



LED-Driver Thermal Design Considerations in LED-Based Fixtures - Part 2

Basic Modes of Heat Transfer

Abstract:

Heat transfer can occur in three different modes: conduction, convection and radiation. The purpose of this application note is not to bombard the reader with a ton of equations. However, a fixture designer must be well aware of the controlling parameters in the equations in each heat transfer mode. Understanding and utilizing the key parameters in the equations will determine the success of the thermal design, hence the performance, cost and reliability of the fixture.

Conduction:

Conduction is the most common method of heat transfer from a heat source, such as an LED and a driver, to the heatsink in LED fixtures. Therefore, it is important to go through this concept and the related equation in more detail. Thermal conduction happens when two solid materials that are at two different temperatures are in direct contact, e.g. an Aluminum heatsink and a driver. Please see Figure 1 for an example of a driver making contact with a heatsink. For all practical purposes, metals are used for heatsinking purposes since they have very good thermal conductivity. Please see Table 1 for thermal conductivity of multiple common materials. For more details on thermal conductivity discussion please refer to the “Practical Thermal Design Considerations” application note.

Material	Thermal Conductivity		
	W/(m K)	Normalized to Al	Normalized to Air
Air, atmosphere (gas)	0.024	8541.7	1.0
Aluminum	205	1.0	8541.7
Copper	401	0.5	16708.3
Gold	310	0.7	12916.7
Iron	80	2.6	3333.3
Silver	429	0.5	17875.0
Zinc Zn	116	1.8	4833.3
Plastics, foamed	0.03	6833.3	1.3
Plywood	0.13	1576.9	5.4
Polycarbonate	0.19	1078.9	7.9

Table 1. Thermal Conductivity of Some Common Materials

Aluminum is the most commonly used metal for the heatsink and mechanical body or chassis of an LED based fixture because of its lower cost compared to other higher heat conductive materials such as copper and silver. Although some high thermal conductivity plastic material is also used for this purpose, metals like aluminum, and to a much lesser degree copper, are used in the overwhelming majority of LED lighting applications. Various grades of aluminum will have somewhat different thermal conductivity.

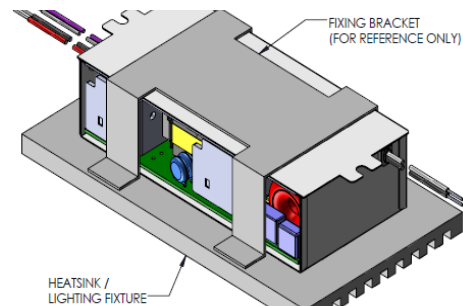


Figure 1. Conduction Mode Heat Transfer: Driver Making Direct Contact with the Heatsink

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Below Equation 1 shows the amount of transferred heat in conduction mode.

$$Q_{\text{cond}} = -k A (\Delta T / \Delta x)$$

Equation 1: Conduction Mode Heat Transfer

where:

Q_{cond} is the amount of heat transferred through conduction (W)

k is the thermal conductivity of the material (W/m K)

A is the contact surface area of the material through which the heat flows (m²)

ΔT is the temperature gradient across the material (°C)

Δx is the distance the heat must travel (m)

The parameters of the above equation are very important for thermal design and must be fully understood by any LED fixture designer. The above equation simply states that the higher the conductivity of the material, the larger the contact area, and the thinner the material is, the more heat can be transferred in a given design. Out of all of the parameters in Equation 1, the easiest to control is the A . Therefore, it is very important to increase the contact surface as much as possible, and take advantage of it by making a good thermal contact with the heatsink to transfer the most amount of heat. The second parameter that one can easily control is Δx . The less distance the heat needs to travel the better the thermal conduction. Thermal conductivity, K , is going to be fixed by the type and grade of the material used. Most often using basic heatsink grade aluminum yields the most optimum system solution since exotic materials and specialized grades tend to increase the system cost dramatically.

Convection:

Convection is the heat transfer mode from a solid material to fluid (gas or liquid). Understanding convection mode is also very important since most heatsinks and fins operate in this mode, basically transferring the heat from the heatsink to ambient air.

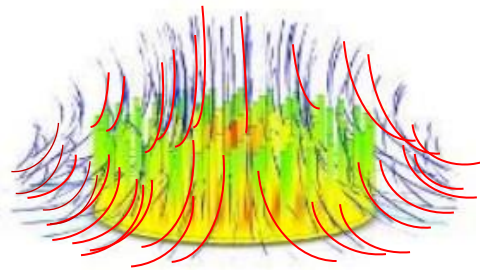


Figure 2. Convection Mode Heat Transfer: Heatsink Transferring Heat to the Ambient Air

Equation 2 below describes the amount of heat transferred in convection mode.

$$Q_{\text{conv}} = h A \Delta T$$

Equation 2: Convection Mode Heat Transfer

where:

Q_{conv} is the amount of heat transferred through convection (W)

h is the heat transfer coefficient (W/m²K)

A is the surface area (m²)

