

## WHY THE THERMAL DESIGN IS BETTER

### Introduction

Thermal design is essential to the performance and reliability of the LED emitters and luminaires. When electrical power input to a LED emitter or a light engine, a portion of the electric energy converts to photon energy (or light), the rest turns into thermal energy (or heat). Currently the luminous efficacy of a LED die is ~ 100 lumen per watt which means it only converts 25% of the electric to light, 75% to heat.

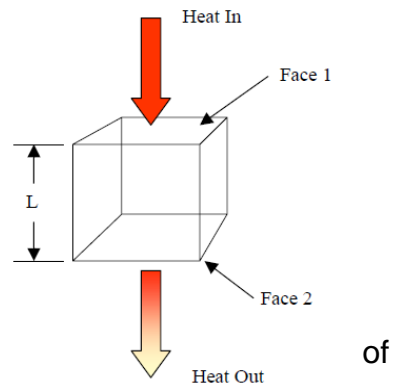
Heat is the prime enemy to any semiconductor device. LED, light emitting diode is a semiconductor device. If the heat can not be removed from the semiconductor when it is in operation, the temperature of LED will elevate, thus the luminous efficacy will decrease, as well as the life span and reliability will reduce.

### Heat transfer

Heat transfer is a science that studies the thermal energy transfer in or between two matters due to temperature difference. There are three basic mode of heat transfer:

- Conduction
- Convection
- Radiation

**Conduction** is a mode of heat transfer that occurs when there is a temperature gradient across a matter. The right hand side figure is a one dimensional conduction heat transfer. If Face 1 temperature is higher than Face 2, heat will be transferred from Face 1 to Face 2.

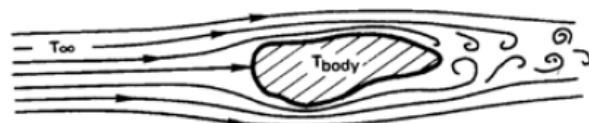


The equation at the right is known as Fourier's law heat conduction, where

- q is the heat transferred via conduction
- K is the thermal conductivity of the matter
- A is the cross section area of the matter
- L is the length the heat passage
- T<sub>1</sub> is the temperature of Face 1
- T<sub>2</sub> is the temperature of Face 2

$$q = \frac{kA}{L} \Delta T_{12}$$

**Convection** is a mode of heat transfer that comprises of two mechanisms; random molecular motion (diffusion) and



energy transfer by bulk or macroscopic motion of fluid. Convection occurs when the cool fluid passes a warm body; the moving fluid can carry the heat away from the body. Vice versus the fluid can heat up the body if the fluid temperature is higher than the body.

The convection heat transfer can be classified according to the nature of the fluid flow.

**Force convection** occurs when the fluid flow is caused by the external means, such as a fan, a pump, or nature wind.

**Natural convection**, the flow is induced by buoyancy force, which arise from density difference caused by temperature variations in the fluid. For example a cup of hot coffee set on the table in side a room, the air is stable, but since the air surrounds the cup is warmer, the density is lighter and it rises which causes the vertical flow movement.

The Newton law of cooling expressing the overall effect of convection; force or natural is:

$$q = hA(T_w - T_\infty)$$

Where

q is the heat transferred via convection

h is the convective heat transfer coefficient

A is the surface area of convection

$T_w$  is convection surface temperature

$T_\infty$  is the fluid temperature

**Radiation** is a mode of heat transfer that transfers heat from a body to another body via electromagnetic wave. The electromagnetic radiation propagated as a result of temperature difference of two bodies calls thermal radiation. An ideal thermal radiator or a blackbody emits the thermal energy at a rate of proportional to the forth power of its absolute temperature.

$$q_{emitted} = \sigma A T^4$$

Where

q is the heat transferred via radiation

$\sigma$  is Stefan Boltzmann constant

$$\sigma = 5.669 \times 10^{-8} \text{ W/m}^2\text{K}^4$$

### Heat transfer design for luminaires

Almost all conventional luminaires are designed using natural convection. The LED luminaires will not be the exception since the consumers will not allow a fan

designed into a luminaire. Fan has moving parts that make noise and also reduces the reliability and longevity of a luminaire.

When designing a natural convection heatsink, there are a few critical criteria:

1. Surface area
2. Ambient temperature
3. Weight

Unlike the force convection, the convective heat transfer coefficient ( $h$ ) of the natural convection is very much a constant in almost all conditions. For the force convection, we can control or manipulate the fluid flow by changing the speed of the fan or the pump, or reconfigure the duct or pipe to get the fluid velocity that can deliver the needed convective heat transfer coefficient. A typical  $h$  of a natural convection is around  $5 \text{ W/m}^2\text{ }^\circ\text{C}$ , where the  $h$  of a force convection may be ranging from 20 to  $200 \text{ W/m}^2\text{ }^\circ\text{C}$  with the air velocity ranging from 1 to 50 meter per second (or 200 to 10000 feet per minute).

To achieve a heatsink design that can dissipate the required heat under natural convection condition, getting a sufficient heatsink or fin surface area is the key. To dissipate the same amount of heat the natural convection needs 10~20 times more surface areas compared to a force convection design.

### **Heatsink or fin manufacturing method**

There are many manufacturing methods that can be applied to fabricate heatsinks: The follow four methods are most widely used.

