Return on Investment of a LED Lighting System

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Abstract - **This paper mainly focuses on the calculation of the ROI(Return On Investment) for the LED. First, introduce the basic concept and application of the LED lamp and ROI. Then, decompose the constitution of the maintenance cost into scheduled and unscheduled maintenance. For these two kinds of maintenance, calculate the maintenance time interval separately and the total maintenance cost. Finally, the ROI equation of the LED lamp is obtained. From this, the LED lighting system is inferred from the calculation of the ROI on the LED lamp. Then, make a case study to simulate the ROI in LED light system of different LED scale and make sure the time to begin obtaining merits.**

I. INTRODUCTION

A. LED lamp

A Light Emitting Diode lamp is a solid state lamp (SSL) that uses light-emitting diodes (LEDs) as the source of light. Since the light output of individual light-emitting diodes is small compared to incandescent and compact fluorescent lamps, multiple diodes are used together. LED lamps can be made interchangeable with other types, but the presently at a higher cost. Most LED lamps must also include internal circuits to operate from standard AC voltages. LED lamps offer long life and high efficiency, but initial costs are higher than for fluorescent lamps.[7]

LED lamps are used for both general lighting and special purpose lighting. Where colored light is required, LEDs come in multiple colors, which are produced without the need for filters. This improves the energy efficiency over a white light source that generates all colors of light then discards some of the visible energy in a filter.

White-light light-emitting diode lamps have the characteristics of long life expectancy and relatively low energy consumption. The LED sources are compact, which gives flexibility in designing lighting fixtures and good control over the distribution of light with small reflectors or lenses. LED lamps have no glass tubes to break, and their internal parts are rigidly supported, making them resistant to vibration and impact. With proper driver electronics design, an LED lamp can be made dimmable over a wide range; there is no minimum current needed to sustain lamp operation. LEDs using the color-mixing principle can produce a wide range of colors by changing the proportions of light generated in each primary color. This allows full color mixing in lamps with LEDs of different colors. LED lamps contain no mercury.

However, some current models are not compatible with standard dimmers. It is not currently economical to produce high levels of lighting. As a result, current LED screw-in light bulbs offer either low levels of light at a moderate cost, or moderate levels of light at a high cost. In contrast to other lighting technologies, LED light tends to be directional. This is a disadvantage for most general lighting applications, but can be an advantage for spot or flood lighting.

Some specific applications of the LED lamp are as follows:

- The 2007 Audi R8 sports car uses two strips of optically-focused high-intensity LEDs for its Daytime Running Lamps.[9]
- AT&T Company adopted the Tetra LEDs light system from GE, changed the 7000 channel letter signs all over the USA. The total amount of the LEDs is 2600 thousand.[10]
- Boeing adopted the LEDs light system of the DLE （Diehl Luftfahrt Elektronik） from German to simulate the daytime condition in the passenger room of the 787 Dreamliner.

The Shenzhou VII used 24 LEDs to consist of a lamp illuminating the outer space . Technology project managers or consultants who design, develop, and deliver projects.

As the main topic of the world is “saving energy and reducing pollution”, the LED light will eventually replace the other lights such as sodium vapor (in these article, it is a reference substance). Thus, the calculation of the ROI(Return on investment) of the LED will show this trend.

B. ROI

Return on Investment (ROI) is a useful means of gauging the economic merits when conduct. In general, ROI is the ratio of gaining to investment. Equation is a way of defining ROI over a system’s life cycle [2][4][5].

Although much progress has been made, the ROI Methodology is not without its share of problems and concerns. The mere presence of the process creates a dilemma for many organizations. When an organization embraces the concept and implements the process, the management team usually anxiously awaits results, only to be disappointed when they are not immediately available[5]. For an ROI process to be useful, it must balance many issues such as feasibility, simplicity, credibility, and soundness. More specifically, three major audiences must be pleased with the ROI process to accept and use it:

- Technology project managers or consultants who design, develop, and deliver projects
- CIOs, senior managers, sponsors, and clients who initiate and support projects
- Researchers who need a credible process.

This paper’s purpose is to calculate the ROI of the LED lighting system and make sure the time to begin obtaining merits.

