Hindawi Publishing Corporation
International Journal of Photoenergy
Volume 2015, Article ID 926235, 10 pages
http://dx.doi.org/10.1155/2015/926235

Review Article

Solar Lighting Technologies for Highway Green Rest Areas in China: Energy Saving Economic and Environmental Evaluation

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Received 7 January 2015; Revised 13 April 2015; Accepted 20 April 2015

Academic Editor: Yuehong Su

In this paper, taking Lushan West Sea highway green rest area in Jiangxi Province of China as the case study, the suitable types, applicability, advantages, and effective methods of solar lighting technologies for highway rest area were determined based on the analysis of characteristics of highway green rest area. It was proved that solar lighting technologies including the natural light guidance system, solar LED lighting, and maximizing natural light penetration were quite suitable for highway rest area in terms of lighting effects and energy and economic efficiency. The illuminance comparison of light guidance system with electrical lighting was made based on the on-site experiment. Also, the feasibility of natural light guidance system was well verified in terms of the lighting demand of the visitor centre in the rest area by the illuminance simulation analysis. The evaluation of the energy saving, economic benefits, and environmental effects of solar lighting technologies for highway rest area was, respectively, made in detail. It was proved that the application of solar technology for green lighting of highway rest facilities not only could have considerable energy saving capacity and achieve high economic benefits, but also make great contributions to the reduction of environment pollution.

1. Introduction

The most recent data from the US Department of Energy show that the energy used for lighting has an incidence of the 7% of the whole energy consumption and reaches 18%, if we just take into consideration the electric energy [1]. In Canada the energy consumed for the lighting system in buildings has an incidence of 10% of the whole consumed energy and reaches 24% of the electric energy [2]. In Sweden the Swedish Energy Agency furnishes percentages which correspond to 23% of the whole electric consumptions [3]. In Italy the energy consumption for lighting systems has an incidence of 16.4% of the whole energy requirements [4]. Globally, according to the International Energy Agency (IEA) [5], the lighting is responsible for 7.2% of the worldwide energy consumption, while the electric energy consumed for illuminating engineering purposes has an incidence of 19% of the electric energy consumed [6].

Tackling such consumptions, by optimizing and operating in the lighting systems, in conditions where all requirements are fulfilled, can bring into enormous amounts of energy savings. Recent studies claim that it can be possible to have an energy saving of two-figure percentage with a technological transition from currently used lighting systems to more highly energy efficient systems or green energy systems [7–10]. Therefore it is important to pay attention to those peculiar environments where an advanced lighting performance is required in order to obtain savings in terms of economic management of such spaces [11].

Highway rest area, as the basic service infrastructure, its service quality, and efficiency are of great importance to vehicles and passengers. The huge consumption and environmental impact of energy and electricity in highway rest area in terms of energy and maintenance have evidenced the necessity of using green energy or energy efficient systems for lighting. Because of the far location away from urban areas, generally highway rest areas have few external energy sources to use. The remote and independent characteristics of highway rest area determine its dependence on resources and environment. As the clean and renewable energy, solar energy will not cause environmental pollution as traditional energy like coal, oil, and other fossil fuels during the using process. Development and utilization of solar energy lighting are one of the most important energy saving measures. The application of solar technology for highway rest facilities lighting could not only reduce energy consumption and environmental pollution, but also improve efficiency of resource and energy and the service quality of rest areas.

During the past 30 years, many developed countries and some developing countries have attached great importance to the development of solar technology, and solar technology has been widely promoted and used for lighting. And the paces of international research and development of solar energy lighting are quite fast. Many studies have been able to demonstrate the importance of solar lighting in buildings. Gago et al. studied the natural light controls and guides in buildings and also analyzed the energy saving for electrical lighting [12]. Stankovic et al. made a comparison analysis of lighting design criteria in green building certification systems [13]. Sharan discussed a replacement method of fossil fuel based lighting systems with solar energy systems in India [14]. Beaupré et al. proposed a new technology of solar-energy production and energy-efficient lighting by using photovoltaic devices and white-light-emitting diodes [15].

Nowadays, solar energy technology has gradually extended to highway field with the introduction of new traffic lighting devices like solar traffic lights, solar orientation lights, solar street lamps, and so forth. Dalla Costa et al. presented a high efficiency autonomous lighting system based on solar energy and LED used for street [16]. Jianzhong introduced the application of solar LED road traffic sign in Highway 208 in China [17]. Li and Jiang made the researches on the energy efficient lighting of tunnels including energy saving methods and energy saving lighting types [18]. Wei et al. illustrated the application of solar LED lighting in tunnels and the energy saving effects based on the green lighting concept [19–21].

