NUMERICAL ANALYSIS OF TUNNEL LED LIGHTING MAINTENANCE FACTOR

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ABSTRACT: It is necessary to periodically maintain lighting equipment in accordance with international standards. Contamination of lamps caused by long-term use of lighting equipment will result in loss of Luminous Flux and optical losses. The decrease in lighting performance poses a visual difficulty for drivers and causes accidents. In this study, the total Maintenance Factor is numerically examined by considering the losses of diffuser and lens for LED lamps used in tunnel lighting. The variation of luminaries performance with years considering Maintenance Factors as regards environmental conditions and features of the luminaries is evaluated to demonstrate the importance of tunnel lighting maintenance. Moreover, to show the importance of LED lamps Maintenance Factor, the variation of illumination levels of LED lamps is analysed under different Maintenance Factors. It is observed that enhancing Maintenance Factor would contribute to energy efficiency.

ABSTRAK: Penjagaan peralatan cahaya secara berkala mengikut piawai kebangsaan adalah amat penting. Pencemaran lampu disebabkan penggunaan peralatan cahaya pada jangka panjang akan menyebabkan kehilangan kilauan kerdipan lampu dan optik. Pengurangan pencahayaan ini menyebabkan kesukaran pandangan pada pemandu dan menyebabkan kemalangan jiwa. Kajian ini mengkaji tentang jumlah Faktor Penjagaan secara numerik dengan mengambil kira pengurangan difuser dan kanta pada lampu LED yang digunakan dalam terowong pencahayaan. Faktor Penjagaan pada perubahan kilauan berdasarkan tahun mengambil kira keadaan sekeliling dan ciri khas kilauan. Tambahan, ini dinilai bagi menunjukkan kepentingan penjagaan terowong pencahayaan dan kepentingan Faktor Penjagaan Lampu LED. Perubahan pada tahap terang pada lampu LED dikaji dengan mengambil kira Faktor Penjagaan. Peningkatan pada Faktor Penjagaan telah didapati dapat menjimatkan tenaga.

KEY WORDS: *Maintenance factor, LED lamps, Luminaries performance, Numerical analysis, and Tunnel lighting.*

1. INTRODUCTION

Luminaries and operating conditions are the most important parameters in lighting. Environmental factors account for the loss in the efficiency of luminaries, as dirty luminaries have reduced luminous transmittance. In addition, operating time affects the efficiency of lamps. The performance of luminaries decrease over the time; thus, the performance of a lamp for a specified period of time can be specified. The performance of luminaries during a period of time may be improved by maintenance processes such as cleaning the glass of luminaire or replacing of the lamp [1-4]. Moreover, renewal of all luminaries will also improve performance. By considering the estimated performance loss at the system design phase, lighting systems would be able supply the minimum required lighting even at the end of the period when it exhibits the lowest performance [5]. Fig. 1 illustrates the tolerance range associated with Maintenance Factor (MF) as regards performance loss.

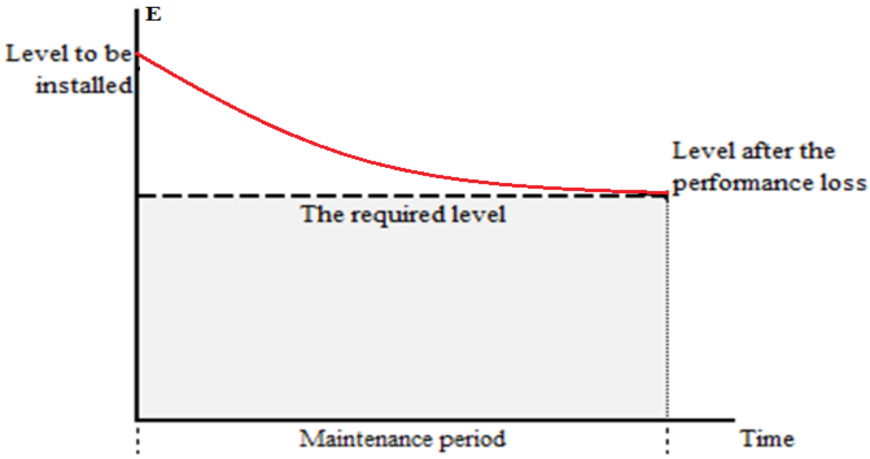

Fig. 1. Tolerance range associated with Maintenance Factor as regards performance loss [5].

