Feasibility Study on LED Street Lighting with Smart Dimming Systems in Wooi Stream, Seoul

Jeong Tai Kim¹ and Taeyon Hwang*²

¹Professor, Department of Architectural Engineering, Kyung Hee University, Republic of Korea
²Assistant Professor, School of Architecture, Chosun University, Republic of Korea

Abstract
The South Korean and Seoul metropolitan governments have been forced to radically change the current High Pressure Sodium (HPS) lamps to Light Emitting Diode (LED) lamps for street lighting in cities according to "LED Plan 2060." Thus, this study aims to evaluate the feasibility of LED-based street lighting by analyzing energy efficiency and life cycle cost. For this purpose, a comparison of the lighting energy consumption by dimming control in Wooi Stream as a test bed project was conducted and the life cycle cost of LED lamps for replacing HPS lamps for street lighting was analyzed. As a result, LED lamp replacement could reduce the energy consumption by 69% compared to HPS lamps, and the dimming control system by pedestrian movements could save 77% of lighting energy. However, the payback period of LED replacement is 11.5 years. This indicates that the high purchase price of LED lamps would decline by 80% within 4–5 years with assertive investment for commercializing LED lamps and rapid growth of the lighting market in Korea, if LED lamps in street lighting have an economic performance.

Keywords: LED; High Pressure Sodium Lamp; energy efficiency; life cycle cost; street lighting

1. Introduction
Recently, the South Korean government is spending more than 2% of its GDP for the constant investment and development of eco-friendly policies such as green growth, reduced energy consumption, and carbon dioxide (CO₂) reduction, in all economic fields¹². Following such measures of the government, companies in Korea are also becoming interested in research and investment for eco-friendly industries, and the feasibility of LED, an environment-friendly material, is being researched from many sides. The energy and CO₂ reduction effects of LED have already been proven through various studies, and the LED is being widely used indoors and outdoors as the next-generation light source³⁷. In particular, street lighting, which is the most typical outdoor light source, is evolving into smart lighting, which possesses high efficiency and performance, by combining with information and communication technology (ICT) and the internet of things (IoT) recently.

In the case of South Korea, the standard for minimum efficiency of incandescent lamps as outdoor street lighting is becoming higher every year. Under the leadership of the Ministry of Knowledge Economy, the "LED Plan 2060," which aims to increase the LED lighting penetration rate to above 60%, is underway in full scale⁸. Moreover, in Seoul metropolitan city, the criteria for the distribution of LED lighting in the public offices of Seoul has been established. By 2014, approximately 348,000 existing lights, including incandescent, halogen, and fluorescent lights, which take up about 50% of lighting in the public sector, were replaced with LEDs. From 2013, the city aims to replace about 30% of its street lighting on roads with LED. For this, support for the installation of LED is being expanded to use LED as an alternative light source that can increase energy efficiency⁹.

Unlike traditional lamps, LED lamps are highly efficient, reduce power consumption, emit less heat, reduce the cooling and heating loads due to long lifetime, save lighting energy, and require low maintenance costs. Nevertheless, the reason for the low penetration rate of LED lamps with so many strong points, both from the perspectives of energy saving and environmental friendliness, is because their price is noticeably higher than fluorescent or incandescent lamps, so the burden for the initial investment costs increase¹⁰.

Therefore, in this study, evaluation of the energy efficiency and economic feasibility of the LED street lighting replacement project, which is one of the energy
efficiency improvement projects currently underway in South Korea, is conducted by a case study analysis of the life cycle cost (LCC) analysis. Further, by using a motion sensor, the energy efficiency and economic feasibility of the smart street lighting is evaluated, as the purpose of the present study.

2. Characteristics of Research Area

To evaluate the energy performance and economic feasibility of the street lighting in Wooi Stream, where the existing HPS lighting is replaced with LED, the study was conducted by the following method. First, to comprehend the physical environment of Wooi Stream, a theoretical study was performed on the characteristics of each light source, the current status regarding the installation of LED and HPS lamps.

Moreover, to evaluate and investigate the improvement of each light source, the power consumption of each light source was compared, and the energy-saving effect obtained by dimming control in each period was compared. Finally, the present value method (PVM) was used for the life cycle cost (LCC) analysis of LED and HPS lamps to evaluate the economic feasibility and validity of LED lighting as street lighting.