In the meanwhile, many researches have focused on the economic effect assessment of solar technology. It could be seen that solar technology brings into very considerable economic benefits as well as reduces environmental pollution. De Maria and Marano proposed the economic analysis methods of solar photovoltaic systems under different climatic conditions and pointed out that the economic analysis methods related to local policy as well as technical level and climatic conditions [22]. Schröder and Reddemann made an analysis on the economic influence of hot water consumption and energy efficiency on solar collectors in different months and climatic conditions in terms of the German federal government's economic conditions [23]. Sinuany-Stern and Mehrez proved that the economic effects became better with the increasing of useful life period, fuel prices, and market demand based on the establishment of a model for the economic practicability of solar hot water systems [24]. Hawlader et al. made the economic evaluation for solar heating water system by using different variables and concluded that the designed collector area is $1000\,m^2$ for best payback period and internal rate of return [25]. Jiangyi made an analysis in the energy consumption constitution and energy saving way for residential building [26].

As previously mentioned, a lot of research works have been made concerning about solar lighting and economic effects and also acquired great achievement. However, few works have been made on solar energy lighting technologies aimed at highway rest areas due to their remote location and subordinate position in the highway system. In this context, it is quite necessary and urgent for launching the research on solar lighting and economic effects of highway rest area to promote the development of green highway rest area and guide solar engineering practice in China.

2. Objectives

The primary objectives of this paper can be outlined as follows:

(1) Determining the suitable types, applicability, and advantages of solar lighting technologies for highway rest area.

(2) Analyzing the best installing tilt angle of light pile of light guidance system for highway rest area based on the geographical position and the local weather conditions.

(3) Verifying the feasibility of natural light guidance system in terms of the lighting demand of the visitor centre in the rest area by on-site experiment and illuminance simulation analysis.

(4) Making the comparison in lighting effects and energy and economic efficiency of solar LED lighting with high voltage sodium lamps used for highway rest area.

(5) Determining the effective methods of maximizing natural light penetration used for highway rest area.

(6) Evaluating the energy saving capacities, economic benefits, and environmental effects of solar lighting technologies for highway rest area.

3. Methods

3.1. The Basic Situation of Highway Green Rest Area in China. Highway green rest areas have been proposed recently under the background of building the green transportation system in the 12th Five-Year Plan in China, and people have been increasingly beginning to be concerned about the service quality and energy saving level of the highway rest area. Highway green rest areas, generally refer to the rest areas integrating various measures of every saving throughout the entire life cycle including planning, design, construction, operation, and management to maximize saving resources, reduce pollution, protect environment, and provide drivers and passengers with a safe, healthy, comfortable, and efficient service environment based on the principle of the virtuous circle of the whole system. Some highway rest areas in China have begun to employ different energy saving technologies to try establishing green low-carbon rest areas. Green building and clean energy technologies have been used in a small number of highway rest areas and achieved good effects [27].

The case of this paper Lushan West Sea highway is located in northern Lushan Scenic Area in Jiangxi Province of China, with the extremely rich natural and landscape resources along and also the highest environmental protection requirements, as shown in Figure 1. The area of Lushan West Sea in Jiangxi Province is naturally endowed with relatively abundant deposit of renewable energy resources, of which solar energy from the sun, and has the rich solar energy resources with 4494.35 MJ/m^2 (horizontal) annual radiation and 1700.7 sunshine hours. Based on the concept of green low carbon highway rest area, solar lighting technologies and energy efficient lighting methods including natural light guidance system, solar LED lighting and maximizing natural light penetration were employed and analyzed in detail according to the natural geographical and climatic conditions to achieve good energy saving effects and effective operational cost reductions. The energy saving economic and environmental evaluations were also made to testify the effectiveness of the solar lighting technologies for Lushan West highway green rest area to maximize energy savings and protect environment.

3.2. The Natural Light Guidance Technologies for Highway Rest Area

3.2.1. The Technical Principles and Structure Composition of Natural Light Guidance System. Natural light guidance systems could guarantee the penetration of daylight into the building, thus reducing the electrical energy consumption for lighting. In the light guidance system, the outdoor natural daylight was captured by outdoor lighting apparatus, introduced inside the system, enhanced and transferred through the light guide installation, and then introduced by diffuse reflector uniformly wherever the light was required indoor. The light guidance system was made up of three main parts including the lighting device on the roof outside, light guidance pipe, and the diffuse reflector indoor, as seen in Figure 2.

