-oriented experience of energy-saving investment benefits in this study, takes 6% [51] of the annual investment return rate of local families as the discount rate. Because the construction period is shorter than its operation period, the construction period is assumed to be one year, then the operation period is 49 years, and the cost change is small, so the cost change rate, γ , in the construction period is taken as 100%. Substituting the above data into Formulas (3)–(6), respectively, the annual net cash flow, accumulated net cash flow, and static and dynamic payback periods of investment under various conditions can be calculated, and the calculation results are presented in Table 4.

The dynamic payback period is the time required for the total energy-saving income of energy-saving buildings to offset the investment required to complete the energy-saving retrofit project. Although the energy-saving retrofit of existing buildings requires increased investment, from the perspective of energy efficiency, the renovated buildings will have considerable annual energy-saving benefits, and the investment in energy-saving retrofit may be recovered within a certain period. When the income and retrofit investment are balanced, a pure income period is reached, which can save a lot of energy consumption over the life cycle. Reducing investment cost and recovering investment as soon as possible

are the most important issues for investors. The payback period method is simple, intuitive, and easy to understand, and it can help investors make more reasonable investment decisions when used together with the net present value.

Table 4. Net cash flow, cumulative net cash flow, and dynamic investment recovery period.

Project Number	Service Life	$\alpha = 100\% \eta = 0 \quad i = 6\% \gamma = 100\%$		$\alpha = 100\% \eta = 7\% \quad i = 6\% \gamma = 100\%$		$\alpha = 80\% \eta = 7\% \quad i = 6\% \gamma = 100\%$	
		NCF_t	$ANCF_t$	NCF_t	$ANCF_t$	NCF_t	$ANCF_t$
1	1	461,516.9	−1,490,883.0	493,823.1	−1,458,576.8	395,058.5	−1,557,341.4
	2	435,393.3	−1,055,489.6	498,481.8	−960,094.9	398,785.5	−1,158,555.9
	3	410,748.4	−644,741.1	503,184.5	−456,910.4	402,547.6	−756,008.3
	4	387,498.5	−257,242.6	507,931.5	51,021.1	406,345.2	−349,663.0
	5	365,564.6	108,322.06	512,723.3	563,744.5	410,178.7	60,515.6
	P'_t	4.70		3.90		4.85	
2	1	684,339.6	−2,127,660.3	732,243.4	−2,079,756.6	585,794.7	−2,226,205.2
	2	645,603.4	−1,482,056.9	739,151.3	−1,340,605.2	591,321.0	−1,634,884.2
	3	609,059.8	−872,997.1	746,124.4	−594,480.7	596,899.5	−1,037,984.6
	4	574,584.7	−298,412.3	753,163.3	158,682.6	602,530.7	−435,453.9
	5	542,061.0	243,648.6	760,268.7	918,951.3	608,214.9	172,761.0
	P'_t	4.55		3.79		4.72	
3	1	1,193,773.5	−2,774,226.4	1,277,337.7	−2,690,662.2	1,021,870.1	−2,946,129.8
	2	1,126,201.5	−1,648,024.9	1,289,388.0	−1,401,274.1	1,031,510.4	−1,914,619.3
	3	1,062,454.2	−585,570.6	1,301,552.1	−99,722.0	1,041,241.7	−873,377.6
	4	1,002,315.3	416,744.6	1,313,830.9	1,214,108.8	1,051,064.7	177,687.1
	P'_t	2.58		3.08		3.83	
4	1	684,709.4	−1,608,490.5	732,639.0	−1,560,560.9	586,111.2	−1,707,088.7
	2	645,952.3	−962,538.2	739,550.7	−821,010.1	591,640.6	−1,115,448.1
	3	609,388.9	−353,149.3	746,527.6	−74,482.4	597,222.1	−518,225.9
	4	574,895.2	221,745.9	753,570.3	679,087.9	602,856.3	84,630.3
	P'_t	3.61		3.10		3.86	
5	1	637,641.5	−1,612,358.4	682,276.4	−1,567,723.5	545,821.1	−1,704,178.8
	2	601,548.5	−1,010,809.9	688,712.9	−879,010.6	550,970.3	−1,153,208.4
	3	567,498.6	−443,311.2	695,210.2	−183,800.3	556,168.2	−597,040.2
	4	535,376.1	92,064.8	701,768.8	517,968.5	561,415.0	−35,625.1
	5	505,071.8	597,136.6	708,389.3	1,226,357.8	566,711.4	531,086.2
	P'_t	3.83		3.26		4.06	
6	1	634,245.2	−1,590,754.7	678,642.4	−1,546,357.5	542,913.9	−1,682,086.0
	2	598,344.6	−992,410.1	685,044.7	−861,312.8	548,035.7	−1,134,050.2
	3	564,476.0	−427,934.0	691,507.4	−169,805.3	553,205.9	−580,844.3
	4	532,524.5	104,590.5	698,031.0	528,225.7	558,424.8	−22,419.4
	5	502,381.6	606,972.1	704,616.2	1,232,841.9	563,693.0	541,273.5
	P'_t	3.80		3.24		4.04	
7	1	952,641.5	−2,220,358.4	1,019,326.4	−2,153,673.5	815,461.1	−2,357,538.8
	2	898,718.4	−1,321,640.0	1,028,942.7	−1,124,730.8	823,154.1	−1,534,384.7
	3	847,847.5	−473,792.5	1,038,649.7	−86,081.1	830,919.7	−703,464.9
	4	799,856.1	326,063.6	1,048,448.2	962,367.1	838,758.6	135,293.6
	P'_t	3.59		3.08		3.84	