Wooi Stream is located in Wolgye-dong, Nowon-gu, Seoul. As shown in Fig.1., the outdoor HPS lighting instruments for the one-way 3 km interval of a 5 km-long walkway have been replaced with LED lamps as a part of the city's pilot street lighting project to save energy and reduce light pollution.

Table 1. The Specification of Light Sources at Wooi Stream

| Type | HPS | LED |
|------|-----|-----|
| Capacity (W) | 250W | 75W |
| Active power (W) | 279.8 | 92.29 |
| Luminous flux (lm) | 25,000 | 5,950 |
| Efficiency (lm/W) | 100 | 85 |
| Lifespan (hour) | 10,000 hours | 50,000 hours |
| Temperature | 350°C | 40°C |

Table 2. Operating Hours of Street Lighting at Wooi Stream

| Season   | Sunrise | Sunset | Lighting Hour |
|----------|---------|--------|---------------|
| Spring-Fall | 6:35 am | 18:44 pm | 11 hrs. 51 min |
| Summer    | 5:11 am | 19:57 pm | 9 hrs. 14 min  |
| Winter    | 7:43 am | 17:17 pm | 14 hrs. 26 min |

Fig.2. Shape of LED Lamp and Light Distribution Curve
[Source: http://www.galed.co.kr]

a. Daytime image     b. Nighttime image

Fig.1. Status of Street Lighting at Wooi Stream

In the lighting improvement project of Wooi Stream, the existing 166 250W-powered HPS lamps were replaced with 202 75W-powered LED lamps. Unlike the existing less efficient lamps that generate heat with a high temperature of approximately 350°C, the LED lamps greatly reduced the energy required for lighting the Wooi Stream while improving the level of illumination from 10.5 (lx) to 21 (lx), thereby helping the safety of pedestrians in the nighttime (Fig.2., Table 1).

Table 2 shows the operating hours of street lighting in Wooi Stream for each season. Since the nighttime street lighting is turned on and off 15 minutes before/after the sunset/sunrise, in this study, the sunset/sunrise times during the day were calculated based on spring/fall, summer, and winter solstices to measure the lighting hours of the street lighting.

3. Results

3.1 Energy Consumption of Light Source

To analyze the energy performance of each light source, the seasonal sunrise/sunset time was used to measure the power consumption of each light source, as shown in Table 3. The results show that the power consumption in wintertime is 36% more than summertime and about 20% more than the spring and fall seasons, depending on the hours of daylight. Due to this, the HPS lamps with higher power consumption consume approximately 1,147.46 kWh per year, while the LED lamps consume only 316.00 kWh, which is about 72.46% less than the HPS lamps. Therefore, replacement of the existing HPS lamps with LED lamps increases energy efficiency, and is very positive from the perspective of energy performance.

3.2 Energy Saving by Dimming Control

Although the replacement of HPS lamps into LED lamps can save electricity, the dimming system of street lighting for each period, depending on the pedestrian traffic, will further increase the energy-saving effect. In this study, the dimming control reduces the electricity consumption and maintenance costs by controlling the luminosity of the lighting by three steps: 100% before 10 pm; 75% from 10 pm to midnight; and 50% after midnight. The energy consumption before and after applying the dimming control showed that the annual power consumption of HPS without the dimming
control (1,147.46 kWh) was reduced to the annual power consumption applied with the dimming control (214.76 kWh), which is about 81.28% reduction in energy-saving effect. Moreover, replacement of the light source resulted in about 990 tons decrease of CO₂ emission, which also contributes to improvement of the environment.

3.3 Life Cycle Cost Analysis of Light Source
The life cycle cost refers to the entire costs that are required for planning, constructing, maintaining, and discarding a product, and the present value method (PVM) is a method for converting the entire costs generated during the life cycle into the present value. Where \( A \) is the repeated cost which is repeated identically every year, \( i \) is the discount rate, and \( n \) is the analysis period, the present value (\( PV \)) of the cost, can be shown as follows:

\[
PV = \frac{A}{1+i} + \frac{A}{(1+i)^2} + \ldots + \frac{A}{(1+i)^n} = \frac{(1+i)^n-1}{i(1+i)^n} \times A
\]