Lighting devices were composed of lighting shield and rainproof device. The transparent lighting shield was made from PC material added to UV resistant additive, with strong abrasion and impact resistance, light transmission rate of up to 87 percent; meanwhile more than 90% ultraviolet rays isolated. It had the temperature adaptation range of -40°C~125°C and can be safely used even in the areas with larger temperature difference between day and night. Light guidance pipe, generally made from aluminium with lighter weight, could introduce the natural light collected by lighting device into the room. There were five special membranes in the interior wall of light guidance pipe to ensure the stability and efficient transmission of light. And the reflection rate of the materials could achieve 98%. Diffuse reflector, made from PC or PMMA with good light transmission, diffusion, heat insulation, and sound insulation, could made the natural light uniformly introduced into the room.

Figure 1: The aerial view of Lushan West Sea highway rest area.

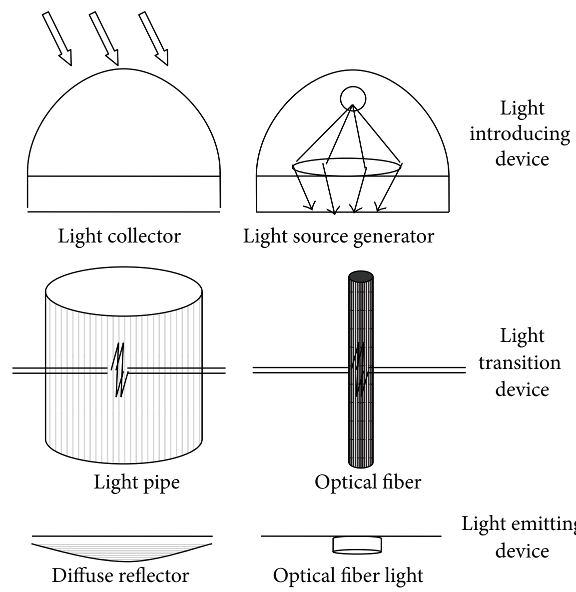

Figure 2: The composition diagram of natural light guidance system.

3.2.2. The Advantages of Natural Light Guidance System. From dawn to dusk, even in a cloudy or rainy day, the lighting introduced by light guidance system into the room is still very considerable. It had the following advantages as listed in Table 1.

3.2.3. The Application of Light Guidance System for Lushan West Sea Highway Rest Area. 31 sets of light guidance systems were installed in the visitor center of Lushan West Sea highway rest area, as seen in Figure 3, which completely replaced the daytime electric lighting, at least provided natural lighting more than ten hours per day with no energy and maintenance.

3.2.4. The Illuminance Comparison of Light Guidance System with Electrical Lighting. The model of the light guidance systems used in the visitor centre was Suntube STGC530 with the diameter of 530 mm. The light transition pipe is 1.2 m long and the distance of diffuse reflector to working surface was set 6.5 m. The on-site illuminance experiment was carried out for 5 consecutive days from March 23rd to 27th. Based

Table 1: The advantages of light guidance system.

Number	The advantages	The specific features
1	Energy saving	Only using natural light without electricity, the sealing system with good thermal insulation properties, classified as "cold light," bringing no heat load effect to the room
2	Health	Natural light with no flash and no harm to human eyes, screening the majority of ultraviolet light by the UV surface of lighting device; only the small amount of ultraviolet light into the room could purify the indoor air, restraining the growth of microorganisms and improving the living environment
3	Good lighting effect	Natural light with a wavelength range of 380 nm~780 nm, color rendering of Ra 100, and the indoor diffusing light through diffuse reflector with gentle light and even illumination distribution
4	Long service life	The service life ≥25 years (the maximum service life of electric lighting is around 10 years)

Figure 3: The natural light guidance systems in the visitor center of Lushan West Sea highway rest area.

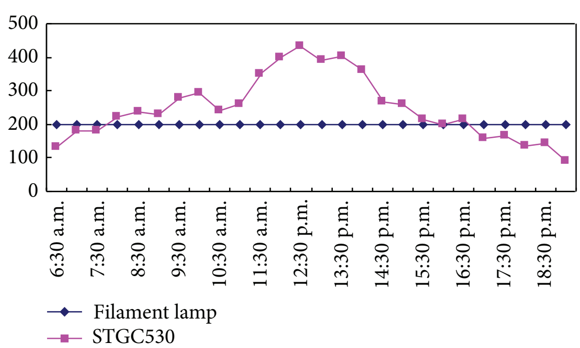

Figure 4: The illuminance effects comparison of light guidance system with electrical lighting.

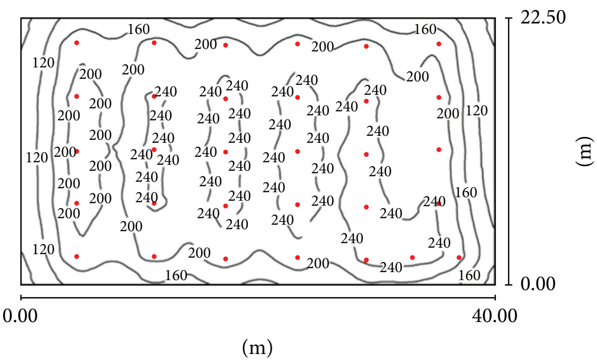

Figure 5: The isolux distribution of natural light guidance systems in the visitor centre.

on the sunny and cloudy condition in spring, the average illuminance effects comparison of the light guidance system with electrical lighting was made in Figure 4.