- Stamping
- Extruding
- Die casting
- Forging

**Stamping** - producing fins using stamping is widely used to fabricate the fin stack of an evaporator coil or condenser coil of an air-conditioning system. Fins stacked configuration can deliver a very large fin surface area within a compact volume and also lightweight. The fin material typically is cold rolled aluminum or copper sheet; the aluminum alloy such as A1050, A1100, or A3003, and the copper alloy such as C102 or C110 are the common materials used for making stamped fins. The compositions of the above aluminum or copper alloys are very close to the pure aluminum and the pure copper respective, therefore their thermal conductivity are slightly lower than the pure metal. In general, the purer the metal means higher thermal conductivity. The thickness of the sheet stock for making stamped fin is ranging from 0.2mm to 0.4mm (or 0.008" to 0.016"). With a



high thermal conductivity property, compact, and light weight, the stamped fin is preferred for the force convection applications

**Extruding** – fabricating heatsink by extrusion process is most widely used in the electronic cooling application. The typical material used to produce the extruded heatsink is aluminum A6063 which the composition is very near the pure aluminum. The typical thinnest fin thickness can be extruded with a high yield rate is 1mm (0.040”). The typical fin aspect ratio (fin height vs. fin pitch) is 6:1. Up to 10:1 aspect ratio can be produced but the life of the extrusion die are very short and also very easy to be broken.



The extruded heatsinks are widely applied to natural or force convection applications. Geometrically comparing with the stamping and die casting heat sinks, the extruded heat sink can only deliver two-dimensional fin geometry. The third dimension mechanical features can be delivered by machining processes.

### Die Casting

If a heat sink needs a three-dimensional fin geometry, only die casting can deliver such design requirement without a secondary process. If the tolerance is not critical, die casting can produce various mechanical features that do not require secondary machining. But there are a few short falls:

- Low fin aspect ratio means thicker fin thickness and shorter fin height
- Need to use the alloys that is formulated for die casting process. Various elements are needed to compose the aluminum alloy that can be flowed in the casting die. Pure aluminum is quite sticky and cannot be cast with reasonable yield. Lower purity alloy means lower thermal conductivity. Typical die cast aluminum alloys are A319, A330, and A356 where the aluminum composition is the alloys is ~ 90%.



Typically, the die casting process selected for mass producing a heat sink is decided based on the cost more than performance.

### Tool and die cost comparison

The typical cost scale for the tool and die among the above heat sink manufacturing methods is 2:1:20, stamping, extruding and die cast respective.

## Why enLux thermal design is better

Using the case study, we compare the thermal design of the popular LED luminaires in the marketplace for demonstrating that enLux thermal design is better:

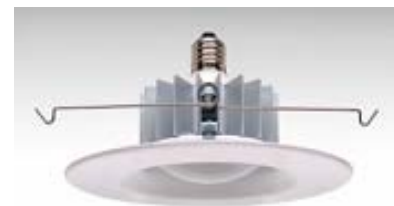
### **6” recessed can LED down light**

Here we have Cree LR6 and enLux DL6-TC and DL6-WF for the comparison: Cree LR6 uses die casting to fabricate the body with fins and the trim. enLux DL6 uses extrusion to form the body with fins and stamping to form the trim. The two main heat dissipation paths for both LR6 and DL6 are from the LED via the trim to the air below the ceiling, and from LED via body fins to the air in the recessed can. But there are differences:

- LR6 is heavier and bulky – Wall and fin thickness of die cast body are thicker than extruded or stamped fin and wall.
- For LR6, more heat is dissipated to the air inside the can where the heat is trapped in the can which makes the air hot. So the temperature of the LED is much hotter.
- For DL6 more heat is dissipated to the air via the trim to the air below the ceiling where the air is much cooler than the air in the can. Therefore the LED is much cooler.
- DL6's body and fins are thin wall but because the materials used are A1050 and A6063. But their thermal conductivities are very high which maintains the heat transfer performance in the thin wall construction. Thin wall construction also means lightweight.



**Cree LR6 Down Light**



**DL6-WF**



**DL6-TC**

## Par 30 Flood light

Here we have LSG R30 and enLux R30 for the comparison: Both LSG R30 and enLux R30 use casting to fabricate the body with fins. But there are differences:

- The fin gap of the LSG R30 is tight comparing to enLux R30. A tighter fin gap is not desirable for the natural convection heat transfer. The prefer fin gap for natural convection is  $>4\text{mm}$  (0.16").
- Also the overall size of LSG R30 is larger than enLux R30, but LSG's total fin surface area is less. enLux R30 has the larger fin gap and more fin surface area which enables dissipate heat more efficient but lighter weight.



LSG R30



enLux R30

die  
are

## Misconception of the mass of the heatsink

Sometime people say to have an efficient heatsink the bulky mass is a must. If this is true then the condenser unit of your home air conditioning system unit in your yard probably weighs more than a M1 tank.

An effective heat transfer system is to design the minimum mass for the heat transfer paths such as heatsink or fins, provided the heat transfer capability is not suffered. Remember, the heat is needed to be dissipated to the ambient air, it should not be stored in the mass of the heatsink or fins because after the mass heats up, it can no longer store the heat.

- *You need fin surface **area** not **mass**.*
- *You need to dissipate heat to the air having lowest temperature not to inside a can where heat is trapped.*