

ECONOMIC ANALYSIS AND ENVIRONMENTAL BENEFITS OF A HYBRID OPTICAL FIBER DAYLIGHTING SYSTEM

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ABSTRACT

Optical fiber daylighting system is a promising alternative for indoor illumination, which provides not only comfortable and safe lighting but also environmental benefits. Economic analysis results show that, total cost of traditional fluorescent lighting system is higher than that of hybrid optical fiber daylighting system after 7 years of operation. In addition, results of environmental benefits for the studied case show that, an annual average 39410kg of CO₂ emission can be reduced when traditional lighting system is replaced by the hybrid daylight system. The potential of applying the hybrid optical fiber daylighting system to save energy and protect environment is promising.

Keywords: optical fiber lighting, solar energy, cost analysis, environmental benefit

1. INTRODUCTION

CO₂ emitted from combustion of fossil fuels causes global warming and climate changes, which has damaging influences on the living environment and animal species. Fossil fuel-based artificial lighting in the developing world releases 244 million tons of CO₂ emissions to the atmosphere every year [1]. As a promising alternative to electrical lighting, optical fiber daylighting system a passive solar design which directly utilizes daylight for illumination. Daylighting system via optical fibers not only provides a comfortable and healthy lighting approach, but also reduces fossil fuels

consumed to generate electrical lighting for indoor illumination [2-3].

A variety of studies have been carried out to investigate the feasibility, operation performance and cost analysis of fiber optic solar lighting systems. Han et al. [4] developed simulation models and carried out tests to assess the performance of the designed fiber optic daylighting system. Ghisi et al. [5] found that carbon dioxide emission of 138 kg/m² can be reduced when fiber optics are integrated with the artificial lighting system in buildings. Wong et al. [6] compared the installation and maintenance costs of remote source solar lighting system with those of conventional lighting system. In the studied lift lobbies, the remote source solar lighting system can save 12% of energy consumption by electric lighting even though the side-emitting technology of fiber optic is still at primitive stage.

We previously developed a hybrid fiber-optic and PV solar lighting system [7], which transfers visually comfortable daylight and stores solar energy as supplementary of illumination. In order to better understand the potential of applying this optical fiber daylighting system for energy saving and reduction in environmental pollution, the present study further evaluates the economic feasibility of the proposed hybrid daylighting system in comparison with traditional incandescent lighting. In addition, it is the interest to analyze the environmental benefits of the hybrid daylighting system based on the studied case.

2. ECONOMIC ANALYSIS

2.1 Configuration of hybrid daylighting system

The hybrid daylighting system is shown in Fig. 1. It is composed of a light collecting subsystem, a light guiding subsystem, an optical fiber light diffuser subsystem and corresponding control system. Detailed information of the system can be found in reference [7].

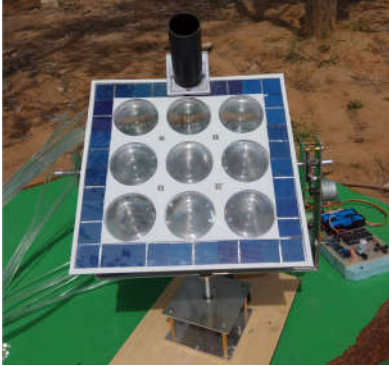


Fig 1 Hybrid optical fiber daylighting system

2.2 Case study

Assuming that 30 stores in an underground shopping mall need indoor illumination system, and each store has an average area of 56m². The dimension of the store is 8×7×2.8m (Length × Width × Height). The opening hours of the shopping mall is 9:00-22:00.

In order to reduce the engineering costs in practical application, T8 fluorescent lamps are commonly used as lighting fixtures. According to GB 50034-2013 <Standard for Lighting Design of Buildings>, general indoor illumination standard for commercial street shall be 200lux. Dialux lighting design software is used for illumination simulation. As shown in Fig. 2 and Fig. 3, nine 54W T8 fluorescent lamps are required to be installed in three rows when the average illumination distribution on the ground is about 222lux.

