Light Emitting Diode

Important Factors to Consider When Using LEDs for Retrofit Lamps

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Light Emitting Diode

1. Overview

As the performance and reliability of LEDs has improved in recent years, the number of light bulbs using LEDs (i.e. LED retrofit lamp) has increased; much of this volume is due to replacing LEDs in light bulbs that had previously used conventional light sources (i.e. incandescent bulbs and compact fluorescent lamp [CFL]).
LED retrofit lamps offer both economic and ecological benefits; two major advantages of LED retrofit lamps over conventional lamps are:

- Low energy consumption
- Long lifetime (e.g. commercially available LED retrofit lamps with a long lifetime of 40,000hours).

However, depending on the thermal design of the LED retrofit lamp (i.e. how to dissipate the heat from the LEDs and keep the LED temperature sufficiently low), the lifetime may become shorter than the designed lifetime. Considering that LED retrofit lamps are designed to be compact, lightweight, and can be used for special applications (e.g. hermetically-sealed luminaire, luminaire in contact with or enclosed/covered by thermal insulation material), careful consideration should be given to ensure appropriate thermal management.

This application note provides information for understanding the lifetime of LEDs and details on how to estimate the useful life of an LED retrofit lamp.

2. Structure of a Typical LED Retrofit Lamp

Refer to Figure 1 for the structure of a typical LED retrofit lamp and Table 1 for the descriptions of its key components.

The performance/reliability of the LED may vary depending on the material of the components; ensure that sufficient verification is performed for the chosen application.

