TACTIK LIGHTING WHITE PAPER:

The Effects of Heat on LED Lighting

Jordy Bradley, LC, IES

TACTIK LIGHTING

Appropriate lighting, without glare or shadows, can reduce eye fatigue and headaches; it can prevent workplace incidents by increasing the visibility of moving machinery and other safety hazards. Good quality lighting also reduces the chance of incidents and injuries from "momentary blindness" (momentary low field vision due to eyes adjusting from brighter to darker, or vice-versa, surroundings).

LED lighting directly impacts workers' safety, mental acuity, vitality and alertness while reducing fatigue and daytime sleepiness. Researchers at the University of Greenwich found in a two-month study that the workers they put under "blue-enriched light bulbs" reported feeling "happier, more alert and had less eye strain."

While intuitively we acknowledge the benefits of proper lighting, unfortunately **heat is the enemy** of LED fixtures and can adversely affect the lighting quality where maintaining proper lighting becomes a real issue for plant maintenance personnel who are tasked with maintaining lighting which was not designed for their environments in the first place.

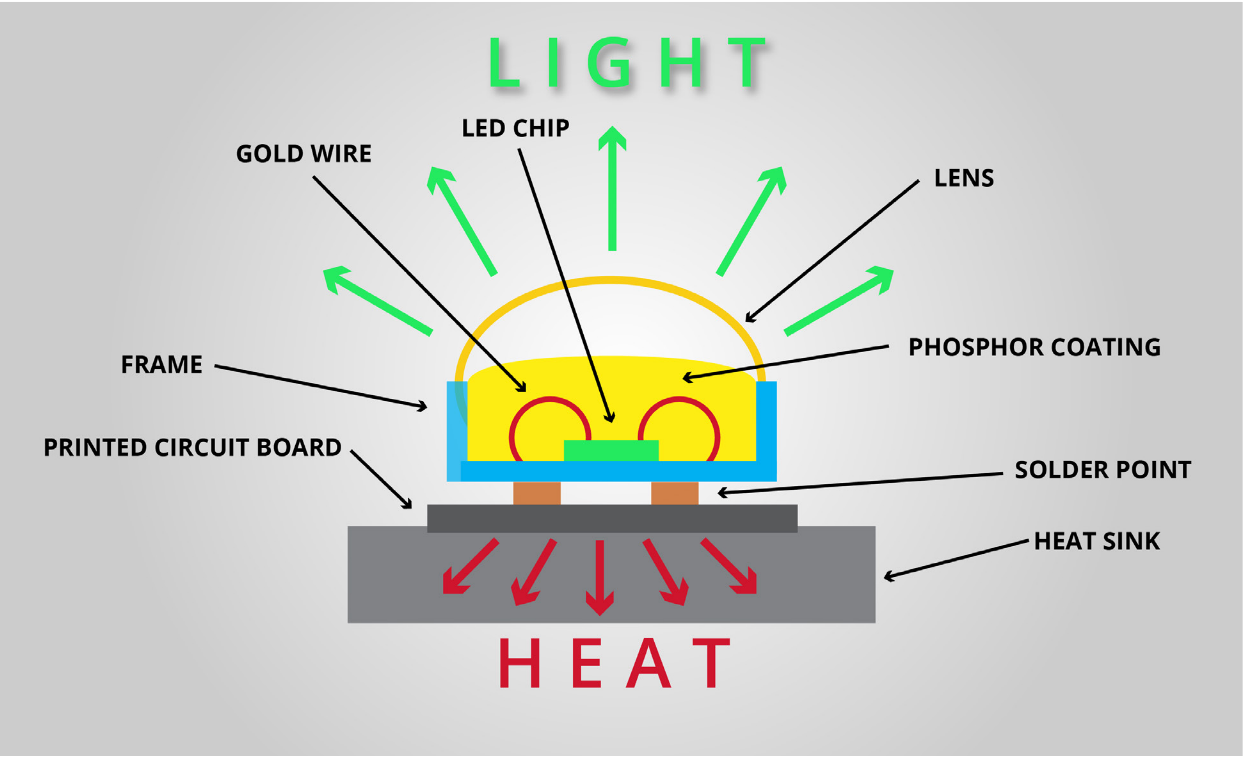
What is the maximum ambient temperature that LED lights can survive/thrive in?