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II. COST STRUCTURE OF A LED LAMP

As we know, LED lamp as itself has a system. To be useful as a light source for a room, a number of LEDs must be placed close together in a lamp to add their illuminating effects. This is because an individual LED produces only a small amount of light, thereby limiting its effectiveness as a replacement light source. If white LEDs are used, their arrangement is not critical for color balance. When using the color-mixing method, it is more difficult to generate equivalent brightness when compared to using white LEDs in a similar lamp size. Furthermore, degradation of different LEDs at various times in a color-mixed lamp can lead to an uneven color output. LED lamps usually consist of clusters of LEDs with driving electronics, a heat sink and optics [6] [7].The general relationships between them are shown on Figure 1.

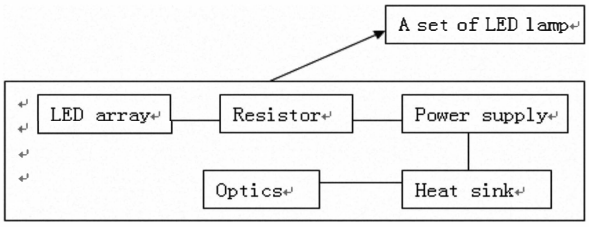

Fig.1. The structure of a LED lamp

In this whole article, the appeared subscripts have the meanings as follows:

1: LED, 2: the electronic circuit, 21 resistors,

22: power 3 heat sink 4 optics

In electronics, the basic LED circuit is an electrical circuit used to power a LED. It consists of a voltage source powering two components connected in series: A current limiting resistor, and an LED. Optionally a switch may be introduced to open and close the circuit [11].

A heat sink is an environment or object that absorbs and dissipates heat from another object using thermal contact (either direct or radiant). Heat sinks are used in a wide range of applications wherever efficient heat dissipation is required; major examples include refrigeration, heat engines, cooling electronic devices and lasers.

A heat sink usually consists of a base with one or more flat surfaces and an array of comb or fin-like protrusions to increase the heat sink's surface area contacting the air, and thus increasing the heat dissipation rate. While a heat sink is a static object, a fan often aids a heat sink by providing increased airflow over the heat sink, thus maintaining a larger temperature gradient by replacing the warmed air more quickly than passive convection achieves alone. This is known as a forced air system.

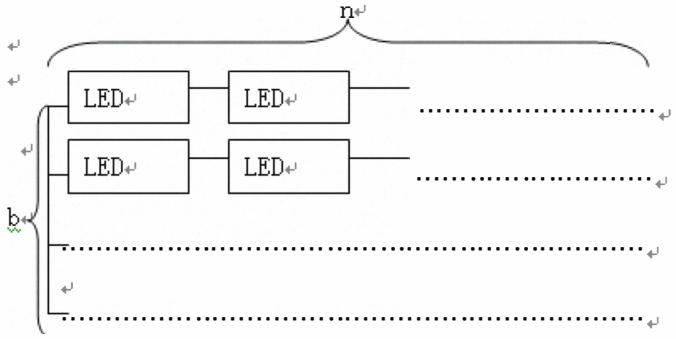

Figure 2 LED array

The LED array is simply set as the Figure 2 shows, with b rows and n columns. Thus, the total number of LED is b*n.

A. Costs of a set of LED lamp

According to the constitution of a set of LED lamp, the cost of a LED lamp consists of four major parts.

$$C_{l0} = n \times b \times C_{l1} + C_{l2} + C_{l3} + C_{l4} \qquad (1)$$

Where

C_{l0} : Total purchased cost of a LED lamp

C_{l1} : The cost of a single LED

C_{l2} : The cost of the LED electronic circuits, which consist of C_{l21} (resistor) and C_{l22} (power)

C_{l3} : The cost of heat sink

C_{l4} : The cost of optical components, which include reflector, diffusion disk, etc.

The value C_{l0} is an original investment on the LED lighting systems, the purchased cost of LEDs. It was a fixed value and the purpose of the calculation the ROI is withdrawing this cost.

B. Maintenance costs in its support time

When a LED lamp fails to work, divide the maintenance with two parts, the repair and replacement. (Use C_{m1}, C_{m2} ……for abbreviation). Repair means not changing the whole structure of the component but the failure part of it. Replace means purchasing the same component to substitute the failure component. They all involved the labor cost. These separation makes the maintenance cost easy to figure out.