Maintenance Factor is a parameter that specifies the performance to be supplied by a lighting system at the end of a certain period depending on the performance at the beginning of the period. Maintenance Factor is described as 80% for a system for which 20% of performance loss is estimated at the end of maintenance period. Since MF is used as a multiplier in programs of lighting calculation, lighting levels reached by lighting calculations display the values at the end of a certain period [7-13]. Maintenance Factor varies with the technology level of luminaries. According to CIE 154:2003, the MF of luminaries is formed by the product of multiple indicators of performance [6]. It depends on the protection degrees of the luminaries against contamination (IP65: completely dust prof, protect against water jets), sources of light used in luminaries and all effects that can cause decrease in illumination [6].

2. LUMİNOUS FLUX NUMERICAL CALCULATION

Luminous Flux is the proportion of flux blazing through a lamp that affects the optic. Its unit is lumen, and it represents ability of radiation to stimulate a sense of radiance. Furthermore, total Luminous Flux is described as the sum of Luminous Fluxes arising from a source and spreading over various parts of the space. The total Luminous Flux falling within a unit surface is defined as the illumination level of that surface, and it is represented by E. Its unit is lux. The radiant power of a lux is equal to a candle light [5]. The Illumination level of a point P and the geometrical representation of the illumination level of the point is illustrated in Equation 1 and Fig. 2, respectively. Equation 3 demonstrates the relationship between Maintenance Factor and lighting level.

$$E_P = \sum_{i=1}^{a} \frac{I(C,\gamma)}{h^2}.\cos^3\gamma \qquad (1)$$

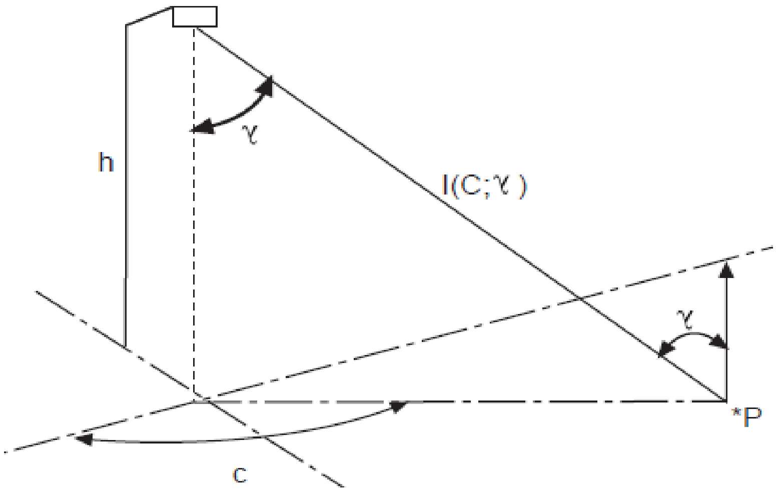

Fig. 2. The tolerance range associated with Maintenance Factor as regards performance loss [5].

Where,

I (C,γ): is value of light intensity reaching from luminaire i to point P (cd),

γ: is angle of gleam falling within point P by the vertical line,

a: is the amount of luminaires contributing to point P,

h: is ground clearance of luminaire photometric center (m)

C: is plane angle.

3. MAINTENANCE FACTOR

For luminaires, Maintenance Factor is defined as the proportion of total light coming from a luminaire at the end of the maintenance period in relation to the total light of the luminaire during its primary use. Following the standards associated with the use of MF in lighting, the specifications of lighting equipment in a lighting system are given considering environmental conditions and the Maintenance Factor calculated for a specified maintenance period CIE 154:2003. According to CIE 154:2003, lighting performance should not drop below the minimum levels specified in the standards. Maintenance Factor comprise Lamp Lumen Maintenance Factor (LLMF), lamp survival factor (LSF), and Luminaire Maintenance Factor (LMF). Lamp Lumen Maintenance Factor is the proportion of the Luminous Flux of a lamp at the end of a specified period in relation to the initial Luminous Flux. Lamp Survival Factor is the percentage of lamp survival ratio for Maintenance Factor. Luminaire Maintenance Factor (LMF) is the proportion of Luminous Flux lost at the end of described/specified period as a result of the structural features of luminaires as well as environmental factors. The LMF depends on the protection degree of luminaires against contamination (IP) and environmental pollution. It is specified by the designer according to the contamination condition of the environment during maintenance period or a relevant specification is consulted [5]. Maintenance Factor is calculated according to Equation 2.