3.2.5. The Illuminance Simulation of Light Guidance System for Lushan West Sea Highway Rest Area. According to "Standard for Lighting Design of Buildings (GB 50034-2013)" of China, the standard luminance for service hall should be 200 lx, and the corresponding illumination power density is 9 W/m^2. Therefore, if the luminance of visitor centre reached 200 lx, the per unit power consumption would achieve 9 W/m^2. Therefore, based on the total area of 904 m^2 for light guidance lighting, 31 sets of light guidance systems need to be installed in the visitor centre.

We used DIALux software to make a simulation to analyze the feasibility of the light guidance system for the visitor centre hall. 31 sets of Suntube STGC530 were installed in even distribution in the visitor centre hall ceiling. According to "Standard for Lighting Design of Buildings" (GB 50034-2013), the area of Jiangxi Province belongs to the IV zone of light climate division with the annual average illuminance value of 30 Klux~35 Klux. In the simulation analysis the outdoor annual average illumination value of 35000 lux was employed, which reflected the local cloudy conditions in spring, summer, and autumn seasons. The height of the visitor centre hall was 7.5 m, and the installing height was 6.0 m. The isolux distribution map with the ratio of 1 : 289 and the illuminance value of natural light guidance systems in the visitor centre was shown in Figure 5 and Table 2.

TABLE 2: The illuminance value of natural light guidance systems in the visitor centre.

Surface	ρ (%)	Average illuminance (xl)	Minimum illuminance (xl)	Maximum illuminance (xl)	Minimum illuminance/ average illuminance
Working surface (0.85 m)	/	201	70	268	0.348
Floor	20	194	77	252	0.395
Ceiling	70	39	26	46	0.680
Wall	50	81	27	207	/

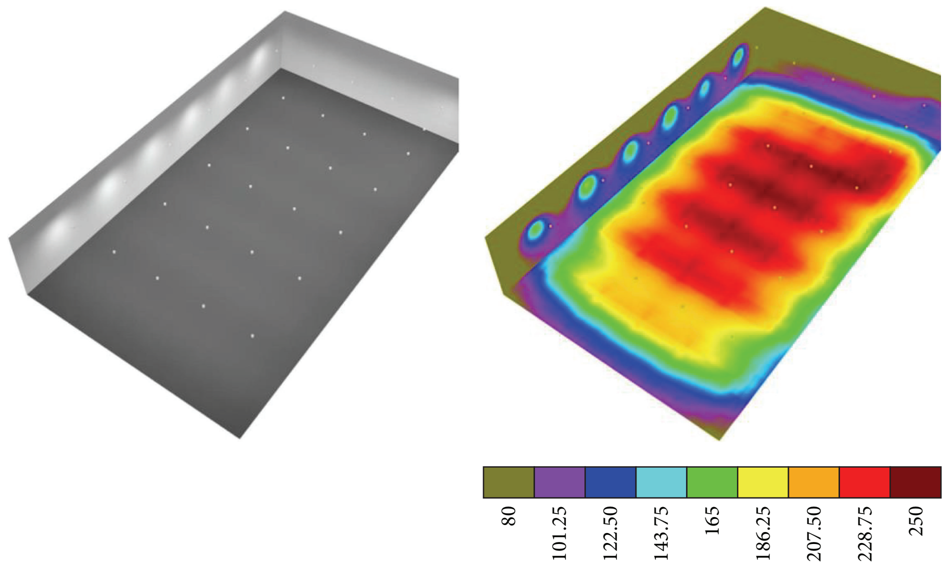

FIGURE 6: The 3D simulation illuminance of natural light guidance systems in the visitor centre.

The 3D simulation illuminance of natural light guidance systems in the visitor centre was shown in Figure 6. In the illumination simulation analysis, we took the closed space as the simulation environment without considering the lateral window lighting. According to "Standard for Lighting Design of Buildings" (GB 50034-2013), the average illumination of architectural service hall was in the range of 200–300 lux. It could be seen from the simulation that, even not considering the contribution of windows lighting, the lighting design of natural light guidance system for the visitor centre in the rest area still well met the lighting demand and verified its feasibility for the visitor centre.