Repair component: resistor and the heat sink

Replace component: LED, power and optics

1) Costs of scheduled maintenance

The component need to be implemented the scheduled maintenance is the electronic circuits, the heat sink and the optics. They can work normally through the scheduled maintenance. When the LED lamp working during its support time.

including labor, additional component replacement cost .(unit: Chinese yuan per person, per hour)

$$\overline{M_{pt}} = \frac{\sum_{i=1}^{n} M_{pti}}{n} = \frac{\sum_{i=4}^{4} M_{pti}}{4} \qquad (2)$$

$$C_{m0} = C_{m21} + C_{m22} + C_{m3} + C_{m4} = \frac{T}{M_{pt}} \times C_l \quad (3)$$

Where

T the supportive time of the LED light system

M_{pti} the total maintenance time when conducting scheduled maintenance on the same type items once

$\overline{M_{pt}}$ mean time between scheduled repairs

n total items in a LED light system

C_l the cost of one time schedule maintenance

Table 1 The steps of scheduled maintenance

item \ time	Preparation	Detection	Correction	Verification	Total	Cost
resistor	1	1	1 0	1 0	M_{pt4}	C_{m21}
power supply	1	1	1 0	1 0	M_{pt22}	C_{m22}
heat sink	1	1	1 0	1 0	M_{pt3}	C_{m3}
optics	1	1	1 0	1 0	M_{pt4}	C_{m4}
total						C_{m0}

1: need time to conduct maintenance; 0: do not need time to conduct maintenance

The constitution of the M_{pti} is shown at Table 1.The result of the Scheduled maintenance cost can be obtained by the steps shown at Table 1.

2) Costs of unscheduled maintenance

We assume the components need to be conducted by the unscheduled maintenance is ONLY the LED (C_{m1}) because the other components (resistor...) can be restored perfectly by the schedule maintenance. There is an even smaller possibility to fails that the unscheduled maintenance can be ignored. Thus, other components need not to be invested on the scheduled maintenance. The failure rates of the LED depends on the time line.

Thus, choose the Weibull distributions to simulate the failure process.

The Weibull distribution is a distribution that aim at the electric component that its failure rate is changed by the time line[13].

$$\lambda_1(t) = (m/\eta^m) \times t^{m-1} \quad (4)$$

$$F_1 = 1 - exp(-(t/\eta)^m) \quad (5)$$

$$C_{m1} = n \times b \times C_{l1} \times \frac{T}{t} \quad (6)$$

Where

λ_1 the failure rate of a single LED

F_1 the cumulative density function of a single LED

η the scale parameter of the Weibull distribution

m the shape parameter of the Weibull distribution

Where m > 0 is the shape parameter and η > 0 is the scale parameter of the distribution. Its complementary cumulative distribution function is a stretched exponential function. The Weibull distribution is related to a number of other probability distributions; in particular, it interpolates between the exponential distribution (m = 1).

The scale parameter η represents the working load level. Generally speaking, more load, less η.Thus, it represents the probability density function of LED varied by the condition.

The equation (3) shows the money spent on the LED per unscheduled maintenance time. t represents the time interval (talks later). Thus, we calculate the t through the Weibull distribution with the cumulative density that has already set.

The unscheduled maintenance time interval is unfixed. Thus, there are two value to firm the interval, the maximum value and minimum value. They are calculated by their corresponding cumulative density ($F_{\max}$, $F_{\min}$)

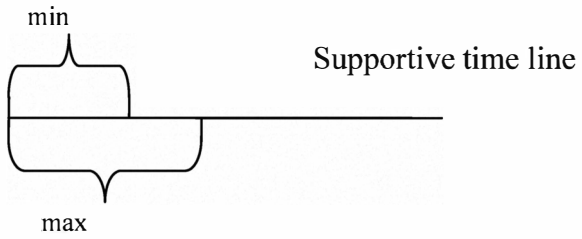

Figure 3 The time interval

Figure 3 shows the maximum and minimum value of the maintenance time. Thus, the maximum maintenance is conducting minimum time interval every time, and vies versa.

Thus, there are two extremums and the formulas of the unscheduled maintenance are as follows:

$$C_{\min m1} = n \times b \times C_l \times \frac{T}{t_{\max}} \quad (7)$$

$$C_{\max m1} = n \times b \times C_l \times \frac{T}{t_{\min}} \quad (8)$$

C. Total cost of a LED lamp

When calculating the total cost on LED lamp during its supportive time, the energy consumes should be considered carefully.