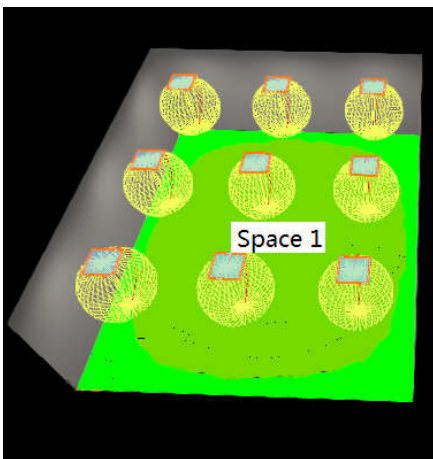


Fig 2 Layout of florescent lamps

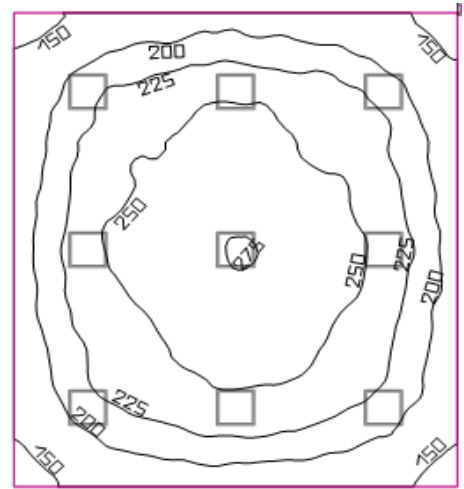


Fig 3 Illumination distribution of nine 54W T8 florescent lamps on the ground

Fig.4 and Fig. 5 are the layout and illumination distribution of the hybrid optical fiber daylighting system on the ground, respectively.

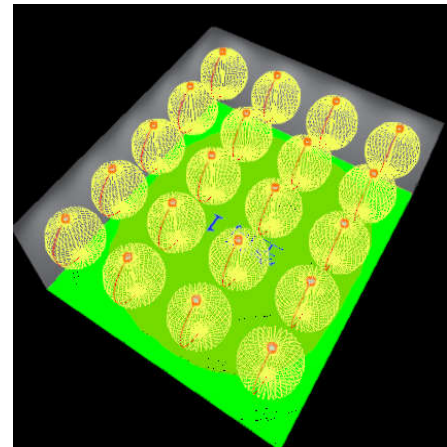


Fig 4 Layout of hybrid daylighting system

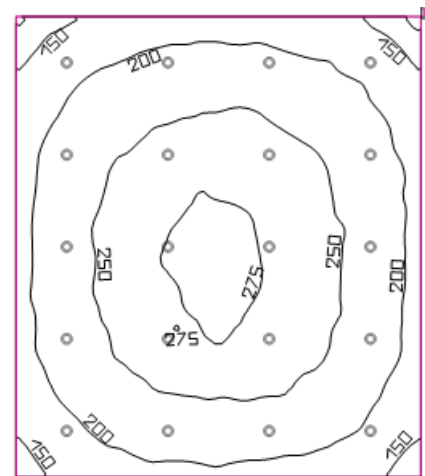


Fig 5 Illumination distribution of twenty hybrid daylighting systems on the ground

Based on the simulation, the illumination distribution of twenty hybrid daylighting system on the ground is approximately equivalent with that of nine 54W T8 florescent lamps, with the average illumination distribution on the ground of about 226lux.

2.3 Cost of traditional lighting system

A 54W T8 florescent lamp consists of three 18W T8 fluorescent lamp. The unit price of T8 florescent lamp is 10 Yuan, and cost of lighting fixture including materials and installation is 200 Yuan. Therefore, the total cost of the traditional lighting systems is 2070 Yuan for one store and 62100 Yuan for entire shopping mall, respectively.

The average life span of a T8 fluorescent lamp is about 15000h. Given that 13h lighting is required during the opening hours of the shopping mall, the T8 fluorescent lamp shall be replaced every 3.2 years. Other maintenance costs can be neglected due to its stable performance. Thus, annual maintenance of traditional T8 lighting system is 2531 Yuan for entire shopping mall.

Illumination is provided to underground shopping mall for 13h from 9:00-22:00 in a day. The total annual energy consumption by traditional electric lighting system in entire shopping mall is 69182 kWh. Electricity prices for general industrial and commercial use in China is 0.76 Yuan/kWh, so annual electricity bill is 52578 Yuan.