The maximum temperature for LED lights depends on how the LED light fixture is engineered and manufactured. Most LED lights are engineered and tested for 25°C / 77°F and a target L70 of 50,000 hours. It is referenced as this.

L70 @ 50,000 hours operating at 25°C / 77°F

That means that if the LED light fixture is operated at 25°C / 77°F, once 50,000 hours of use have taken place the LEDs will emit 70% of their original light output.

As the operating or ambient temperature increases, the life of the LEDs drops. For example, a more robustly built LED high bay is rated L70 @ 182,000 hours operating at 25°C / 77°F. That same LED high bay light would have a diminished L70 at 50°C / 122°F. It would be L70 @ 104,000 hours operating at 50°C / 122°F, which is a 42% shorter LED life.



So - what actually are the effects of heat above the “normal range” of industrial rated high bay lights? a

Lumen Depreciation

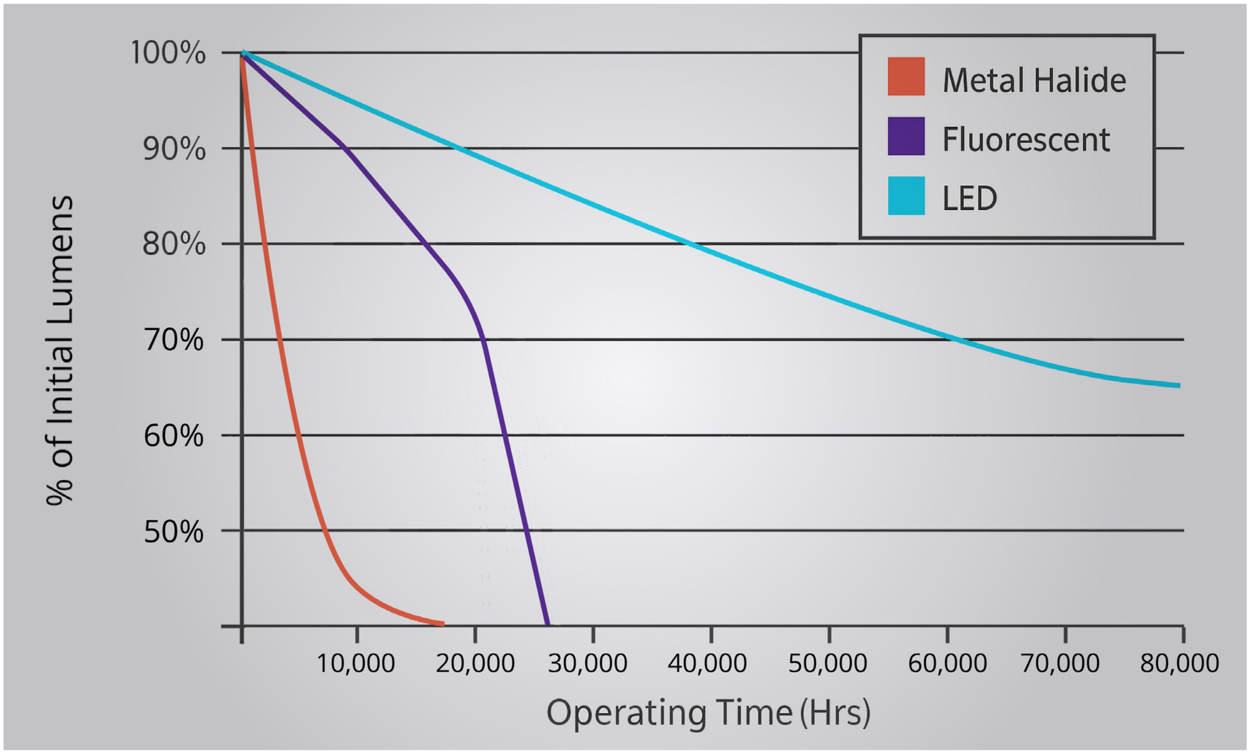
The first effect, which nobody can avoid, is the speed up in the lumen depreciation of the LED chip. This is a very important aspect to bear in mind, especially if your project is in a sector that has regulation and compliance standards you must stick to, such as the Aviation industry. If you don’t, your lighting solution will probably become non-compliant if this depreciation hasn’t been considered as part of the initial solution provided.