$$MF = LLMF\ x\ LSF\ x\ LMF \tag{2}$$

$$E = \frac{I.\cos^3 \varepsilon.\Phi.MF}{h^2} \tag{3}$$

4. TUNEL LED LIGHTING AND MAINTENANCE FACTOR RELATIONSHIP

In this study, LED lamp luminaires dually inserted 6 m high used in a tunnel are investigated. The MF for LED lamp luminaires is the product of the three main factors described above. The MF of an LED lamp luminaire with protection degree IP65 is numerically determined. Fig. 3 illustrates a sample of tunnel LED lighting with double suspensions [5].

Fig. 3. A sample of tunnel LED lighting with double suspensions.

The time intervals for maintenance (by replacing LED lenses and diffusers) should be specified by the environment pollution level in the site where lighting system will be installed for tunnel lighting. According to the principle of maintenance yearly followed and an environmental condition of high level of pollution, the Luminaire Maintenance Factor (LMF) depending on the contamination of a luminaire with protection degree IP65 is specified as 0.91 in report CIE 154 [6]. Luminaire Maintenance factor according to protection degree of luminaire and the category of environmental pollution is illustrated in Table 1.

Table 1: Luminaire Maintenance Factor according to protection degree of luminaire and the category of environmental pollution is [5]

Optical Compartment IP Rating	Pollution Category	Exposure time [Years]				
		1.0	**1.5**	**2.0**	**2.5**	**3.0**
	High	0.53	0.48	0.45	0.43	0.42
IP2X	**Medium**	0.62	0.58	0.56	0.54	0.53
	Low	0.82	0.80	0.79	0.78	0.78
	High	0.89	0.87	0.84	0.80	0.76
IP5X	**Medium**	0.90	0.88	0.86	0.84	0.82
	Low	0.92	0.91	0.90	0.89	0.88
	High	**0.91**	0.90	0.88	0.85	0.83
IP6X	**Medium**	0.92	0.92	0.89	0.88	0.87
	Low	0.93	0.93	0.91	0.90	0.90

4.1 LLMF

Table 2 illustrates the LLMF of an LED lamp with a service life of 70000 hours.

Table 2: LLMF of LED lamp according to operating time in years

Years	Duration of study	LLMF%
1	8.766	0.980
2	17532	0.955
3	26.298	0.930
4	35.064	0.905
5	43.830	0.875
6	52.596	0.845
7	*61.362*	*0.825*
8	*70.128*	*0.800*

Lenses are generally used to direct beams transmitted from LED light sources towards the area to be lighted. Unlike traditional reflector systems, the luminous transmittance of lenses decreases over time. Time-dependent performance criteria of luminaries have been specified by IEC 62722-2-1 and IEC-62717. According to these criteria, confirmation tests of LED modules and LED luminaries were carried out considering 6000 hours maximum [14-16]. Fig. 4 illustrates optical variance caused by use of LED lens at UV/65°C for 6000 hours.

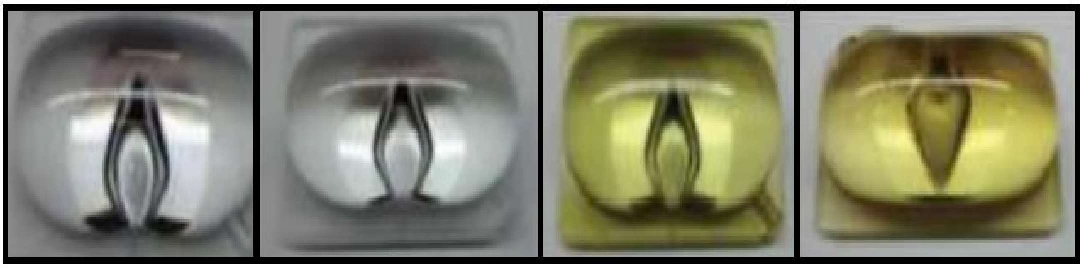

Fig. 4. Optical variance caused by use of LED lens at UV/65°C for 6000 hours.