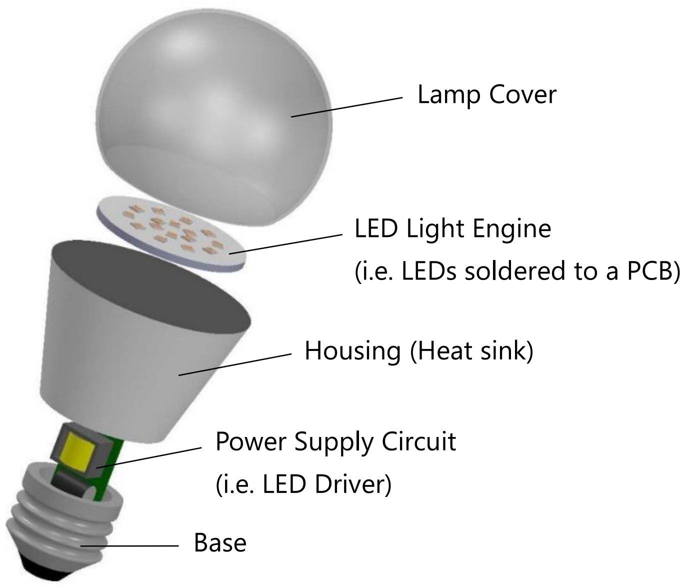


Figure 1. Structure of a Typical LED retrofit lamp

Table 1. Structure of a Typical LED retrofit lamp

Key Component	Function/Feature	Notes
Lamp Cover	A lamp cover is a means of providing protection for the LEDs and diffusing the light. For further control of the lamp light (e.g. directing the light upwards, collimating the light, etc.), additional lenses may be installed inside the lamp cover.	The lamp cover may affect the luminous flux of the lamps depending on its visible transmittance. To minimize the reduction, a lamp cover with a high visible transmittance should be used. However, this lamp cover may not be effective to diffuse the LED light, increasing the glare of the lamp (i.e. allowing more light to enter the eyes and cause difficulty seeing objects).
LED Light Engine	A light engine serves as the light source for an LED retrofit lamp. It is a PCB populated with LEDs and protection devices.	It is important for LED retrofit lamps to dissipate the heat from the LEDs effectively; metal core printed circuit boards (i.e. MCPCB) with a high thermal conductivity may be required depending on the design of the chosen application.
		The copper layer should be sufficiently large to ensure that the heat from the LEDs spreads evenly and effectively.
		To extract more light from the light engine and improve the luminous flux of the lamp, a material with high reflectivity should be used for the solder mask.
Housing (Heat Sink)	A heat sink is a means of dissipating the heat from the LEDs and provides mechanical support for the lamp.	The light engine temperature can be high and this is more likely to occur in the LED retrofit lamp than other lighting applications. To keep the temperature sufficiently low, a thermal interface material (e.g. thermal grease, thermal film) with a high thermal conductivity should be used to dissipate the heat from the LEDs.
		It is possible to improve the heat dissipation capability of the LED retrofit lamp by optimizing the shape of the heat sink (e.g. heat sink with pins/fins to dissipate heat more effectively); however, this will increase the lamp's weight.
Power Supply Circuit (i.e. LED Driver)	A LED driver holds the power supply circuit to transform the general-purpose alternating current (i.e. AC) to the direct current (i.e. DC) for the LEDs.	The LED driver's AC-DC transformation efficiency has a significant effect on the luminous efficacy of the LED retrofit lamp.
		LED retrofit lamps are designed to be compact and the LED driver is positioned close to the LED light engine; electronic components in the LED driver are more likely to be affected by the heat from the LEDs and become warm. If this occurs in the electrolytic capacitor, it will extremely shorten the component's life and accordingly the lamp life/performance will be significantly affected.
		To provide insulation between the LED driver and the heat sink and allow for better heat dissipation of the LED retrofit lamp, the LED driver should be completely surrounded by a resin material (e.g. silicone resin).
Base	A base (also sometimes referred to as a lamp cap) is a means to electrically and mechanically connect the lamp to the lamp holder of a luminaire.	There are standards/specifications (e.g. shape) for bases and sockets by the type of luminaire[1]. For more details, refer to standards/specifications corresponding to the chosen application.

Note:

[1] JIS C 7709-1 Lamp caps and holders together with gauges for the control of interchangeability and safety, Part 1 Lamp caps

3. Lifetime of a LED Retrofit Lamp

As discussed in the Overview section, as the junction temperature of the LEDs increases the lifetime of the LEDs will shorten, causing the life of the LED retrofit lamp to decrease. Understanding the effect of temperature on lifetimes is critical to ensure good thermal management for the chosen application. For more details, refer to the following section.

3.1. Factors that affect the life/performance of the LED retrofit lamp

Unlike incandescent light bulbs which stop illuminating suddenly, LED retrofit lamps instead lose their brightness over time as the lamp is used. The lifetime of an LED retrofit lamp is defined by the Japanese Industrial Standards[2] as the point at which the light output (i.e. lumen) has depreciated to 70% of the initial light output (i.e. rated luminous flux) when the lamp is operated under specified conditions.

When designing a LED retrofit lamp, the design life may be determined based on the lumen maintenance data for the LED being used. However, it is important to consider the lifetimes of the other components in the lamp when estimating the lifetime of the system. For example, electrolytic capacitors are one of the components that are commonly used in the LED driver and are particularly susceptible to heat. If electrolytic capacitors are used where the ambient temperature (i.e. T_A) is high, it can cause the capacitance to significantly decrease causing the component's life to decrease. The life of an electrolytic capacitor may be halved for every increase of 10°C in the component. Once the electrolytic capacitor has reached its end-of-life, it may cause the LED retrofit lamp to flicker or not to illuminate.

3.2. Factors that affect the LED lifetime

LEDs consist of a semiconductor device (i.e. LED die) and other component parts/materials. While LED dice have very long lifetimes, LED component parts/materials can discolor over time as they are exposed to high ambient temperature and this causes the LED's light output to decrease. For the NICHIA 757 series LEDs, the following changes have a significant effect on the amount of light extracted from the package, leading to a reduction over time in the luminous flux:

- Encapsulating resin discolors and it causes the transmittance to decrease
- Package materials discolor and it causes the reflectance to decrease
- Die-bonding resin discolors and it causes the reflectance to decrease
- Lead frame discolors and it causes the reflectance to decrease

For the internal structure of a NICHIA 757 series LED and the positional relationship between these part/materials and the LED die, refer to Figure 2 below.