There are many ways to estimate the depreciation curves of LED chips and they are always based on two main factors:

>>The driving current.

>>The junction temperature (Tj).

The junction temperature is the temperature under the die of the chip itself. The higher this Tj is, the faster the LED will degrade and lose efficiency during its lifetime.



Color Shift

Then we have a second effect, color shift. Which is also a sort of lumen depreciation. Color shift is when the light emitted by the chip loses parts of its flux in certain areas of the spectrum.

So you install a 4,000 Kelvin LED chip and after two years of an installation in the desert, you'll find that the light has turned green. This doesn't mean that the LED has started emitting more green light. It's just lost the rest of the parts of the spectrum that made the lights look white. This can lead of course to lumen depreciation. But it can also lead to a very inconsistent color situation across lighting installations… a big problem when you're dealing with large infrastructures because you need color recognition to be consistent across a whole working environment.

In the photo below, the building on the right is experiencing color shift.

Total Light Engine Failure

Turning our attention to the worst-case scenario which is a total light engine failure. If the high heat isn't addressed properly, the lifetime of the chip will be shorted so much that there will be a catastrophic failure of the LED engine. This wouldn't only be limited to the chip itself; you could have a failure of the Printed Circuit Board (PCB) which will start delaminating, make shorts, and the lenses could become detached from the PCB. So you can have a complete failure of the luminaires and the only solution is to replace the whole fixture.

Then a secondary problem is that it speeds up the power supply unit aging. Of course, the LED driver is a group of electronic components and this lifetime as you will be able to see on any datasheet is strictly related to the TC. The maximum case temperature (Tc) is a crucial parameter for LED drivers. It indicates the highest permissible temperature that can occur on the outer surface of the driver. Higher Tc values generally imply a higher tolerance to heat and potentially a longer lifespan, but they also mean the driver can withstand more heat before component degradation becomes significant.

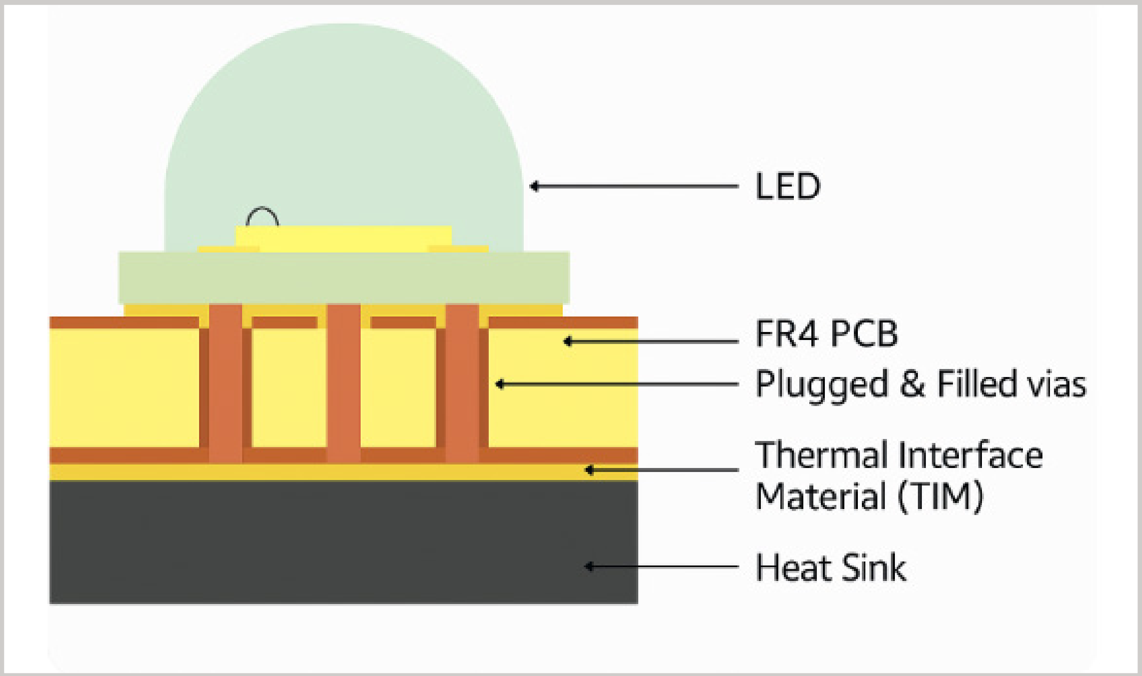
In 2024, a lighting manufacturer named Best Lighting Products had to issue a recall of 710,600 high bays due to a potential for a fire hazard.

