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Investigation of Thermal Management Technique in Blue LED Airport Taxiway Fixtures

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ABSTRACT

On airport runways, blue light fixtures denote taxiways between the runway and the airport terminal. Blue optics transmit mostly short-wavelength radiation, which makes traditional incandescent lamps a poor choice of light source; the resulting fixture efficiency could be less than one percent. LEDs are replacing incandescent lamps in this application. But unlike incandescent sources, LEDs do not radiate enough heat to melt ice and snow from the fixture optics. To meet Federal Aviation Administration (FAA) regulations for weatherability, some LED-based fixtures incorporate electric heaters that, when switched on, nearly negate the energy-savings benefit of converting to LED sources. In this study, we explored methods for conduction and convection of LED junction heat to taxiway fixture optics for the purpose of minimizing snow and ice buildup. A more efficient LED-based system compared to incandescent that would require no additional heaters was demonstrated.

Keywords: Light-emitting diodes (LEDs), incandescent, thermal, junction temperature, airport, taxiway

1. INTRODUCTION

On airport runways, taxiway light fixtures are located between the runway and the airport terminal. Taxiway lights emit aviation blue light. They are fixed fixtures and are elevated or in-pavement (semiflush/inset). In this paper, only the elevated type (L-861T specified by Federal Aviation Administration [FAA]) is discussed. The typical power requirement for a traditional incandescent taxiway fixture is 30 or 45 watts per fixture for incandescent or tungsten-halogen lamps, respectively. The most commonly used light sources are a 6.6 amp T10 lamp with medium prefocus base, or a tungsten-halogen lamp with bi-pin prefocus GY9.5 base.¹ A blue fresnel dome made of borosilicate glass is commonly used as the fixture's optics because of the high thermal conductivity of the borosilicate glass. Modern taxiway fixture optics were modeled after early 20th century railroad signals, which used kerosene light sources.²

Most of the energy exiting from an incandescent light source is in the long wavelength end of the spectrum. Therefore, standard blue aviation filters made of tinted borosilicate glass have photopic transmission values of approximately 4% to 5% when matched to an incandescent source.² Furthermore, one test has shown that the transmission drops from 5.7% to 1.6% when the thickness of the glass increases from 0.23 inch (0.58 cm) to 0.37 inch (0.94 cm), if combined with an incandescent lamp with a color temperature of 2856 Kelvin (CIE illuminant 'A').³ However, the photopic transmission is over 82% if a blue LED is combined with a modified aviation blue glass optic.² Therefore, much less energy is required by LED taxiway fixtures. It is estimated that approximately 0.05 terawatt hours per year of the electricity in the United States, or 50 million kilowatt hours, could be saved if all taxiway fixtures were converted from incandescent to LEDs⁴

In addition to energy savings, LED taxiway fixtures can reduce airport maintenance costs because of the extended lamp life LEDs offer. And because of the reduced energy requirement, there are reductions in sizes and ratings for cables or other circuit components. Therefore, airport installation costs can be reduced. Therefore, this is a more affordable lighting alternative for smaller airports.

However, unlike incandescent sources, LEDs do not radiate enough heat to melt ice and snow from the fixture optics, which reduce the fixture's photometric performance. For this reason, manufacturers have developed a heating system for LED fixtures operating during winter weather conditions. In 2003, the FAA required that all LED taxiway fixtures installed in the Great Lakes region must employ an integral heating system to prevent lighting from becoming obscured due to snow or ice.⁵ Thus, the energy-savings benefit of converting to LED sources is reduced when the heater is activated.

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Therefore, the objective of this study was to evaluate blue taxiway lights (LED and incandescent) in order to understand the ice buildup issue during freezing temperatures and to systematically quantify energy use for the two systems. Finally, a more efficient LED-based system was demonstrated (compared to incandescent) that would require no additional electric heaters for minimizing ice buildup.

2. EXPERIMENTS

2.1 Thermal performance of current commercial taxiway fixtures

The FAA mandates that taxiway fixtures must meet specified performance criteria at ambient operating temperatures ranging from -40° to $+55^{\circ}\text{C}$.⁶ Therefore, the optics temperature should increase at least 40°C at -40°C ambient temperature to reach 0°C , the melting point for ice. The testing procedures outlined in the relevant brief state, “With light source and arctic kit off, the light fixtures must be stabilized for 4 hours at -20°C . Then, in still air and with the light source activated at the highest brightness setting, the main beam light emitting surface temperature must rise a minimum of 15 degrees Celsius after 30 minutes operation”.⁷ Unlike incandescent lamps, LEDs produce very little radiant heat. The main mechanism for removing heat from the LED junction is conduction and convection.

Therefore, a preliminary study was conducted to understand the thermal performance of presently available commercial taxiway fixtures. The tested fixtures were a 30-watt incandescent taxiway fixture and an LED fixture. The LED taxiway fixture employed a one-watt LED and a thermostatically controlled heater. The optical surface temperatures of both fixtures were measured at room temperature and -20°C ambient temperature. The low temperature condition was tested in a cold wall chest-type deep freezer with the fan turned off. Thermocouples were attached firmly to the optics. Both fixtures were supplied 6.6 A current with full light output.