However, with the non-repeating cost, which is generated only once after \( n \) years as \( F \), and the discount rate at that time as \( i \), the present value at this time (\( PV' \)) can be shown as follows:

\[
PV' = \frac{1}{(1+i)^n} \times F
\]

As a result of the LCC analysis, the HPS and LED lamps installed in the study area show a great difference between their respective life cycles, as shown in Table 5. The life cycle of an HPS lamp is approximately 2 years and 3 months, while that of an LED lamp is approximately 11 and a half years. Therefore, considering that the replacement period of an LED lamp is about 11 years, the period of analysis was assumed as 22 years, in which two replacements can occur, and the interest rate was set at 2.5% (benchmark rate of the Bank of Korea\(^{10}\)), which is the average value of the past 5 years.

The initial investment cost, as a component of the LCC analysis, included the product of the lamp’s unit price and 166 (i.e., the number of currently installed lamps), unit price of lighting fixture, and cost of stabilizer and converter, which are included with the equipment. Therefore, the unit prices of HPS lamps and LED lamps are respectively $238 and $664, which shows a difference of about 2.8 times.

Such high price of LED lamps has a disadvantage in that it increases the initial investment cost. However, the maintenance cost was calculated by summing the lamp replacement cost, other costs including the use of replacement equipment, and annual energy use. In particular, the annual energy cost is based on the power consumption of each lamp. The electricity charge for the actual use of each lamp was derived from the electricity charge table\(^{12}\) of KEPCO ($0.075/kWh = 2nd grade, which is the charged unit price for street lighting). Therefore, the LED lamps require an energy cost of about $5,372 every year, and a replacement cost of about $454 every 11 years. However, the HPS lamps require an energy cost of about $13,223, which is about 3 times that of the LED lamps, and the replacement period is 2 years, which is relatively very short.

Considering the initial investment costs of LED and HPS lamps in the simple break-even period analysis, the estimated break-even point of the replacement of existing LED lamps was about 10 years, which means that the return on investment is nearly impossible. Using the same analysis, it is found that while the initial investment cost of the LED lamp is about 8 times more expensive, the energy consumption of the HPS lamp is higher than that of the LED lamp, which makes the difference nearly 3 times in terms of maintenance costs. Moreover, the existing HPS lamps should be replaced every 2 years due to their short lifetime; such replacement cost also increases the maintenance cost. However, as shown in Table 6., the results of the LCC analysis for each lighting source, which assumes the investment period as 22 years from the long-term perspective using the PVM, the
Table 5. Life Cycle Cost Summary; HPS Lamps and LED Lamps

| Type                | LED lamp | HPS lamp | Difference |
|---------------------|----------|----------|------------|
| **Initial Investment Cost** |          |          |            |
| Lamp cost           | $403     | $30      |            |
| Lamp post cost      | $261     | $208     |            |
| Number of lamps (ea) | 202      | 166      |            |
| Total lamp cost     | $81,474  | $4,910   |            |
| Total lamp post cost| $52,637  | $34,553  |            |
| Installation cost   | $1,190   | $505     |            |
| Sum cost            | $135,302 | $39,968  | ($95,335)  |
| **Operation Cost**  |          |          |            |
| Lamp Lifespan       | 11 Years 6 months | 2 Years 3 months | |
| Relocation cost     | $403     | $30      |            |
| Extra Cost          | $50      | $50      |            |
| Electricity Fee per kWh | $0.075  | $0.075   |            |
| Annual Electricity Fee | $4,764  | $14,216  | ($9,452)   |

Simple Break-even point Period: $95,335/$9,452 = 10.1 years

Table 6. LCC Analysis using the Present Value Approach

| Type                | LED lamp | HPS lamp | Difference |
|---------------------|----------|----------|------------|
| **Cost**            |          |          |            |
| Initial Investment cost | $135,302 | $39,968  |            |
| Annual operation cost | $4,764   | $14,216  |            |
| Incurred expense in 2 years | -       | $80      |            |
| Incurred expense in 4 years | -       | $80      |            |
| Incurred expense in 8 years | -       | $160     |            |
| Incurred expense in 12 years | $454    | $160     |            |
| Incurred expense in 16 years | -       | $160     |            |
| Incurred expense in 20 years | -       | $160     |            |
| Incurred expense in 22 years | $454    | $480     |            |
| **Present Value**   |          |          |            |
| Initial Investment cost | $135,302 | $39,968  |            |
| operation cost      | $4,764   | $14,216  |            |
| Relocation cost     | $454     | $80      |            |
| Sum                 | $220,548 | $292,859 | ($72,311)  |

Fig. 3. Expected Purchase Price Changes of HPS Lamps and LED Lamps Depending on the Electricity Cost and Interest Rate
LED’s LCC is about $22,055, while the existing HPS’s LCC is about $292,859, making the LED lamp about $72,311 more efficient. Therefore, the LED, which has high initial investment cost, is economically feasible compared with the HPS (the existing light source) from the maintenance cost perspective.