Now, let's look at the components of an LED lighting system to understand how heat or improper design for hot environments can be impacted.

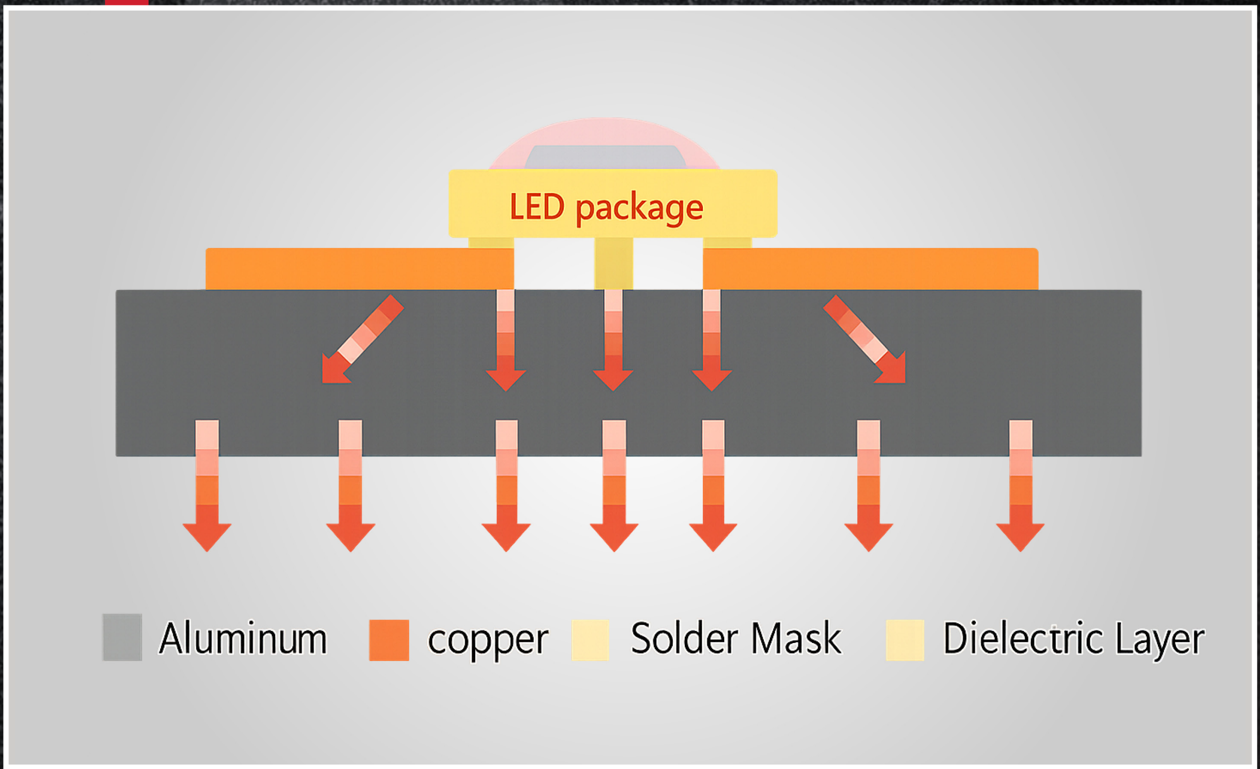
An LED chip is typically made of a diode with a small protective dome over the diode. That is the primary optic which serves to protect and shape the output of the small diode. The light from the LEDs primary optic is still too broad for most applications, lacking intensity over distance. This is why we apply a secondary optic – our optic lenses (but it can refer to reflectors, TIR optics, etc.) to collect all that light and magnify its intensity towards the target. These components are held together like a sandwich of layers by glue. If the right glue for the environment is not used, delamination occurs. Degradation is indicated by brittleness, cracks, fractures and delamination. If the phosphor layer is completely separated or missing, the LED produces blue light instead of the white light it should emit in streetlights. The impact on each LED can vary.

