

Thermal design of integral LED replacement lamps

G. Allen¹, A. Rotella¹, D. Cai¹, J. Rintamaki¹, G. Kuenzler¹, K. Benner¹

¹ GE Lighting Solutions, General Electric Lighting, 1975 Noble Road, East Cleveland, OH, 44112, USA

Contact: garyr.allen@ge.com

ABSTRACT

The temperature of the p-n junction typically must be maintained below ~100-150 °C for long life and high efficiency of an LED lamp or luminaire. In the thermal management system of an LED lamp that is intended to replace a traditional lamp, e.g. in an Edison socket, the limiting impedance in the thermal circuit between the p-n junction and the thermal ambient is typically the convective impedance to air. This convective impedance is generally inversely proportional to the surface area of a heat sink exposed to air. The LED replacement lamp must fit into the same space as the lamp being replaced, so there is a strict limit on the external lamp dimensions. The limited surface area of the external profile of the lamp must be shared by the thermal management system and the optical output of the lamp. Especially in omnidirectional lighting applications, and especially at higher thermal loads, the competition between thermal and optical functions requires novel solutions that share the constrained space.

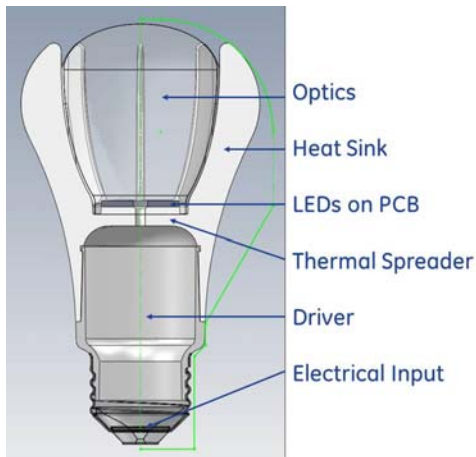


Figure 1 (left) A cross-section view of an LED replacement lamp for an A-line incandescent lamp showing the basic functional subsystems shared by most LED lamps and luminaires, superimposed with the ANSI profile (green curve) for an A19 incandescent replacement lamp from Reference [1].



Figure 2 (right) Rendering of the first Energy Star® qualified A19 LED omnidirectional lamp.

LAMP SIZE CONSTRAINTS

With reference to Fig. 1, most LED lamps or luminaires consist of the same basic subsystems, including a thermal management system, in this case shown as a heat sink having multiple cooling fins. As depicted in Fig.1, an LED lamp that is intended to replace an existing light source must conform to dimensional constraints defined by ANSI [1], IEC, or other regulatory agencies, to ensure that it will fit into standard existing sockets and application spaces.

In the case of an A19 size (or A60 metric) bulb, the total surface area of the profile defined by the ANSI dimensions is 210 cm², while the total surface area of the profile defined by the somewhat smaller A19 lamp of Fig. 2 is 166 cm². All of the electrical power that is supplied into the lamp must be dissipated through the total surface area of the lamp profile through four channels: visible radiation (light), non-visible (thermal) radiation; convection to ambient air; and conduction to any other medium in contact with ambient (e.g. the Edison base).

LAMP POWER BALANCE

The thermal balance diagram of a typical 12 watt LED lamp, providing 900 lumens, is shown in Fig. 3. It

indicates that the electronic driver typically dissipates ~1 W (~90% eff); the LEDs radiate ~3.5 W as visible light, of which ~0.5 W is absorbed in the optics (~85% eff), so that net ~3 W is radiated as visible light (~75 LPW), leaving ~9 W of heat to be dissipated thermally.

In most LED lamps, the limiting impedance in the thermal circuit between the LEDs and ambient is R_{HS-a} , the convective impedance from the heat sink to ambient air. The thermal conduction, convection, and radiation channels can be evaluated semi-quantitatively as follows. First, conduction through a standard Edison base is limited to only ~1W.