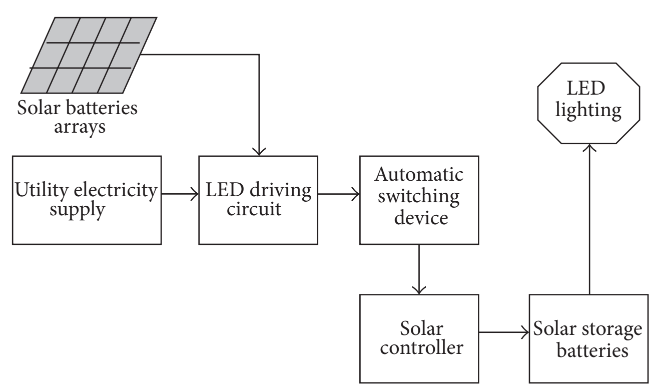

FIGURE 7: The diagrammatic sketch of solar Photovoltaic LED lighting technology.

3.3. The Solar Photovoltaic LED Lighting Technologies for Highway Rest Area

3.3.1. The Technical Principles and Structure Composition of Solar Photovoltaic LED Lighting. Solar Photovoltaic LED lighting technology was based on the solar photoelectric effect, through the use of solar cells to convert solar energy directly into electricity, as shown in Figure 7. Solar Photovoltaic LED lighting systems consisted of five major components of solar panels, automatic switching device, solar controller, solar storage batteries, and LED lighting. Solar panel was the core part of the system and its role was to convert solar radiation to electrical energy stored in batteries or generated. The role of the switching device was to automatically switch the power supply from solar batteries arrays to utility electricity when the energy of the solar battery got relatively low, and the power supply for LED lights switched automatically back to solar battery arrays once the solar storage got exceed some certain value. Solar controller was to control the working status of the entire system and made an overcharge or overdischarge protection for battery [28]. Solar controller also had the function of temperature compensation in the place with large temperature differences.

Table 3: The advantages of solar Photovoltaic LED lighting.

Number	The advantages	The specific content
1	Economic efficiency	Energy and electricity saving due to a high luminous efficiency with the extremely low power of 0.06~1 W and the long service life of 50~100 thousands hours
2	Green and health	Unlike fluorescent lights, having no mercury and lead and no harm to human health and also reducing the environmental pollution without glass wastes
3	Safety and reliability	With low operating voltage of 1.5~3.0 V and low current of 75 mA~150 mA

Figure 8: The comparison of lighting effects of high voltage sodium lamp and solar Photovoltaic LED lamps in parking lot.

Figure 9: The LED lights used for landscape lighting before the visitor centre in Lushan West Sea highway rest area.

Figure 10: Maximizing the glass area facing the south.

Figure 11: Glass roofs at the entrance of the visitor centre.

3.3.2. The Advantages of Solar Photovoltaic LED Lighting System. Compared with other conventional lights, LED lighting had many advantages as listed in Table 3.

3.3.3. The Application of Solar Photovoltaic LED Lighting System for Lushan West Sea Highway Rest Area. The solar Photovoltaic LED lights were replaced with the high voltage sodium lamp in the original design in the parking lot of Lushan West Sea highway green rest area. And the LED lights were also used for landscape lighting, as shown in Figures 8 and 9.

3.4. The Maximizing Natural Light Penetration Technologies for Highway Rest Area. Natural light significantly influences both the balance of energy use in buildings and actual human activity [29–31], offering the occupants comfort and health benefits. The maximizing natural light penetration is one of the most important energy saving measures on the basis of independent on conventional energy. The main measures of the fully use of natural light were taken in Lushan West Sea highway rest area as follows, as shown in Figure 10 to Figure 12, which could dramatically reduce lighting energy use during the day: (1) To take full advantage of natural light, the major buildings were arranged along Zhelin Lake

Figure 12: Glass roofs of the washing rooms.

to the south of Lushan West Sea highway rest area to avoid the light blocking among the single building; (2) the rooms with higher demand for lighting were all assigned to the south of building group, maximizing the glass area of the building facing the south in order to fully get natural light and basically with no need for auxiliary lighting during the day throughout the year; (3) glass roofs were installed at the entrance in the atrium of the visitor centre, with the overall permeability and zero energy consumption; (4) under the presupposition of privacy guarantee, the washing rooms were built as permeable as possible in order to reduce daytime lighting energy using.