PCB with LED's

Then we go one level below and we're looking at the PCB where the LED chips are mounted. Now, this is probably the single component that can make the biggest difference in an engine. This is because the material the PCB is made of is the first barrier the heat will encounter when going from the chip to the air. You'll often find some manufactures' luminaires on the market that feature things like FR4 PCBs. These are made with fiberglass with a little additional copper solder – but they only dissipate a fraction of the heat.



The only smart choice to make when dealing with high heat environments is to use what's called a metal core PCB which typically are comprised of aluminum and copper. The aluminum for great heat dissipation and the copper for excellent conductivity.



Body Design

Another factor to consider is the body design. Does it facilitate cooling? The majority of LED high bay cooling occurs through convection cooling. This is probably the best-known form of cooling. The temperature difference between the LED TC and the ambient air temperature heats up the air in the case. Hot air wants to rise so cold air comes in place. What influences the efficiency of convection cooling is for sure the amount of surface you can create to touch the air. But also you have to keep in mind that you need space for the air. If the air gaps are getting too tight, then there are barely temperature differences between the cooler and the air, what makes that area of the cooler you can see as actually not helping at all.

Methods of Thermal Management

There are other designs that exist that use cooling fans like what is in a personal computer, or laptop, or a design that uses fluids to cool using a radiator style coolant to manage the heat. Both of these are complex, and the risk of total failure could expose the user or facility to fires as a result of the failure.

Because in a traditional high bay type design which is based on cost, not performance and is built for “most environments”, the driver is enclosed in the same body as the LED light engine, about the LED’s. Remember that heat rises, so that heat will heat up the driver enclosure. The “typical” max range for a driver case is going to be 70 Celsius and the typical maximum ambient for an industrial light fixture is going to be 65C (149F).

Another consideration in thermal management is how hard are you driving the LED’s. The drive current is matched with the proper LED to maximize light and minimize energy ideally. Sometimes it is rare, but the LEDs are underdriven to minimize the heat while maintaining adequate light output. What is much more common is driving the LEDs to their maximum output and in some cases overdriving them. This can cause overheating.

There are a couple of ways to manage this: What thermal foldback does is to reduce the LED current when the temperature rises. Driver IC manufacturers agree that the critical component of any **thermal foldback** circuit is the negative temperature coefficient (NTC) thermistor, which monitors the temperature of the LEDs. This resistive device is typically placed as close as possible to the LEDs to obtain the most accurate thermal sensing. As the temperature rises (above the set value), the NTC’s resistance decreases, resulting in a decrease of the output current of the LED, (and dimming of the light output). Driver IC makers use either pulse width modulation (PWM) or analog dimming to control the light output.

Most manufacturers say it is acceptable to reach 125°C, but beyond that temperature, LEDs start to degrade, and their lifetimes become shorter. What’s more, if they get too hot they fail, noted John Perry, product marketing engineer for Texas Instruments’ lighting power solutions in Dallas, TX.