When determining MF in LED luminaries in which lenses are used as a collimator, losses of 5% should be considered. In this study, it was assumed that lenses were used and that the luminous transmittance of the lenses would change by at least 5% over the considered time. Table 3 illustrates the total LLMF (%) of an LED lamp exposed to optical effect.

Table 3: Total LLMF (%) of an LED lamp exposed to optical effect.

Years	Duration of study	LLMF%	Optical effect %	Total LLMF%
1	8.766	98.00	5	93.00
2	17532	95.50	5	90.50
3	26.298	93.00	5	88.00
4	35.064	90.50	5	85.50
5	43.830	87.50	5	82.50
6	52.596	84.50	5	79.50
7	*61.362*	*82.50*	*5*	*77.50*
8	*70.128*	*80.00*	*5*	*75.00*

The decrease in Luminous Flux depending on the operating time of lamps was obtained from the catalogue of the producing company [17]. Figure 5 presents the image as obtained from the catalogue. The figure displays the performance loss of LED lamps, which lights the tunnel for 24 hours, depending on operating time. The decrease in Luminous Flux was determined as 7%, 9.5%, 12%, 14.5%, 17.5% and 20.5% at the end of operating times of 1, 2, 3, 4, 5 and 6 years, respectively. Fig. 5 displays the decrease in Luminous Flux depending on the operating time of LED lamps.

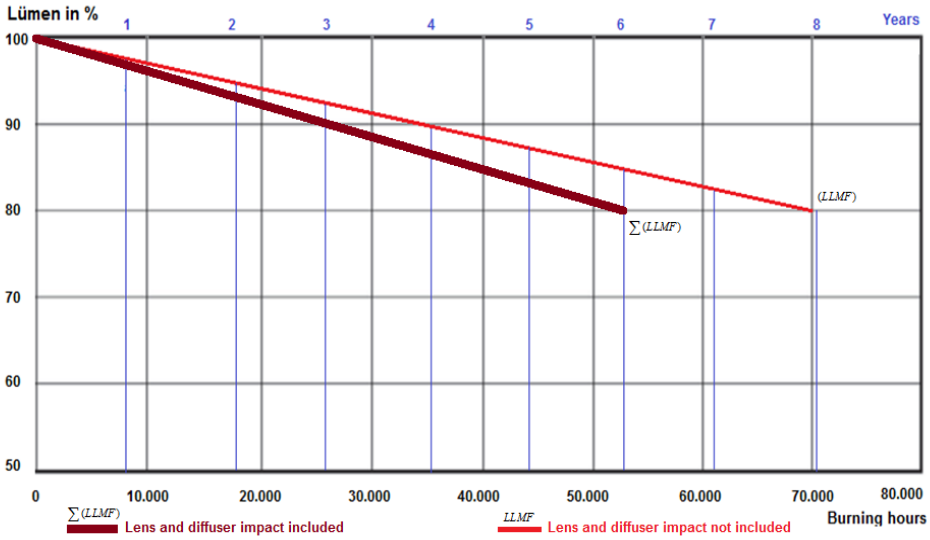

Fig. 5. Decrease in Luminous Flux depending on the operating time of LED lamps.

4.2 LSF

In operation strategy, LSF = 1 is accepted in a case where each attenuated lamp is replaced as early as possible. However, since in general lamping applications, it is not possible to replace broken lamps in a short time, lamps are replaced periodically and collectively. All lamps are replaced in a period of attenuation by 10% in an area where 10% is accepted as the maximum ratio of the prescribed attenuation of lamps to replace lamps collectively. Fig. 6 displays the line of LSF for LED lamps.