4. Results

4.1. Energy Saving and Economic Effects Analysis of Natural Light Guidance System in Lushan West Sea Highway Green Rest Area

4.1.1. Energy Saving Capacity of Natural Light Guidance System. The light guidance system was used for an average of 10 hours during day time every day, and the total area of the visitor centre for light guidance lighting in Lushan West Sea highway rest area was 904 m^2. Based on that the luminance of visitor centre reached 200 lx and the per unit power consumption achieved 9 W/m^2 according to "Standard for Lighting Design of Buildings (GB 50034-2013)," so the energy saving of natural light guidance system during day time for the visitor centre per year was calculated as follows:

$$904 \times \frac{9}{1000} \times 10 \times 365 = 29696.4\,\text{kW} \cdot \text{h}. \quad (1)$$

4.1.2. Economic Benefits of Natural Light Guidance System. In terms of the current electricity price of 0.60 RMB/kW·h in Jiangxi Province, the electricity bills saving of natural light guidance system lighting during the day for the visitor centre in Lushan West Sea highway green rest area per year was calculated as follows, which also meant that the reduction of the cost by electricity savings of natural light guidance system in Lushan West Sea highway green rest area per year was 17.8 thousand RMB:

$$29696.4 \times 0.60 = 17.8\,\text{thousand RMB}. \quad (2)$$

4.1.3. Payback Period of Investment for Natural Light Guidance System. In view of the investment of natural light guidance system, the payback period of every saving for the light guidance system was calculated according to the following formula:

$$T = \frac{y}{n_0}, \quad (3)$$

where T is the payback period of investment for the system, y is investment of the system, and n_0 is cost saving of the system.

Taking the instalment and maintenance cost of light guidance system into account, the overall installation charge and maintenance cost were, respectively, 7.00 and 1.00 thousand RMB, and the cost of light guidance system was around 3.5 thousand RMB per set, so the total investment of light guidance system was

$$3.5 \times 31 + 7 + 1 = 116.5\,\text{thousand RMB}. \quad (4)$$

Therefore, the payback period of the investment of solar photovoltaic system was about 7 years. As we know the useful life period of natural light guidance system was at least 25 years, so the economic profits of natural light guidance system were quite high. After the payback period of 7 years, the net economic profit of light guidance system in Lushan West Sea highway green rest area would still reach 320.4 thousand RMB, which equated 51.7 thousand dollars.

4.2. Energy Saving and Economic Effects Analysis of Solar Photovoltaic LED Lighting in Lushan West Sea Highway Green Rest Area. Considering that the ground luminance of 100 W LED with amendment is 37.6 lx while that of high voltage sodium lamp is 28.2~37.6 lx, a 100 W LED can be replaced for a 200 W high voltage sodium lamp with much better lighting effect. Therefore, the solar Photovoltaic LED lights were replaced with the high voltage sodium lamps of the original design in the parking lot of Lushan West Sea highway green rest area. The comparison of economic effects of high voltage sodium lamp and solar LED lamp was made as follows.

Taking the service time of lighting per day as 10 hours, and the life cycle period as 25 years, the total power consumption within the life cycle of 25 years was calculated according to the following formula:

$$W_T = 25 \times 365 \times 10 \times W \times N, \quad (5)$$

where W_T is total power consumption for the life cycle of 25 years, W is lighting power for one lamp, and N is the number of lamps.

The original invest cost within the life cycle of 25 years was calculated in terms of the following formula:

$$C_o = C_L + C_T + C_I, \quad (6)$$

where C_o is the original invest cost within the life cycle of 25 years, C_L is the cost of the total lamps, C_T is the cost of the total voltage transformers or ballasts, and C_I is the cost of installing and wiring.

Generally, the cost of voltage transformers or barretters and the cost of installing and wiring for one lamp were both about 100 RMB, and LED lamp needs no ballasts.

The maintenance cost within the life cycle of 25 years was calculated in terms of the following formula:

$$M = t \times s \times 25, \tag{7}$$

where M is the maintenance cost within the life cycle of 25 years, t is the times of the lamps needing maintenance every year, and s are the material cost and labor cost every time.

Generally, for the high voltage sodium lamp, it needed maintenance two times every year, and the material and labor cost every time were around 110 RMB per set while for the solar LED lamp, it needed maintenance only one time every year, and the material and labor cost every time were about 140 RMB.

Therefore, the total cost within the life cycle of 25 years of the lighting was calculated according to the following formula:

$$C_q = C_o + M + P, \tag{8}$$

where C_q: the total cost within the life cycle of 25 years, C_o: the original invest cost, M: the maintenance cost within the life cycle of 25 years, and P: the electricity cost within the life cycle of 25 years that was $P = 0.6 \times W_T$.

Considering that the attenuation with time of the lighting efficiency of LED lamps differed greatly with the factors like material and environmental temperatures and so on, according to the LED lamps design parameters, the service life of LED lamps in this study was around 90~100 thousands hours which took 20% attenuation into account.