The LED die temperature (i.e. LED junction temperature) affects the LED lifetime. The higher the LED die temperature, the higher the temperatures of the surrounding parts/materials and the more rapidly discoloration progresses in these parts/materials. The following section provides more details on how the LED junction temperature affects the LED lifetime.

Note:

[2] JIS C 8157: 2011 Self-ballasted LED-lamps for general lighting services > 50V – Performance requirements.

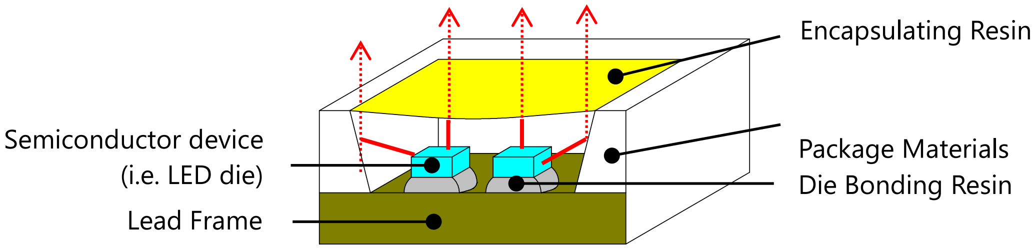
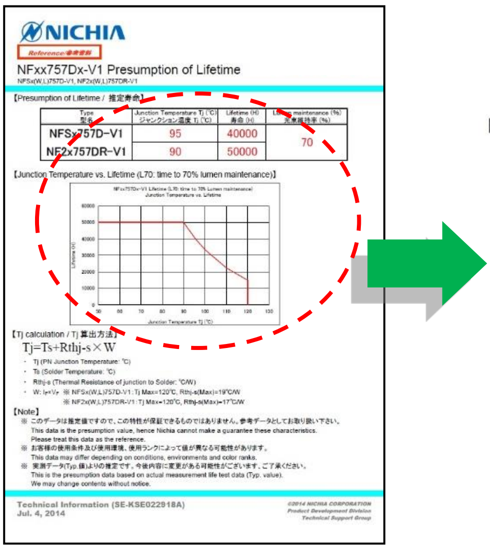


Figure 2. Internal Structure of a NICHIA 757 series LED

3.3. How to Estimate the LED Lifetime

Nichia provides technical data/information that is required to estimate the LED lifetimes upon request (See Figure 3 below). This includes the Junction Temperature (i.e. T_J) vs. Lifetime data that shows how the T_J affects the lifetime (i.e. L70 lifetime: time at which the LED has degraded to 70% of its initial luminous flux). For example, if the NFSx757D-V1 or NF2x757DR-V1 LED is used to design a LED retrofit lamp with a lifetime of ≥ 40,000 hours, ensure the T_J ≤ 95°C per the T_J vs. Lifetime data for the LED model (see Figure 3 below). There are important issues to consider when using this technical data/information for the chosen application:

- The lifetimes in the technical information/data are estimates using an average of measured data; the measurement conditions/environments may differ from those for the chosen application. Ensure a thermal design with sufficient margin/tolerances is used for the chosen application.
- If the LEDs are used at junction temperatures (T_J) that exceed the absolute maximum T_J (See Figure 3), it may cause issues (e.g. the LED performance to degrade, damage to the LED).
- The LED lifetime can be extended until it reaches a certain point of time; however, it is limited by the component parts/materials. For example, the maximum estimated lifetime of the NFSx757D-V1 or NF2x757DR-V1 LED is 50,000 hours (See Figure 3).
- If the period of use exceeds the maximum estimated lifetime, it may cause issues (e.g. the LED performance to degrade, damage to the LED).