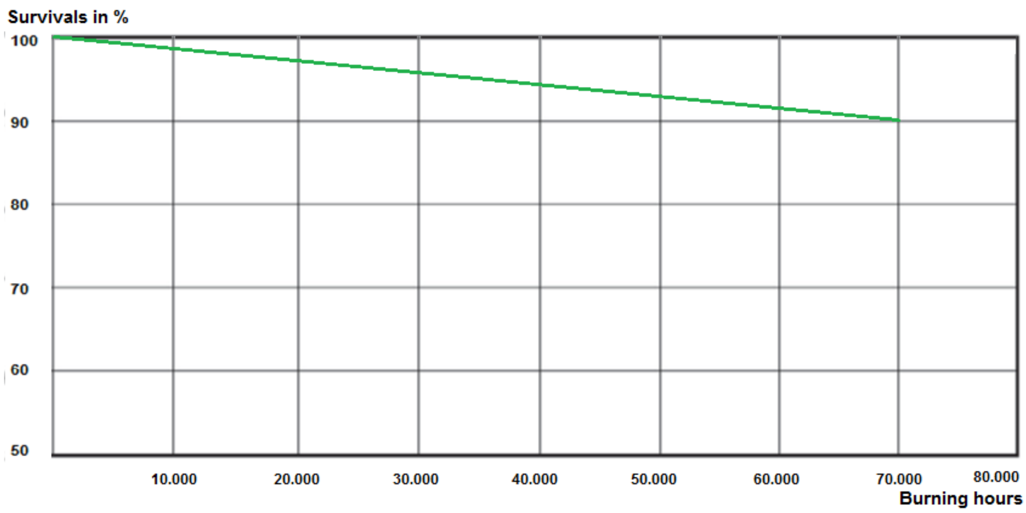

Fig. 6. Line of LSF for LED lamps.

Table 4 illustrates the LSF (%) of LED lamp according to operating time in years.

Table 4: LSF (%) of LED lamp according to operating time in years.

Years	Duration of study	LSF%
1	8.766	98.75
2	17532	97.50
3	26.298	96.25
4	35.064	95.00
5	43.830	93.75
6	52.596	92.50
7	61.362	91.25
8	70.128	90.00

According to the LSF of the LED lamp, 10% attenuation rate occurred after eight years. This demonstrates that it is not possible to use the lamp more than eight years. Table 5 illustrates the MF and minimum luminance level required for tunnel lighting with LED lamps.

Table 5: MF and minimum luminance level required for tunnel lighting with LED lamps.

Years	IP65- High Pollution LMF	LSF	Total LLMF	MF (MF=LMF*LSF*LLMF)	E%
1	0,91	0,9875	93	0,8357	1,1966
2	0,91	0,975	90,5	0,803	1,2454
3	0,91	0,9625	88	0,7708	1,2974
4	0,91	0,95	85,5	0,7391	1,3529
5	0,91	0,9375	82,5	0,7038	1,4208
6	0,91	0,925	79,5	0,6692	1,4943
7	*0,91*	*0,9125*	*77,5*	*0,6435*	*1,5539*
8	*0,91*	*0,9*	*75*	*0,6143*	*1,628*

The LED lamp investigated in this study has a service life of 70000 hours. This period corresponds to an operating time of about eight years. As seen in Figure 4, the LED lamp cannot be used when Luminous Flux decreases by 20%, that is, drops below 80%. The Luminous Flux of the LED lamp would decrease by 20% after eight years (70000 hours) when LED lens and diffuser effect are neglected. It is seen in Table 2 that the LLMF (%) of the LED lamp is 80% in the eight year.

The 5% loss is formed by time-dependent decrease in the Luminous Flux of the lenses used in directing LED light. When this effect is considered in Table 2, Table 3 is reached. According to Table 3, LLMF is 80% in the sixth year. In other words, the LED lamp cannot be used after six years because it is indicated in the producer's catalogue that the LED lamp should not be used if LLMF decreases to below 80%. The operating time of the LED lamp decreased from eight years to six years when the effect of optical lens was not considered.

4.3 Tunnel Lighting Evaluation

Fig. 7. illustrates the optic performance change depending on operating for LED luminaires.