It can be seen form Table 4, compared with high voltage sodium lamp, the energy saving capacity of solar LED lamp was 219×10^3 kW·h within the life cycle of 25 years and the reduction of the cost by electricity savings of solar LED lamp was 131.4 thousand RMB, which equated 21.2 thousand US dollars. Considering the total cost including original investment, maintenance, and electricity cost, the total cost saving of solar LED lamps reached 44.7 thousand US dollars in the parking lot of Lushan West Sea highway green rest area within the service period of 25 years. Taking the maintenance cost of LED lamps into account, the payback period of the investment of LED lamps was about 17 years. After the payback period of 17 years, the net economic profit of LED lamps in Lushan West Sea highway green rest area was still about 42 thousand RMB, which equated 6.8 thousand dollars. Because the payback period of LED lamps was relatively long, the government subsidies would be considered to apply for encouraging the green and clean energy usage.

4.3. Environmental Benefits Analysis of Solar Energy Technology in Lushan West Sea Highway Green Rest Area. By acting on energy efficiency in the highway rest area, it is possible to reduce energy consumption and therefore CO_2 emissions into the atmosphere [32, 33]. The statistics from the National Development and Reform Commission of China reveals that every saving 1 kW·h electricity equated the consumption of 0.4 kg standard coal and also equated an emission prevention of 0.997 kg carbon dioxide (CO_2), 0.03 kg sulphur dioxide (SO_2), 0.015 kg nitrogen oxides (NO_x), 0.272 kg smoke, and other pollutants.

Table 4: The comparison of high voltage sodium lamp and solar LED lamp within the life cycle of 25 years.

Comparison items	High voltage sodium lamp	Solar LED lamp
Cost for one lamp (RMB)	1000	3500
Number of lamps N	24	24
Service life (thousand hours)	12	90~100
Lighting power for one lamp (W)	200	100
Total power consumption WT (10^3 kW·h)	438	219
Total electricity bills P (thousand RMB)	262.8	131.4
Replacing times	8	0
Original invest cost C_o (thousand RMB)	230.4	86.4
Maintenance cost M (thousand RMB)	5.5	3.5
Total cost C_q (thousand RMB)	498.7	221.3
Total cost saving (thousand RMB)	277.4	
Total cost saving (thousand dollars)	44.7	

The energy saving of the solar lighting technology including natural light guidance system and solar photovoltaic LED lighting in Lushan West Sea highway green rest area per year reached 248.7×10^3 kW·h, which equated the reduction of 99.5 tons standard coal and also 248-ton CO_2, 7.5-ton SO_2, 3.7-ton NO_x, and 67.6-ton smoke. It could be seen that the solar lighting technology of Lushan West Sea highway green rest area would make great contributions to the reduction of environment pollution.

5. Conclusion

(1) The remote and independent characteristics of highway rest area determine its dependence on resources and environment. The huge consumption and environmental impact of energy and electricity in highway rest area in terms of energy and maintenance have evidenced the necessity of using green energy or energy efficient systems for lighting. The application of solar technology for highway rest facilities lighting could not only reduce energy consumption and environmental pollution, but also improve efficiency of resource and energy and the service quality of rest areas.

(2) It was proved that the natural light guidance system was quite suitable for highway rest area which was generally located in remote suburb based on its advantages of energy saving, health, good lighting effect, and long service life period. The design of natural light guidance system was proved to well meet the lighting demand of the visitor centre in the rest area and verified the feasibility by on-site experiment and illuminance simulation analysis.

(3) Compared with other conventional lights, solar LED lighting was proved quite suitable for highway rest area based on the advantages characteristics including low energy consumption, green and health, and safety and reliability. 24 solar LEDs of 100 W lamps were replaced for 24 high voltage sodium lamps of 200 W in the original design in the parking lot of Lushan West Sea highway green rest area.

(4) A couple of effective methods of maximize natural light penetration were used in Lushan West Sea highway rest area, which was proved quite effectively energy saving and dramatically reduced the lighting energy use during the day through the full use of natural light.

(5) The total energy saving of natural light guidance system during day time for Lushan West Sea highway rest area per year was 29696.4 kW·h with the reduction of the cost by electricity savings of 2.9 thousand US dollars per year.

Taking the investment of the solar photovoltaic system into account, the payback period of the investment of solar photovoltaic system was about 7 years, which proved that the economic profits of natural light guidance system were relatively quite high. Taking 25 years as the effective service period, after the payback period of 7 years, the net economic profit of light guidance system in Lushan West Sea highway green rest area would reach 51.7 thousand dollars.

(6) Compared with high voltage sodium lamp, the energy saving capacity of solar LED lamp was 219×10^3 kW·h with the reduction of the cost by electricity savings of 21.2 thousand US dollars in Lushan West Sea highway green rest area within the life cycle period of 25 years.