【Presumption of Lifetime / 推定寿命】

Part No. 型番	Junction Temperature Tj (°C) ジャンクション温度 Tj (°C)	Lifetime (H) 寿命 (H)	Lumen maintenance (%) 光束維持率 (%)
NFSx757D-V1	95	40000	70
NF2x757DR-V1	90	50000	

【Junction Temperature vs. Lifetime (L70: time to 70% lumen maintenance)】

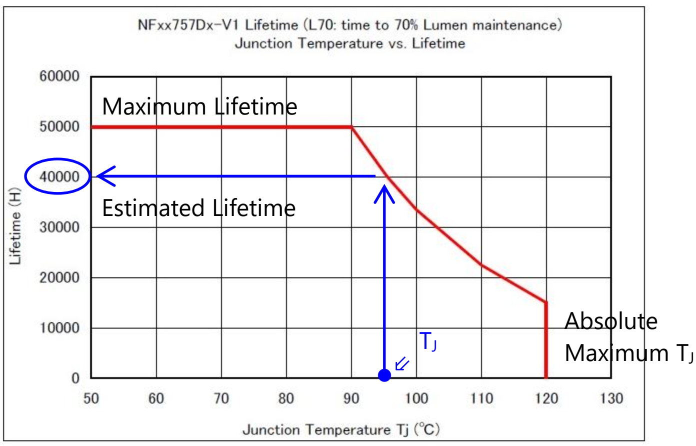


Figure 3. Example of the Technical Data (NFSx757D-V1/NF2x757DR-V1 Presumption of Lifetime)

4. Thermal Evaluation of the LEDs for a LED Retrofit Lamp

The lifetime of an LED is determined by the T_J; to estimate the lifetime of the LEDs, the correct T_J value is essential. This section provides details on how to determine the T_J and cautions/suggestions when performing thermal evaluations.

4.1. How to Determine the LED Junction Temperature (T_J)

For information on how to determine the T_J, refer to Nichia's Application Note SP-QR-C2-210274 Thermal Design of the LEDs that details the following two recommendations:

- Measuring the temperature at the T_S Measurement Point (i.e. T_S) or the temperature at the T_C Measurement Point (i.e. T_C) to calculate the T_J (i.e. Equation 1)
- Operating the LED under the specified conditions to measure the V_F according to Nichia's Application Note SP-QR-C2-210274 Thermal Design of the LEDs and calculate the T_J using the V_F data.

For other information specific to each LED model that is necessary to perform these calculations (i.e. location to attach the thermocouple, $R_{\theta JS}/R_{\theta JC}$), refer to both the specification for the LED model and the technical data/information as mentioned in Section 3.3. Note that the $R_{\theta JS}/R_{\theta JC}$ may vary depending on the LED; to calculate the T_J use the maximum $R_{\theta JS}/R_{\theta JC}$, instead of the typical $R_{\theta JS}/R_{\theta JC}$.

Equation 1: $T_J = T_S + R_{\theta JS}\,W$

$(\text{or } T_J = T_C + R_{\theta JC}\,W)$

T_J = LED junction temperature: °C
T_S = Soldering temperature: °C
T_C = LED case temperature: °C
$R_{\theta JS}(R_{\theta JC})$ = Thermal resistance from junction to $T_S(T_C)$ measurement point: °C/W
W = Input power ($I_F \times V_F$) : W

4.2. Cautions/Suggestions when performing a thermal evaluation

Ensure that the evaluation LED light engine/conditions meet the following requirements/ recommendations prior to measuring the T_S/T_C:

1. Verify that the temperature is distributed evenly over the surface of the evaluation LED light engine
2. Estimate the maximum T_A for the chosen application and use this value for the evaluation
3. Install the evaluation LED light engine in the actual LED retrofit lamp and measure the T_S/T_C with all the lamp component parts (e.g. lamp cover) in place
4. Operate the evaluation LED retrofit lamp to ensure the saturation temperature at the LED junction has been reached
5. Set the evaluation LED retrofit lamp according to the intended position/orientation

For more details, refer to Sections 4.2.1 to 4.2.5 below.

4.2.1. Verifying the Temperature Distribution over the Evaluation LED Light Engine

The temperature of the LED light engine may not be distributed evenly (See Figure 4-b below) when:

- there is a defect in the parts/materials (e.g. housing/heat sink, thermal interface material) on the thermal path between the LED and ambient air
- there is an issue with the LED configuration design and it causes an excessive amount of electrical current to a specific LED, causing this LED to generate excessive heat.