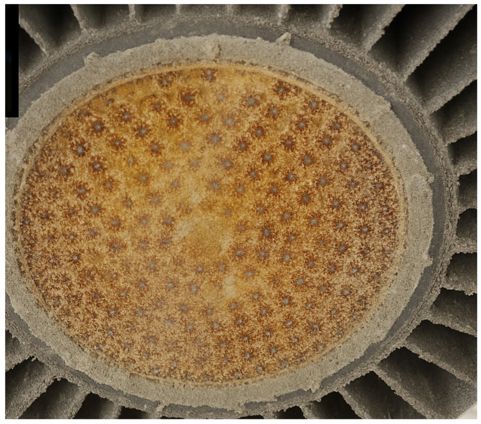
Environmental Factors

Another issue that can lead to premature failure is the accumulation of debris that rests on top of a round or linear fixture. Their shape is perfect to accumulate mill dust and debris, and that material acts as a "blanket" which traps heat which is supposed to flow out of the top of the fixture but is blocked by material. This can raise the inner case temperature of the drive beyond specifications, leading to thermal foldback or even complete failure.

Alternate Design Considerations

In high heat environments such as in foundries, it is possible to engineer and build a product that can withstand ambient temperatures of up to 118°F (or 245°C). The way that this is done is by ***remoting the driver***. This solves many of the above problems you have read about.

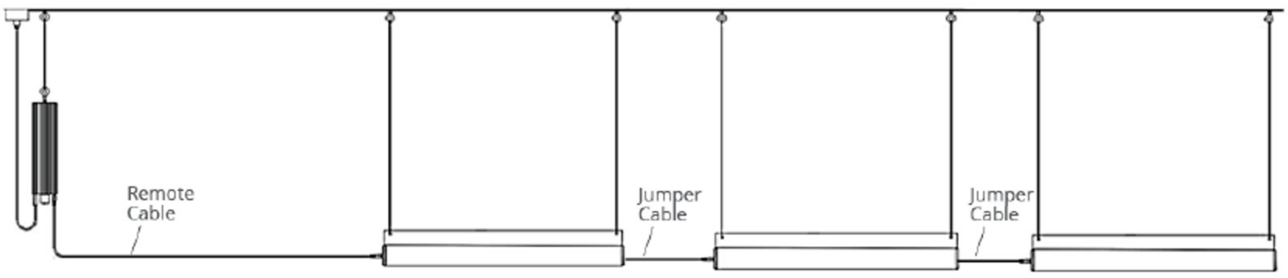
By remoting the driver, you separate one heat source from another, taking that problem out of the equation. Because you are still relying on convection cooling you have lowered the "heat in the oven" by separating these components. Manufacturers of such systems can confidently offer longer warranties than their competitors, which benefits the customer with more uptime of such systems.



Fixtures with remote drivers **simplify maintenance procedures**, allowing technicians to replace the driver without disrupting the light fixture, **minimizing downtime** and operational disruptions. Alongside these benefits, the energy efficiency inherent in LED technology is retained, contributing to sustainability goals and long-term cost savings. In essence, high-heat LED light fixtures with remote drivers exemplify a comprehensive solution, combining effective heat management, extended lifespan, adaptability, and reduced maintenance downtime for reliable and efficient lighting in demanding environments.

Furthermore, *it is possible to "remote" the driver and position it **up to 1000'*** (304.8 Meters) away from the light engine without any voltage drop. This gives the engineering team many options on where and how to mount the drivers to maximize efficiency. Additionally, this design allows you to "daisy chain" multiple fixtures off one driver.

| Daisy Chain for Multiple Lights.



Additionally, because heat is now not the primary concern, you can underdrive the LED boards. Also, an efficient and well-designed heat sink helps in getting the heat out of the LED body, giving you more light and less heat as a result.

Because your components run cooler, and proper high temperature paste is being used, your failure rate versus conventional LED high bay lighting is much lower.

Thank you for your attention!

Jordy Bradley, LC IES
Tactik Lighting
3115 N 21st Street, Suite 2
Sheboygan, WI 53083
(920) 287-3840
tactiklighting.com

Sources:

1. Canadian Centre for Occupational Health and Safety
2. United States Department of Energy
3. Midstream Lighting
4. LED Systems Reliability Consortium
5. Lighting Research Center
6. Texas Instruments