4. Discussion

Through this study, it was found that the LED has a longer lifetime and higher efficiency, and contributes positively to the environment. However, the LED lighting market has not been properly commercialized despite various policies for its distribution owing to high initial investment cost. This indicates that the unreasonable LED circulation system due to unsystematic settlement and high raw material cost are becoming major problems for reducing the initial investment cost. Such problems are expected to be resolved by expanding the regulations concerning incandescent lighting since 2012 in Europe, the United States, and Japan. In fact, the price of LED lamps in Europe (Finland and Turkey) is about 3–6 times the price of existing incandescent lights and HPS lamps. However, the electricity charge ranges from $0.11 to $2.24/kWh, which is about 1.5 to 30 times the electricity charge in South Korea. Therefore, without improvement to lighting efficiency and lower price, the return on investment on the traditional light source is expected to be nearly impossible. Thus, the return on investment (payback period) can become possible within 5–9 years approximately 2–5 years later than now, which makes the replacement of LED lamps easier.

Meanwhile the electricity cost for 75W-powered LED, which is mainly used in the street lighting of the United States is 30% less than in South Korea. By assuming the analysis period as 15 years, the break-even point is expected to be 5–6 years. In the case of South Korea, the LED lamps as of now do not possess economic competitiveness, compared with the traditional light source. However, as can be seen in Fig.3., if the price of LED lamps consistently decreases by 30% as the LED lighting market rapidly grows, after 2 years, the break-even point is expected to be approximately 5 years, and after 4 years, the expected break-even point is approximately 2 years. This is a reduction of about 80% from the current price, which makes replacement of the existing HPS lamp possible.

However, the data used for the LCC analysis in this study were from 2014 and 2015. Therefore, variables such as the lighting efficiency and lifetime will be improved by the technological advancement of the LED lighting market in the future. Moreover, the inflation rate and electricity charge’s rate of increase might make differences to the results. Further, since the South Korean government is providing $15 million as subsidy, just as the federal government of the United States is providing $140 million to 22 states, the price competitiveness of LED lighting is expected to steadily improve. Therefore, if the reliability and penetration rate of LED is increased as an alternative light source through active studies, it can prove itself useful as an appropriate countermeasure for the energy crisis as well as the climate change issue.

5. Conclusions

The comparison of energy performance and economic feasibility between the existing lighting lamps and LED lamps due to street lighting replacement results in the following:

The energy performance analyses before and after the replacement of LED lamps showed that the 250W-powered HPS lamps consume about 1,147 kWh per year, while the 75W-powered LED lamps consume about 316 kWh. Therefore, the LED lamps save about 73% energy every year.

The energy consumption before and after the dimming control of each time period depending on the pedestrian traffic showed that the annual power consumption of the existing HPS lamps without the dimming control is approximately 1,147 kWh, while the annual power consumption of the LED lamp applied with dimming control is about 214 kWh, which represents about an 81% energy-saving effect. Currently, in the United Kingdom and Finland, the ratio of energy saved by the dimming control ranges from 25 to 45% [15-16]. In this study, the energy-saving ratio obtained by the dimming control of LED lamps was 25%, which is similar to the energy-saving figures in other countries.

A comparison of the economic feasibility between LED lamps and existing lamps, as derived from the PVM, showed that the LED lamps save about $72,000. Through the exchange of LED lamps, it was found that even though the maintenance cost of LED lamps can be reduced and become lower than that of HPS lamps, LED lamps are hardly economically feasible, because their break-even point of investment return is approximately 10 years. Therefore, until the demand for LED lamps increases and the initial investment cost is thereby reduced, the economic feasibility of LED lamps will remain low and the economic support program by the government for LED exchange should be kept up to propagate it for a while.

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