These may cause the T_J to exceed the expected value causing the LED life to decrease; the LED retrofit lamp/LED light engine should be designed to ensure that the temperature is distributed as evenly as possible on the LED light engine (see Figure 4 below).

Note that the thermal imaging results represent the LED's surface temperature (i.e. temperature of the encapsulating resin) instead of the actual T_J of the LED; thermal imaging cameras should be used only to verify the temperature distribution and determine the LED with the highest surface temperature. To calculate the T_J to estimate the lifetime of the LED retrofit lamp, use this LED and measure the T_S/T_C.

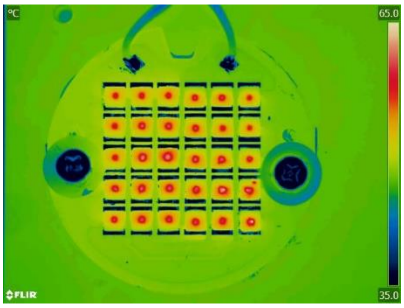


Figure 4. Example of an Even Temperature Distribution

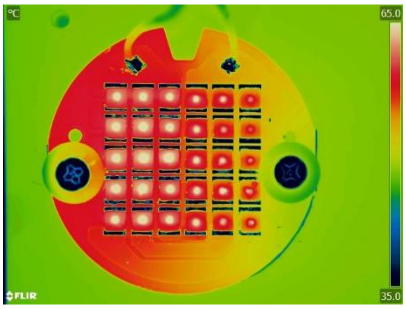


Figure 5. Example of an Uneven Temperature Distribution

Figure 5 shows that there is a significant difference in the LED surface temperature between the left side and right side of the evaluated LED light engine, indicating that heat is dissipated less efficiently on the left side than the right.

4.2.2. Using the maximum ambient temperature

The T_S/T_C of the LEDs changes according to the T_A. For special applications (e.g. a hermetically-sealed luminaire, luminaire in contact with or enclosed/covered by thermal insulation material), the T_A is likely to be higher than the T_A in other applications. Before measuring the T_S/T_C, determine the maximum T_A for the chosen application and use this value for thermal evaluation. Otherwise the estimated lifetime may be incorrect and longer than the lifetime when used in actual environments.

Refer to Table 2 below for an example of T_A/T_S measurement data for an LED operated under different environmental conditions. When there was a difference of 15.2°C in the T_A between these two environmental conditions, the difference in the T_S between the LEDs in these environments was 15.7°C; this result indicates that the increase in the T_A has a direct effect on the T_S.

Table 2. T_A/T_S Measurement Results

	T_A (°C)	T_S (°C)
Environment Condition 1	32.0	71.7
Environment Condition 2	47.2	87.4
Difference in temperature	15.2	15.7

4.2.3. Measuring the T_S/T_C of the LEDs installed in the chosen LED retrofit lamp

Ensure that the evaluation LED light engine and all the other component parts of the LED retrofit lamp are installed in place. Do not dismount the light engine from the lamp and measure the T_S/T_C of the LEDs or remove the lamp cover from the lamp and measure the T_S/T_C of the LEDs for the convenience of measurement (i.e. to attach a thermocouple to the LEDs). Otherwise this may cause the thermal path to change, affecting the T_J calculation. If an opening for the thermocouple is made in the lamp cover/housing and/or tape is used to secure the thermocouple, ensure that there are no adverse effects on the heat dissipation.

4.2.4. Ensuring that the saturation temperature at the junction has been reached

Operate the evaluation LED retrofit lamp for a sufficient period of time and measure the T_S/T_C of the LEDs once the saturation temperature at the junction has been reached.

4.2.5. Positioning the LED retrofit lamp for its intended use

For accurate measurement of the T_S/T_C, set the evaluation LED retrofit lamp according to the intended position/direction. The T_J may vary depending on the installation position/orientation of the LED retrofit lamp. Generally, hot air rises and cold air sinks and this may occur inside the LED retrofit lamp; if the evaluation LED retrofit lamp is not positioned/oriented in the intended manner/direction, it may affect the internal temperature distribution of the lamp causing the calculated T_J to be inaccurate.