Taking the maintenance cost of LED lamps into account, the payback period of the investment of LED lamps was about 17 years. After the payback period of 17 years, the net economic profit of LED lamps in Lushan West Sea highway green rest area was still about 6.8 thousand dollars within the life cycle period of 25 years.

(7) The energy saving of the solar lighting technology including natural light guidance system and solar Photovoltaic LED lighting in Lushan West Sea highway green rest area reached 248.7×10^3 kW·h, equating the reduction of 99.5-ton standard coal and also 248-ton CO_2, 7.5-ton SO_2, 3.7-tons NO_x, and 67.6-ton smoke, which proved that the solar lighting technologies make great contributions to the reduction of environment pollution.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

The research work was supported by the National Natural Science Foundation of China under Grant no. 51108216 and the Fundamental Research Funds for the Central Universities nos. 2015JBM067 and 2015RC023. The authors are very grateful for the helpful comments and criticisms of the anonymous reviewers.

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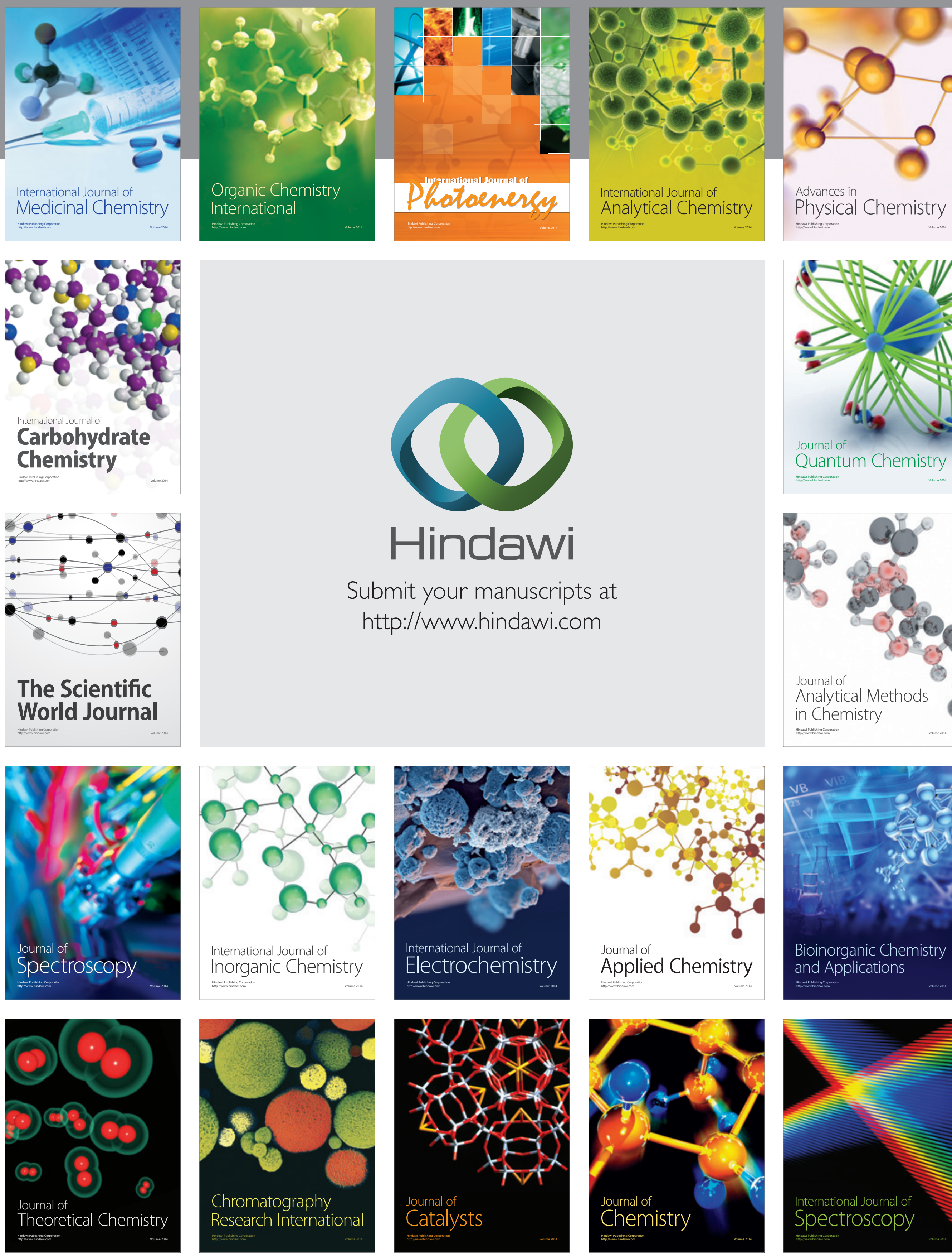
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