For traditional florescent lighting system, the sum of annual maintenance and electricity bill in entire shopping mall is 55109 Yuan. Total cost of traditional lighting system in Yuan can be estimated by the following formula:

$$\text{Total cost} = 62100 + 55109n$$

Where n is the operation year.

2.4 Cost of hybrid daylighting system

Based on the simulation result, twenty hybrid optical fiber daylighting systems are required to replace nine 54W T8 florescent lamps in one store. As shown in Table 1, the cost of one hybrid daylighting system is about 1050 Yuan. In order to further reduce the cost, the lens area of standard model is increased by 15 times, equivalent with 15 previously designed prototypes.

The initial investment and installation cost of 40 standard hybrid daylighting systems for entire shopping mall is 281000 Yuan.

Table 1 Cost per standard hybrid daylighting system

| Name | Specification | Quantity | Total price Yuan |
|--------------------|---------------|----------|---------------------|
| Fresnel lens | φ 100mm | 49 | 735 |
| Solar cell | 125*125mm | 28 | 168 |
| Optical fiber | φ 3mm | 294m | 3528 |
| Lighting collector | | 29 | 294 |
| Diffuser | | 6 | 600 |
| Tracker | | 1 | 200 |
| Accessories | | | 1500 |

Generally, the optical fiber and Fresnel lens can work for 20 years almost without any maintenance. The annual cost for structural inspection of supporting frame, lubrication of moving parts and replacement of LED lamps for entire shopping mall is about 10000 Yuan.

Based on our experiments [7], the hybrid daylighting system can provide 5 hours of illumination only via optical fiber at least, and 4 hours of illumination in combination with LED lamps. Illumination of residual 4 hours is provided by pure LED lamps (total power is 15.5W). In addition, energy storage unit of 40 standard hybrid daylighting systems can generate 5457 kWh power every year. Assuming 8 hours of pure LED lamps powered by municipal electricity, it will cost 21700 kWh electrical power, corresponding to 16492 Yuan annually.

Therefore, Total cost of traditional lighting system in Yuan can be estimated by the following formula:

$$\text{Total cost} = 281000 + (10000 + 16492)n$$

Where n is the operation year.

Fig. 6 is the comparison in total cost between traditional lighting system and hybrid daylighting system. Even though the initial investment of hybrid daylighting system is much higher than that of traditional lighting system, it is still economically competitive after 7 years of operation.

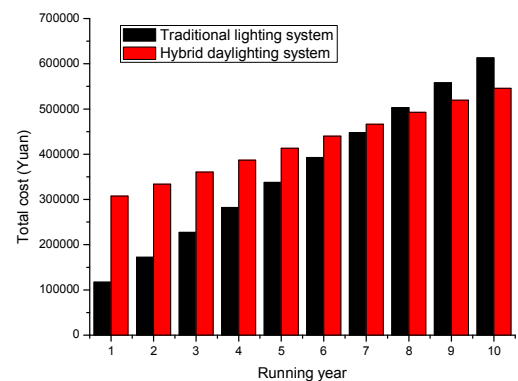


Fig 6 Total cost comparison between two systems

3. ENVIRONMENTAL BENEFITS

For the entire shopping mall, the total annual energy consumption by traditional electrical lighting system in entire shopping mall is 69182 kWh. In comparison, the standard hybrid daylighting system only additionally consumes 21700 kWh electricity every year, which is 31.4% of traditional lighting system. According to the CLP Group 2009 sustainability Report, the estimated amount of carbon dioxide emitted from the electricity generation is 0.83kg/kWh of electric power [8], so the studied standard hybrid optical fiber daylighting systems in the entire shopping mall can reduce 39410 kg carbon dioxide emission in a year.

4. CONCLUSION

In the studied case, 40 standard hybrid daylighting systems can replace 270 nos. of 54W T8 florescent lamps in the entire shopping mall. The initial investment and installation costs for traditional and hybrid lighting system are 62100 Yuan and 281000 Yuan, respectively. The hybrid daylighting system is still economically competitive due to its lower maintenance cost and lower energy consumption. After 7 years of operation, the total cost of hybrid daylighting system is even lower than that of traditional lighting system, not to mention that 39410 kg carbon dioxide can be reduced every year.

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