Proper Thermal Interface Calculation for an Optimized Heatsink Design

Jan de Graaf from Philips Lighting, Uli Mathis from Tridonic and Evans Thompson from Cooper Lighting explain how to calculate the thermal resistance of Zhaga compliant modules properly to optimize the thermal system.

To enable interchangeability of LED light sources, the Zhaga consortium has created several interface specifications for LED light engines covering different general lighting applications. One of these interface specifications is called "Book 3: Spot LED Light Engine with Separate Electronic Control Gear". This Book defines the interface between a luminaire and a LED light source consisting of a round ø50 mm LED module and its associated electronic control gear (driver) in separate housings.

LED light sources that comply with "Book 3" are interchangeable. That means that a luminaire manufacturer can replace the light source with another Book 3 - compliant light source without any change in the mechanical, thermal, and photometric components of the luminaire.

In this article we explain the thermal interface of the LED module-luminaire system and we show which thermal design freedom both the LED module and the luminaire manufacturer still have when designing their products. We will also discuss why the thermal interface is specified in this way and how it stimulates interchangeability of LED light engines.

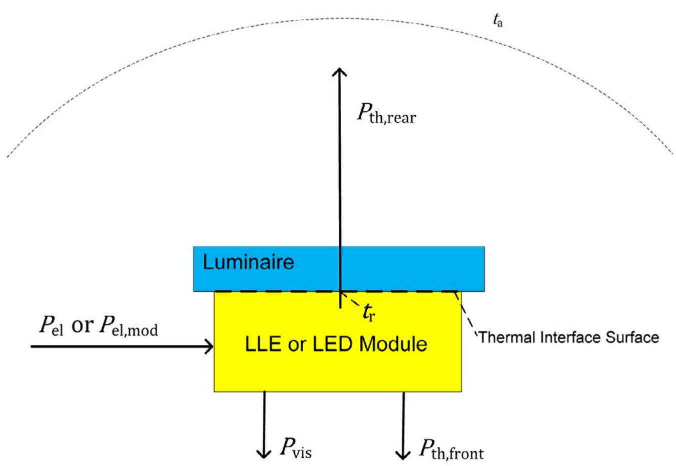


Figure 1: **Thermal model of a LLE-luminaire combination**

Thermal Resistance as Key Parameter of the Thermal Interface

One of the main interfaces that need to be defined to ensure interchangeability between LED light engines is the thermal interface of the LED module–luminaire system. Zhaga interface specifications provide sufficient thermal design freedom to manufacturers to create their own designs, while ensuring thermal interchangeability between LED light engines of different manufacturers.

Specification of the maximum thermal resistance, suitable for the LED light engine

A proper thermal interface between a LED module and luminaire ensures that the thermal power, $P_{th,rear}$ (W) that is generated in the module is dissipated to the ambient via the luminaire heat sink without exceeding the maximum temperature that the LED module can tolerate for its proper functioning (Figure 1). In Zhaga, the LED module manufacturer specifies the maximum temperature at the thermal interface ($t_{r,max}$) that the module can tolerate. The maximum thermal resistance of the luminaire heat sink that is suitable for this LED module is given by:

$$R_{th,max} = \frac{t_{r,max} - t_a}{P_{th,rear}} \qquad (1)$$

with t_a being the ambient temperature around the luminaire. The LED module manufacturer has the freedom to design the LED module with any $t_{r,max}$ and $P_{th,rear}$ values.

Measurement of the thermal resistance of the actual luminaire

In Zhaga, the thermal resistance of a luminaire is measured with a thermal test engine. For each type of LED light engine an appropriate thermal test engine has been defined. This test engine contains power resistors that dissipate heat equal to the thermal power $P_{th,rear}$ of the light engine. The temperature at the thermal interface (t_r) of the test engine and the luminaire is measured as a function of the thermal power that is applied to the thermal test engine (Figure 2). The thermal resistance of the luminaire heatsink is given by:

$$R_{th} = \frac{t_r - t_a}{P_{th,rear}} \qquad (2)$$

The luminaire manufacturer has the freedom to design a luminaire with any R_{th} value.

Thermal compatibility check

In order to check whether a specific LED light engine is compatible with a specific luminaire, a comparison is made between the $R_{th.max}$ and R_{th} values of respectively the LED module and the luminaire:

$$R_{th} \leq R_{th,max} \qquad (3)$$

If this condition is met, the temperature of the module will not be exceeded.

Thermal spreading resistance

One important prerequisite for comparing the thermal resistance values of both LED module and luminaire heatsink as stated above in the thermal compatibility check is that the thermal spreading resistance of the LED light engine – heatsink combination, $R_{th,sp}$ is similar to the thermal spreading resistance of the thermal test engine – heatsink combination (Figure 3 and equation).

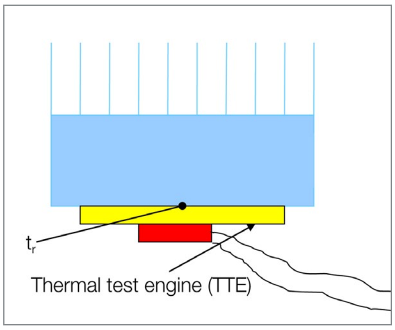
$$R_{th,sp} = \frac{t_r - t_{i,min}}{P_{th,rear}} \qquad (4)$$

In order to deal with this situation, a reference heatsink has been defined in Zhaga to measure the thermal spreading resistance of thermal test engine-reference heatsink – and LED module – reference heatsink combinations. In Book 3, any deviation in thermal spreading resistance of the LED light engine to the thermal test engine can be accounted for in the value of $R_{th,max}$ of the LED light engine.

Thermal power at the thermal interface surface

The total thermal power,P_{th} (W), that is generated in a LED module is partly directly transferred to the ambient via radiation and convection and the large remaining part $P_{th,rear}$ is transferred to the ambient via the heat sink over the thermal interface surface (Figure 1). In Zhaga this $P_{th,rear}$ value is measured with a heat flux setup. The use of the $P_{th,rear}$ value instead of the P_{th} value allows for an optimised heatsink design with smaller dimensions and cost.

Summarizing, Zhaga brings together luminaire and LED module designers by defining the thermal interface. This facilitates both module and luminaire design enabling interchangeability of LED light sources. ■



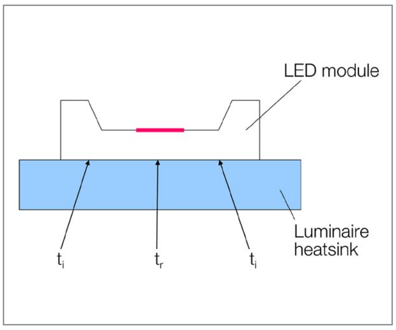


Figure 2: **Measurement of the thermal resistance of the actual luminaire (left)**
Figure 3: **Thermal interface between LED module and heatsink with interface temperatures (right)**

Definitions and References:

LED Light Engine: A combination of on ECG (Electronic Control Gear) and one or more LED modules.

LED Module: A light source that is supplied as a single unit. In addition to one or more LEDs, their mechanical support and their electrical connection, it may contain components to improve its photometric, thermal, mechanical and electrical properties, but it does not include the electronic control gear.

Book 3: The interface specification for a spotlight LED light engine, consisting of an LED module and an electronic control gear in separate housings. See also: http://www.zhagastandard.org/specifications/book-3.html

Electronic Control Gear or ECG: A unit that is located between the external power and one or more LED modules to provide the LED module(s) with an appropriate voltage or current. It may consist of one or more separate components, and may include additional functionality, such as means for dimming, power factor correction, and radio interference suppression.