Table 4. Cont.

Project Number	Service Life	$\alpha = 100\% \eta = 0 \quad i = 6\% \gamma = 100\%$		$\alpha = 100\% \eta = 7\% i = 6\% \gamma = 100\%$		$\alpha = 80\% \eta = 7\% i = 6\% \gamma = 100\%$	
		NCF_t	$ANCF_t$	NCF_t	$ANCF_t$	NCF_t	$ANCF_t$
8	1	1,094,433.9	−1,982,566.0	1,171,044.3	−1,905,955.6	936,835.4	−2,140,164.5
	2	1,032,484.8	−950,081.1	1,182,091.9	−723,863.7	945,673.5	−1,194,490.9
	3	974,042.3	23,961.1	1,193,243.7	469,380.0	954,594.9	−239,896.0
	4	918,907.8	942,869.0	1,204,500.7	1,673,880.7	963,600.6	723,704.6
	P'_t	2.98		2.61		3.25	
9	1	1,078,133.7	−2,185,866.2	1,153,603.1	−211,0396.8	922,882.5	−2,341,117.4
	2	1,017,107.3	−1,168,758.8	1,164,486.1	−945,910.6	931,588.9	−1,409,528.5
	3	959,535.2	−209,223.6	1,175,471.9	229,561.2	940,377.5	−469,151.0
	4	905,221.9	695,998.2	1,186,561.2	1,416,122.4	949,249.0	480,097.9
	P'_t	3.23		2.80		3.49	
10	1	1,128,993.1	−2,196,206.8	1,208,022.6	−2,117,177.3	966,418.1	−2,358,781.9
	2	1,065,087.8	−1,131,119.0	1,219,419.0	−897,758.3	975,535.2	−1,383,246.6
	3	1,004,799.8	−126,319.1	1,230,923.2	333,164.7	984,738.4	−398,508.2
	4	947,924.3	821,605.2	1,242,535.5	1,575,700.2	994,028.4	595,520.1
	P'_t	3.13		2.73		3.40	
11	1	980,660.3	−1,629,339.6	1,049,306.6	−1,560,693.4	839,445.2	−1,770,554.7
	2	925,151.3	−704,188.3	1,059,205.7	−501,487.6	847,364.5	−923,190.1
	3	872,784.2	1,68,595.9	1,069,198.2	567,710.5	855,358.5	−67,831.5
	4	823,381.3	991,977.2	1,079,285.0	1,646,995.5	863,428.0	795,596.4
	P'_t	2.81		2.47		3.08	
12	1	1,339,786.1	−2,781,013.8	1,433,571.6	−2,687,228.4	1,146,856.3	−2,973,943.0
	2	1,263,949.1	−1,517,064.6	1,447,095.2	−1,240,133.2	1,157,676.3	−1,816,266.4
	3	1,192,404.8	−324,659.8	1,460,747.2	220,613.8	1,168,597.81	−647,668.9
	4	1,124,910.2	800,250.4	1,474,527.9	1,695,141.4	1,179,622.3	531,953.3
	P'_t	3.29		2.85		3.55	
13	1	1,580,943.4	−3,207,056.6	1,691,609.4	−3,096,390.5	1,353,287.5	−3,434,712.4
	2	1,491,456.0	−1,715,600.5	1,707,568.0	−1,388,822.5	1,366,054.4	−2,068,658.0
	3	1,407,033.9	−308,566.5	1,723,677.1	334,854.5	1,378,941.7	−689,716.3
	4	1,327,390.5	1,018,823.9	1,739,938.2	2,074,792.8	1,391,950.6	702,234.2
	P'_t	3.23		2.81		3.50	
14	1	2,258,490.5	−3,499,509.4	2,416,584.9	−3,341,415.0	1,933,267.9	−3,824,732.0
	2	2,130,651.4	−1,368,857.9	2,439,382.8	−902,032.2	1,951,506.3	−1,873,225.7
	3	2,010,048.5	641,190.6	2,462,395.9	1,560,363.7	1,969,916.7	96,690.9
	P'_t	2.68		2.37		2.95	
15	1	2,790,000.0	−4,188,000.0	2,985,300.0	−3,992,700.0	2,388,240.0	−4,589,760.0
	2	2,632,075.4	−1,555,924.5	3,013,463.2	−979,236.7	2,410,770.5	−2,178,989.4
	3	2,483,090.0	927,165.5	3,041,892.1	2,062,655.3	2,433,513.6	254,524.2
	P'_t	2.63		2.32		2.90	