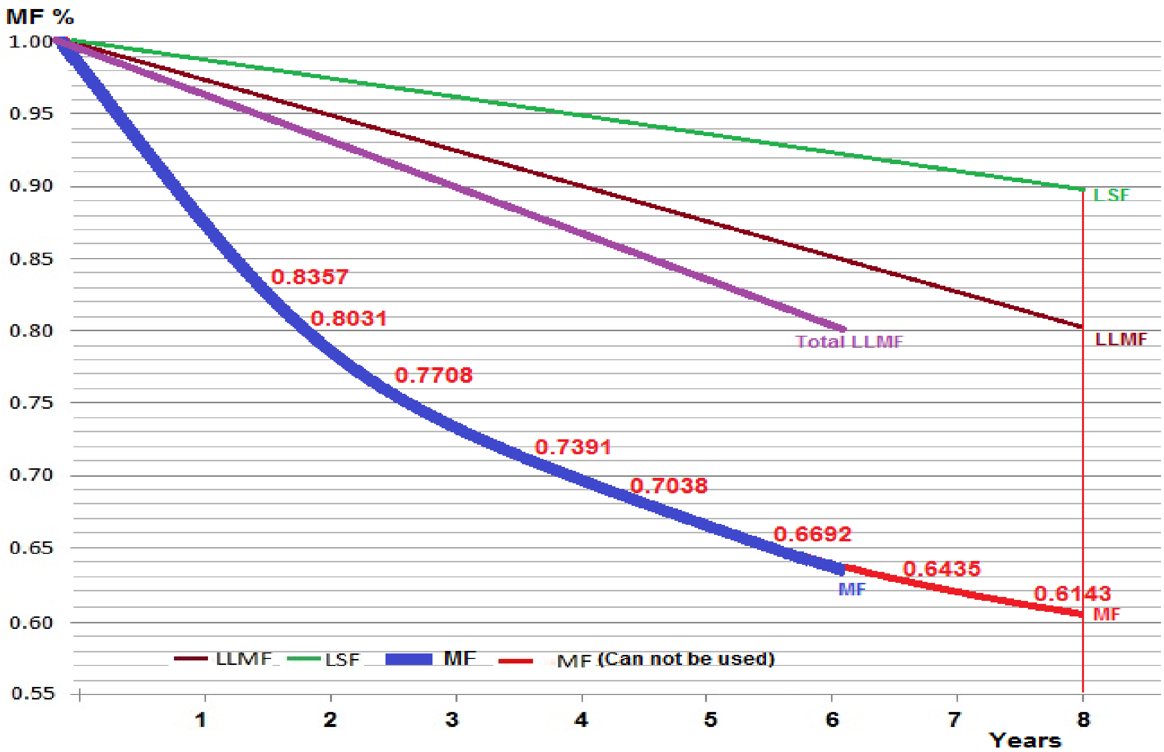

Fig. 7. Optic performance change depending on operating for LED luminaires

According to Figure 7,

• While MF decreases to 83.57% at the end of the first year, MF increases to 91% by replacing LED lenses and diffusers

• While MF decreases to 80.30% at the end of the second year, MF increases to 88% by replacing LED lenses and diffusers.

• While MF decreases to 77.08% at the end of the third year, MF increases to 83% by replacing LED lenses and diffusers.

• At the end of the sixth year, MF decreases to 66.92%. This indicates that all lamps should be replaced as cleaning the luminaire glasses is not sufficient. All lamps were changed since the decrease in illumination level cannot be tolerated as a result of the decrease in Luminous Flux at the end of the sixth MF year.

According to these results, the following comments can be made:

Considering that the LED lenses and diffusers for this lighting system will be replaced every six years and all the lamps will be replaced in the sixth year, to realize an illumination level of 100% at the end of the six-year period, an initial illumination level of additional 49.43% is required (1/0.6692 = 1.4943).

The illumination level in interior zone of the tunnel is required to be 149.43 rather than 100 since the illumination level of the LED lamps will decrease from 149.43% to 100% at the end of the six-year period. If the tolerance margin of 49.43% is not allowed, then illumination deficiencies can cause accidents as they can adversely affect the visual condition in the tunnel.

5 CONCLUSION

It is seen in this study that an LED lamp for tunnel lighting may have a service life lasting for 70000 hours. When examining the usage features of the LED lamps used in the tunnel, it is seen that the LSF and LLMF are 90% and 80% in the eighth year, respectively. Moreover, 80% was reached at the end of the sixth year when optical LED lens and diffuser effects are considered in the LLMF. The conditions related to the use of LED lamps in the tunnel were determined by LLMF, which considers the lens and diffuser effects Since the LLMF decreased to below 80% at the beginning of the seventh year, the visual conditions in the tunnel will deteriorate at the seventh year, which may result to accidents. The MF at the end of the sixth year was calculated as 66.92% according to conditions. The total Luminous Flux (E%) is required to be higher by 49.43%, according to the lowest MF formed at the end of the year.

Efficiency will increase when MF is high. In addition, LED lamps are not required to be replaced frequently and LED lamps can be used for up to six years.

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