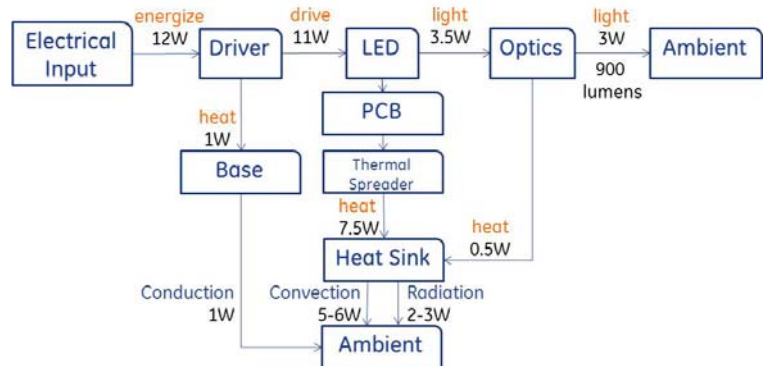


Figure 3 Power Balance block diagram for a typical 12 Watt A19 LED replacement lamp.

In the case of the 75 LPW lamp of Fig. 3, 3W is radiated as visible light, and the remaining 8 W must be dissipated to air by radiation and convection. Second, radiation is fundamentally limited by the Stefan-Boltzmann Law to a maximum of $P_{rad} = \epsilon \sigma A (T_{HS}^4 - T_a^4)$, where $\epsilon = 1$ for an ideal black-body. The largest possible effective surface area, A , for thermal radiation from the lamp is the surface area of the lamp profile defined by the ANSI dimensions = 0.0210 m². It's important to note that while the effective surface area for convection can be enhanced by addition of multiple cooling fins or convoluted surfaces, the surface area through which radiation can escape is thermodynamically limited to the surface area of the external profile of the lamp. With $T_{HS} \sim 80$ °C, and $T_a \sim 45$ °C, the black-body-limited radiation for an A19 lamp is ~4 W. In a practical lamp, where $\epsilon \sim 0.9$, $A \sim 0.8$ of max ANSI, and $T < 80$ °C over most of the surface, $P_{rad} \sim 2-3$ W, so $P_{conv} \sim 5-6$ W.

Since $P_{conv} \gg P_{rad}$, convection to air must be aggressively maximized by the design of the heat sink.

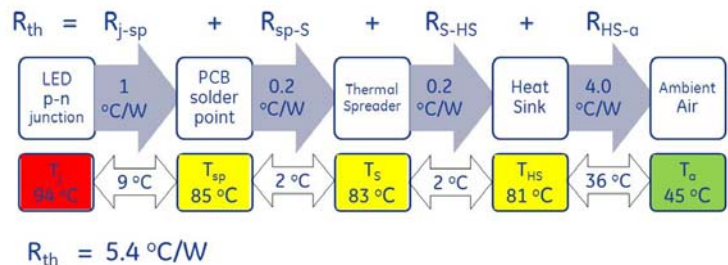


Figure 4 Thermal Impedance Circuit for a typical 12 Watt A19 LED replacement lamp.

Third, the convective heat transfer can be estimated as $P_{conv} = h A (T_{HS} - T_a)$, where $h \sim 6$ W/m²-K for an A19 lamp burning vertically in air. If the entire ANSI profile is operating at 80 °C, then $P_{conv} \sim 4$ W. Since operating the entire ANSI profile at 80 °C isn't feasible, and since 4 W is not sufficient, A for convection must be made significantly larger than the total area of the ANSI profile. That's typically done by adding cooling fins spaced apart by an air gap that is comparable in width circumferentially to the radial width of the fins. In that case, A is enhanced ~ 2X. However, if only ~ 1/2 of the ANSI profile is covered with cooling fins, as is the case for most LED lamps, then the convective cooling may still be insufficient.

One novel solution to this constraint is to cover nearly the entire lamp envelope with cooling fins, and to allow the light from the optic to shine between the cooling fins, as shown in Fig. 2.

REFERENCES

- [1] American National Standard for electric lamps, ANSI C78.20-2003