The dynamic payback period of energy-saving retrofit of 15 existing hotels in Jiangsu Province is presented in Figure 4. The payback period of the project ranges from 2.32 years to 3.90 years, with an average payback period of 2.96 years. Due to the same building type for all 15 retrofit projects, the recovery period differs little, and will be recovered within 4 years. It meets the Design Standard for Energy Efficiency of Civil Buildings requirement that the investment payback period of energy-saving buildings should not exceed 10 years.

Different technical paths adopted in building energy-saving retrofit projects will affect the dynamic payback period of building investment. If appropriate retrofit technology is adopted, the cost can be recovered in a short time.

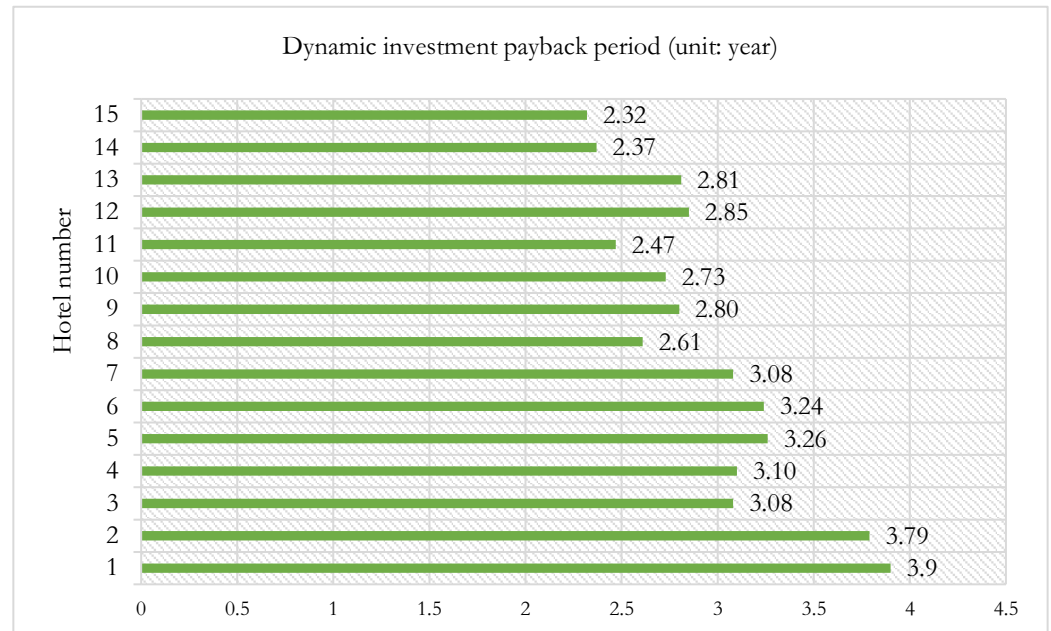


Figure 4. Comparison of dynamic investment payback period.