$$C_{l5} = \overline{C_{l5}} \times t \quad (9)$$

$\overline{C_{l5}}$ the cost of the power supply per hour

The total cost on LED lighting system during its supportive time is as follows:

$$C_t = C_{l0} + C_{l5} + C_{m0} + C_{m1} \quad (10)$$

C_t Total cost of a LED lamp

D. Calculation of ROI on a LED lamp

The final definitions offered in this chapter are the basic formula for return on investment and payback period. Common formulas for ROI are offered [1]:

$$ROI = \frac{return - investment}{investment} = \frac{avoid\,cost}{investment} - 1 \quad (11)$$

$$C_x = C_s + C_{ms} + \overline{C_{ss}} \times t \quad (12)$$

$$ROI = \frac{C_x - C_t}{C_t} \quad (13)$$

Where

C_s The purchasing cost of the sodium vapor

C_{ms} The maintenance cost of the sodium vapor lamp

$\overline{Css}$ The cost of power supply per hour

C_x The total cost of the sodium vapor

Obviously, the calculation of the ROI is varied by the number of the LED (b rows and n columns), the time. Other factors are fixed value when they input into the equation.

III. CALCULATION OF ROI ON A LED SYSTEM

As we have known the process of the calculating a LED lamp, the methods of calculating a LED lighting systems is easily obtained. We need only simulate the rate of the failure of the LED lamps in the whole LED lighting system, and then the process of calculating the ROI of a LED lighting system is just like the process of calculating the ROI of a LED lamp.

VI. CASE STUDY

In this section, the manager who may invest on the LED lighting systems will first raise a question: What is the balance point between the revenue and the cost (ROI=0) when replacing the sodium vapors with LED lighting system? We assume that there are 1000 LED lamps in the LED light system.

The parameters will be set as some specific value. The steps are as follows.

1 set a set of value

2 substitute this set of value into the ROI equation.

3 show the result in the Figure

A. ROI of a LED light system

A set of value is shown on the Table 2.

Table 2 A set of value

C_{l1}	5(China yuan)	C_l	20(yuan/hour/person)
b	7(number)	m	0.8
n	5(number)	η	0.002
C_{l21}	5(yuan)	$\overline{C_{l5}}$	0.1(yuan/hour)
C_{l22}	20(yuan)	C_s	20(yuan)
C_{l3}	20(yuan)	C_{ms}	50(yuan)
C_{l4}	10(yuan)	$\overline{C_{ss}}$	0.2(yuan/hour)
T	10000(hour)	$F_{\max}$	0.6
M_{pti}	1000(hour)	$F_{\min}$	0.4

Figure 4 shows the result of the ROI of LED light systems. In conclusion, whether the unscheduled maintenance time interval is the maximum or the minimum, the ROI is bigger than 0 when the time surpass the 2200 or 4800.Thus, we can believe the LED light system do give us a lot of merits.

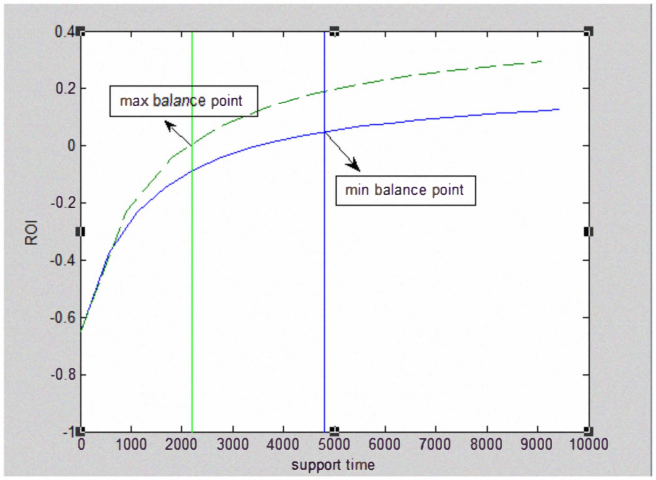

Figure 4 The output of the ROI

B. ROI of other LED lamp system

Now, give some LED light systems of different LED scale for reference.

factor / scale	supportive time/hour	max balance point/hour	min balance point/hour
500	10000	1500	3800
1000	10000	2200	4800
3000	10000	3000	5400
5000	10000	2800	4900
10000	10000	4100	7250

C. Discussion

We can see the balance point is varied by the scale of the LED light system. For recovering the cost more quickly, the scale should be at 3000. However, it is just an assumption and not consider the effect of the illumination.

D. Conclusions

The ROI of the LED can help us to easily make the decision that whether to make the replacement of the sodium vapor lamp with the LED lamp. Undoubtedly, we can make the right decision to the project through

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