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5. Evaluation of the Lifetimes of Selected LED Retrofit Lamps

This section provides an analysis of the lifetimes of four 60W LED retrofit lamps with different shapes. All these selected lamps use either a Nichia 757 series LED or a competitor's equivalent LED for its light engine. For the measured electrical/optical data and temperatures of the selected lamps, refer to Section 5.1. For the analysis of the lifetimes of these LED retrofit lamps, refer to Section 5.2.

5.1. Characteristics/temperature measurement

The electrical/optical characteristics and temperature measurements were performed on the selected LED retrofit lamps prior to estimating the lifetimes.

5.1.1. Measurement method

1. The selected LED retrofit lamps were operated at T_A=25°C.
2. Once the saturation temperature was reached, the electrical/optical characteristics of the selected lamps were measured.
3. The LED with the highest surface temperature among the LEDs on the light engine was determined and the T_S was measured.
4. The temperature of the LED driver was measured.
5. The T_J of this LED was calculated using a thermal resistance ($R_{\theta JS}$) of 17°C/W (max.)[3].

5.1.2. Measurement results

Table 3. Measurement results of selected LED retrofit lamps

			Lamp A	Lamp B	Lamp C	Lamp D
Lamp	Luminous Flux	(lm)	881	855	923	820
	Electric Power	(W)	8.7	10.4	12.1	7.5
LED	T_S	(°C)	74	88	101	74
	T_J[4]	(°C)	81	95	113	81
LED Driver	Temperature	(°C)	68	69	80	66

5.2. Evaluation of the lifetimes

The lifetimes of the selected LED retrofit lamps were estimated using the calculated T_J in Table 3 above to verify that the LED retrofit lamps have a lifetime of 40,000 hours as claimed for many 60W LED retrofit lamps.
Note that the LED T_J vs. estimate lifetime characteristic of the NF2x757DR-V1 LED was used for the following evaluation of all the selected LED retrofit lamps' lifetimes.

Note:

[3] Since the selected lamps use either a Nichia 757 series LED or a competitor's equivalent LED for its light engine, the thermal resistance ($R_{\theta JS}$) of the NF2x757DR-V1 LED was used for all these lamps.

[4] Calculated based on the measured T_S for each lamp

5.2.1. Evaluation results

Lamp A and Lamp D

The estimated lifetime was 50,000 hours, exceeding the targeted lifetime (i.e. 40,000 hours) with a sufficient T_J tolerance (i.e. 14°C). The measured T_J was no more than 81°C (See Table 3) while the T_J at which these LED retrofit lamps (i.e. Lamp A and Lamp D) can last to 40,000 hours is 95°C (See Figure 6).

Lamp B

The estimated lifetime reached 40,000 hours with little T_J tolerance. Depending on the variation of the LED/LED driver characteristics, the actual lifetime may be shorter than 40,000 hours. Note that the T_A may be higher and accordingly, the lifetime may be shorter than 40,000 hours when the LED retrofit lamp (i.e. Lamp B) is used in a special application (e.g. a hermetically-sealed luminaire or a luminaire in contact with or enclosed/covered by thermal insulation material).

Lamp C

The measured T_J significantly exceeded 95°C (i.e. T_J=113°C per Table 3) and accordingly the estimated lifetime was no more than 20,000 hours. Additionally, the measured temperature of the LED driver was the highest among the selected LED retrofit lamps; this may cause the electrolytic capacitor life to decrease, adversely affecting the lifetime of the lamp.