4.3. Cost–Benefit Analysis of Energy-Saving Retrofit Technology

In order to further analyze the causes for the variation in payback period of energy-saving retrofit of existing buildings, this study first selects five types of retrofit technologies with high utilization rates, which are HVAC system (100%), monitoring system (100%), lighting system (86.7%), domestic hot water system (73.3%), and building envelope system (60%). In addition, although the utilization rate of the kitchen system is low (33.3%), the energy-saving benefits are very objective, so the above six items are taken as research objects and evaluated by cost-effectiveness ratio. Figure 5 presents the cost–benefit ratio comparison of six energy-saving technologies used in the retrofit project.

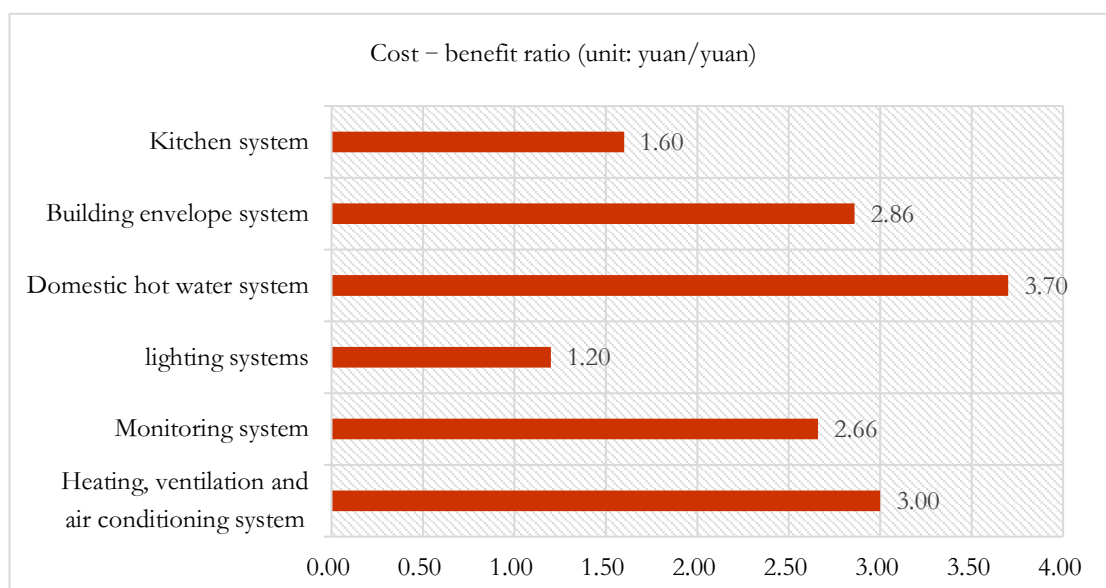


Figure 5. Cost–benefit ratio comparison of six energy-saving technologies used in the retrofit project.