ΔT is the temperature gradient across the material (°C), difference between the surface temperature and ambient air temperature

Based on Equation 2, the higher the heat transfer coefficient, and the larger the surface area (typically heatsink fin surface) the higher the amount of heat transferred in convection mode for a given design. Needless to say, the hotter the heatsink the more heat will be transferred to the ambient air. This equation is a bit tricky because h , heat transfer coefficient, encompasses several parameters, namely airflow. It is extremely important to understand air flow and making proper design considerations for airflow since it plays a major role in convection. To give the reader an idea for natural convection, h is roughly between 5 to 20 W/m²K. If there is a fan in the system, depending on the speed, h could be as high as 120 W/m²K. Based on the above examples, a thermal design can be over 10 times more efficient if there is good airflow around the heatsink fins. This is not to suggest or promote including a fan in every design. On the contrary, fan usage should be limited to only a very small percentage of designs where a passive heatsink design won't work under certain size or cost

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constraints. This topic will be covered in the “Fin Design” application note in great detail. In passive heatsink designs, a great deal of attention must be paid to increasing air flow as much as possible. There is a diminishing point where adding extra fin surface area doesn’t help the thermal performance because the air flow is restricted. Most often having good airflow yields better results than increasing the size and cost of the heatsink. Promoting good airflow in the heatsink and fixture chassis design is a critical factor for good fixture thermal performance. A good airflow design in a passive heatsink system will often reduce the cost and size of the system.

Radiation:

Radiation is the third and least important mode of heat transfer in LED lighting fixtures. Radiation heat transfer is done through electromagnetic radiation which is generated by the thermal motion of particles inside the materials. For all practical purposes, radiation may be ignored since it is a very small percentage of the heat transfer for LED based lighting fixture designs. As a rule of thumb, radiation becomes more important only for very high power concentrated designs where the temperature on the heatsink is typically above 100°C.

To visualize the concept of radiation, the sun is the simplest example, as shown in Figure 3. Energy from the surface of the sun is radiated from an extremely long distance to earth without the need for air to transfer the heat.

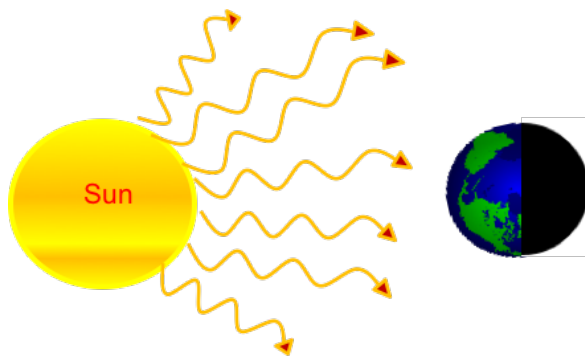


Figure 3. Example of Radiation Mode Heat Transfer

Another good example of radiated heat is an iron rod heated over 1000°C. The radiated color of the rod has a direct relationship to the temperature that it is heated up to. In fact, the

temperature in Kelvin degrees on the blackbody locus defines the CCT (Correlated Color Temperature) of LEDs.

As shown in Equation 3, emissivity of the material and the surface area have a direct relationship with the radiated heat transfer. Please note that the Boltzmann constant σ ($5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$) is an extremely small number, therefore when multiplied by other parameters in Equation 3, it results in a minuscule figure, hence the reason for radiation heat transfer mode being ignored for most lighting fixture thermal calculations.

$$Q_{rad} = \epsilon \sigma A (T_s^4 - T_f^4)$$

Equation 3: Radiation Mode Heat Transfer

where:

Q_{rad} is the amount of heat transferred through radiation (W)

ϵ is the emissivity of the surface (dimensionless)

σ is the Stefan-Boltzmann constant ($5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$)

A is the surface area (m^2)

T_s is the surface temperature of the material (°C)

T_f is the fluid (e.g. ambient air) temperature of the medium (°C)

Based on the heat transfer modes described above, for an optimum thermal design the following general guidelines should be seriously considered.

- The contact surface between the driver and the heat sink is as large as possible.
- Make good thermal contact between the driver and the heat sink.
- The heat sink bulk material is as thin as possible.
- Increase heat sink fin area while making sure the fin density doesn’t restrict air flow.
- Allow as much air flow as possible.

In conclusion, a fixture designer is advised to fully understand the three modes of heat transfer. One may not be very concerned about the equations and detailed thermal calculations, however it is imperative to understand, fully consider and utilize the critical parameters of the above heat transfer mode equations, like surface area, thermal conductivity and airflow in order to come up with a good thermal design. Conduction and convection heat transfer modes are well utilized in a lighting fixture, however for all practical purposes the radiation heat transfer

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mode may be ignored since it is a very tiny percentage of the total heat transferred.

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U.S.A. Headquarters
Tel: +1-805-517-1300
893 Patriot Drive, Suite E
Moorpark, CA 93021

CHINA Operations
Tel: +86-756-6266298
No. 8 Pingdong Road 2
Zhuhai, Guangdong,
China 519060

SaveEnergy@erp-power.com