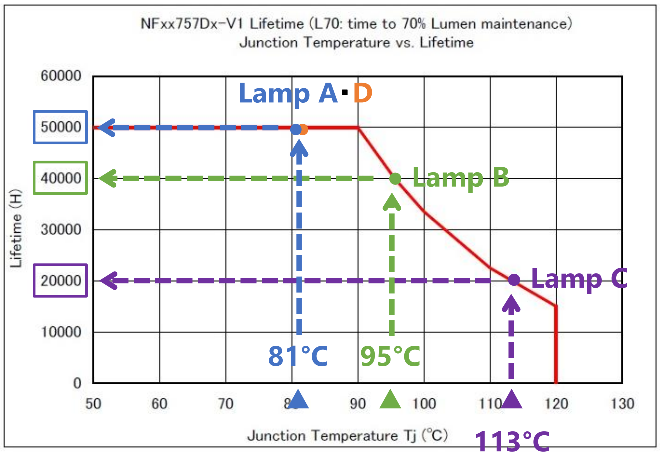

Figure 6. Lifetime Estimation of Selected LED Retrofit Lamps

6. Thermal Design Considerations for a LED Retrofit Lamp

The following are items that should be considered when designing a LED retrofit lamp to ensure good thermal management of the LEDs.

6.1. Performing the thermal evaluation with an accurate T_J

Sufficient verification is required at the design stage to ensure that there are no issues with the thermal design. If the LED retrofit lamp allows the T_J to exceed the design value while in actual use, it may cause issues (i.e. color shift, decrease in the luminous flux) before the end of its designed lifetime. For the details of how to determine the T_J and lifetime of the LEDs, refer to Section 4.

6.2. Ensuring the thermal design with a sufficient tolerance

For LEDs/LED drivers, there are variations in their characteristics; this requires that the design of the chosen LED retrofit lamp have a sufficient tolerance for the target T_J (i.e. the maximum possible T_J for the target lifetime of the LED retrofit lamp per the T_J vs Lifetime data for the LED being used). Otherwise, while the LED retrofit lamp is operated in actual use the T_J of the LEDs may exceed the target T_J and this may cause the LED retrofit lamp to reach its end-of-life earlier than the target lifetime. To improve the lifetime of this lamp, appropriate thermal management measures should be taken to ensure that the thermal design has a sufficient tolerance. Examples are:

- Review the component parts that dissipate the heat (e.g. housing/heat sink, PCB for the LED light engine)
- Reduce the input power

6.3. Ensuring that the absolute maximum T_J is not exceeded

The thermal design must ensure that the absolute maximum T_J is not exceeded under any circumstances. Otherwise the reliability/performance of the LEDs will be jeopardized (e.g. performance degradation, damage to the LED). If the LED retrofit lamp is designed for specific applications (e.g. a hermetically-sealed luminaire, luminaire in contact with or enclosed/covered by thermal insulation material), the resulting effect on the LEDs (i.e. increase in the T_J) must be considered and necessary thermal management measures are incorporated into the design.

6.4. Ensuring that the absolute maximum current is not exceeded

The circuits in the LED driver and the LED light engine must be designed to ensure that the absolute maximum current is not exceeded under any circumstances. Otherwise the reliability/performance of the LEDs will be jeopardized (e.g. performance degradation, damage to the LED). If the LED driver produces a current waveform with noticeable periodic variation (i.e. ripple), the average value of the current flowing through the circuit may be lower than the absolute maximum current for the LEDs and yet the peak current may not. To ensure that this does not occur in the circuit of the chosen application, use an oscilloscope to verify that any part of the current waveform does not exceed the absolute maximum current.

6.5. Taking measures to protect the LEDs from surges

Measures should be taken to protect the LEDs from surges (i.e. voltage/current spikes). If excess voltage/current is applied to the LEDs, it may cause the LED to be damaged. This may occur when the LED retrofit lamp is first turned on (i.e. inrush current) or if electrostatic discharge occurs (e.g. two electrically charged objects come in contact with each other). Nichia recommends using a protection device for the LEDs in both the LED driver and LED light engine circuits.

7. Summary

Since the lifetime of an LED can vary depending on the T_J, the thermal management of the LEDs is critical and careful consideration should be given to the thermal evaluations (e.g. measuring the T_S/T_C and calculating the T_J). When determining the overall system design, ensure that other factors that affect the T_J (e.g. variations in the LED/LED driver characteristics) are considered and the thermal design has a sufficient margin for the target lifetime.

For more details on the information/data and technical documents outlined in this application note, contact Nichia's sales team.

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