Cost-effectiveness ratio refers to the ratio of input cost to output benefit, so the higher the cost-effectiveness ratio is, the lower the energy-saving benefit will be, and vice versa. It can be observed from Figure 5 that there is a large gap in the energy-saving efficiency of different technologies. The energy-saving benefits from high to low are: lighting system, kitchen system, monitoring system, building envelope system, HVAC system, and domestic hot water system. Among them, the lighting system has the highest energy-saving benefit. The efficiency of the kitchen system is second, mainly because the kitchen uses new energy-saving range instead of old gas range, which reduces energy consumption significantly, and is an energy-saving retrofit technology worth popularizing in hotels. The energy-saving efficiency of monitoring system retrofit is average, and the application of itemized metering in hotels is becoming more common. At present, the itemized metering system on the market is becoming more and more developed, the utilization rate is increasing, and the incremental cost is controllable. It is also an energy-saving retrofit technology suitable for promotion in hotels and even existing public buildings. HVAC system retrofit mainly focuses on intelligent control, and its equipment and system are less updated, so the energy-saving efficiency is low. The domestic hot water system mainly uses renewable energy, and the utilization forms are solar hot water and air source heat pump, which leads to the lowest energy-saving efficiency due to the large investment cost.

5. Discussion and Conclusions

Building retrofit plays an important role in improving the energy efficiency of existing buildings. However, the cost-effectiveness is the key for the decision making of building retrofit. This study investigates the economic evaluation for existing hotel retrofit projects, and constructs an economic evaluation model using economic evaluation and cost-effectiveness ratio as the base. The energy-saving retrofit measures of 15 existing hotels in Jiangsu Province, China, are used as a case study to demonstrate the research framework.

This research on energy saving retrofit of existing hotels is supported by Jiangsu Province's special guiding fund for building energy efficiency in 2019, entitled "Research on Post-energy-saving Evaluation of Existing Public Buildings in Jiangsu Province". The incremental cost per unit building area, energy savings, annual net cash flow, dynamic payback period, and cost-effectiveness ratio of energy-saving retrofit of 15 hotels in Jiangsu Province are evaluated and analyzed, and the following observations are obtained:

- (1) There are many retrofit technologies in existing hotels, so time cost, technology cost, and comprehensive benefit should be carefully considered to make the most suitable technology choice. HVAC system, monitoring system, lighting system, domestic hot water system, and building envelope system are the five energy-saving retrofit technical measures with the highest application ratio.
- (2) The scale of hotels will have a great impact on the incremental cost per floor area. The incremental cost per floor area of luxury hotels is clearly lower than that of economy hotels, but there is a large gap in energy savings per floor area. The dynamic payback period of hotels in Jiangsu Province is at least 2.32 years and at most 3.90 years, with an average payback period of 2.96 years, which meets the requirement that the payback period of increased investment in energy-saving buildings should not exceed 10 years as stipulated in the energy-saving building standards. From an economic point of view, energy-saving retrofit of existing buildings has significant economic benefits.
- (3) The cost-effectiveness ratio of different technologies differs significantly. Lighting and kitchen systems have the highest energy-saving efficiency, followed by monitoring systems, whereas HVAC and domestic hot water systems have the lowest.
- (4) Among the 15 hotels, the highest and lowest incremental cost per unit area and energy saving per unit area are Hotel No. 3 and Hotel No. 13, respectively. However, the shortest payback period of dynamic investment is Hotel No. 15. The reason is that the dynamic investment payback period depends on the cost-benefit of energy-saving retrofit technology, while the first five technologies with the lowest cost-effectiveness ratio, namely lighting, kitchen, monitoring, building envelope, and

HVAC, are adopted in Hotel No. 15, but the domestic hot water system with higher cost-effectiveness is not adopted.

The results indicate that the average dynamic investment payback period of hotels in Jiangsu Province is 2.96 years, which meets the requirement of no more than 10 years specified in the energy-saving building standard. The cost-effectiveness ratio of different technologies differs significantly. Lighting and kitchen systems have the highest energy-saving efficiency, followed by monitoring systems, while HVAC and domestic hot water systems have the lowest. The research presented in this paper contributes to the economic evaluation of the energy-saving retrofit of hotels.

The research limitations and future research are discussed as follows. (1) The research mainly focuses on the hotels in southern China, while China has great climate differences between the south and the north, which has significant impacts on the energy-saving retrofit strategies. Therefore, similar building retrofits in northern China will be considered for comparison in further research. (2) Based on the economic evaluation and analysis of the energy-saving retrofit of existing hotels in this paper, future work can also optimize the technical scheme of building energy-saving retrofit to improve the economic benefits and save energy simultaneously.

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