Figure 1 shows the optics temperature over time under both temperature tests. At room temperature, the optical surface temperature increased 49 degrees for the incandescent fixture. However, the optical surface temperature for the LED fixture increased only 6 degrees. When operated at -20°C ambient temperature, the incandescent optics temperature elevated 53 degrees after one hour of operation. It took the incandescent optics less than 10 minutes to increase to a surface temperature of 0°C . With the heater activated, the optical surface temperature of the LED fixture increased 34 degrees after 30 minutes. After that, the optics temperature fluctuated more than 10 degrees because the heating circuit kept cycling on and off. The LED fixture reached the 15-degree temperature rise within 10 minutes, as required by FAA. However, its optical surface temperature increased only a few degrees once the heater was disconnected.

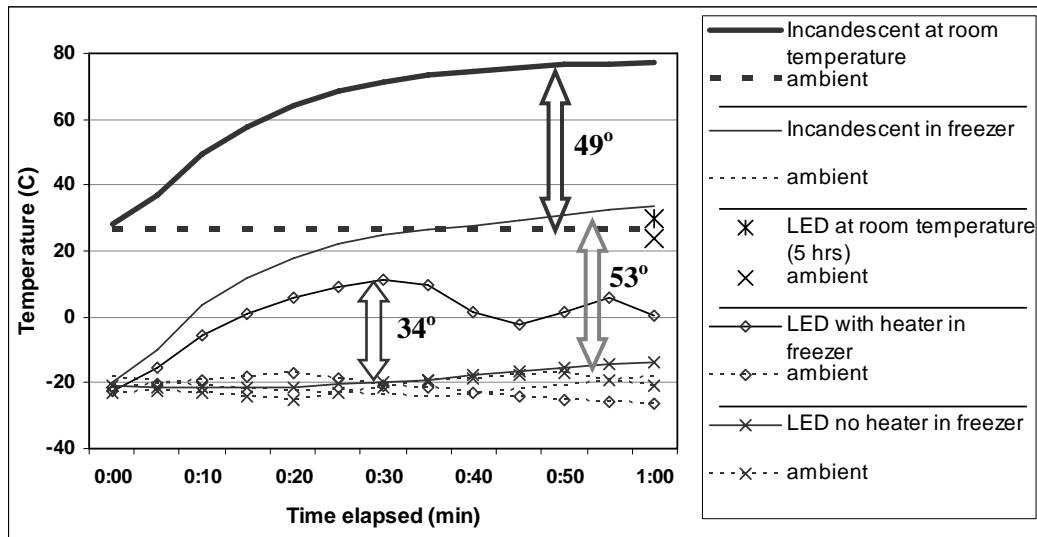


Figure 1. Fixture optics temperature over time.¹

Therefore, the incandescent fixture produced much more heat than the LED fixture. For ambient temperatures as low as -20°C , the incandescent fixture produced enough heat to melt ice and snow buildup. With the heating element engaged, the optics temperature of the LED fixture will be higher than 0°C .

2.2 Potential LED-based solution

Currently available LED taxiway fixtures mimic the incandescent units with top-mounted borosilicate glass optics, and LED heat is not fully utilized to heat the optics. However, according to FAA requirements, it is not necessary to follow the traditional design. Because the thermal conductivity of metal is much better than glass, an alternative design is to top the fixture with a metal component attached with LEDs. Therefore, the LED junction heat can be transferred through the metal component to the optics and melt ice and snow. At the same time, decreasing the junction temperature can extend the LED life because junction heat is the major cause for LED degradation.

Computer ray-tracing simulations were conducted to study the feasibility of the proposed concept. The results showed that luminous intensity distribution requirements of FAA^{6,7} can be met even with a 1 watt blue LED. However, several LEDs may be needed to meet FAA thermal requirements.¹

Another study was conducted to determine the thermal design criteria for a good LED taxiway fixture. Based on this study it was concluded that a low T_{pin}/T_{opt} ratio is desired for a good LED fixture. The parameters T_{pin} and T_{opt} represent temperatures of the LED cathode lead wire (pin) and the optics. A high T_{opt} is necessary because more heat transferred from the LEDs to the optics equals less ice and snow buildup. On the other side, a lower T_{pin} value is important in considering a longer LED life. Study shows that LED life decreases exponentially with pin temperature (half the life for every 10° C increase).⁸ Moreover, if there are additional electrical heaters, the thermal flow from the heater to the LED should be minimized.

2.3 Experiment

The objective of the experiment is to develop a LED taxiway fixture that can simultaneously meet the photometric and temperatures of the fixture optics and the LED pin at lowest power. Based on the above findings we developed two solutions for experiment evaluation. The first one uses a single one-watt blue LED with an electric glass heater and the second one uses several one-watt LEDs.

2.3.1 Solution 1

This concept utilized a heater and a single Luxeon one-watt blue LED with a side-emitting luminous intensity distribution. An 82% transparent adhesive heater (H6707R11.2L12B by Minco) was attached to the inner wall of a 1.5 inch (3.8 cm) diameter borosilicate glass cylinder. However, there is no direct thermal connection between the heater for the glass and the LED. The power consumption for the heater was 2.5 watts.

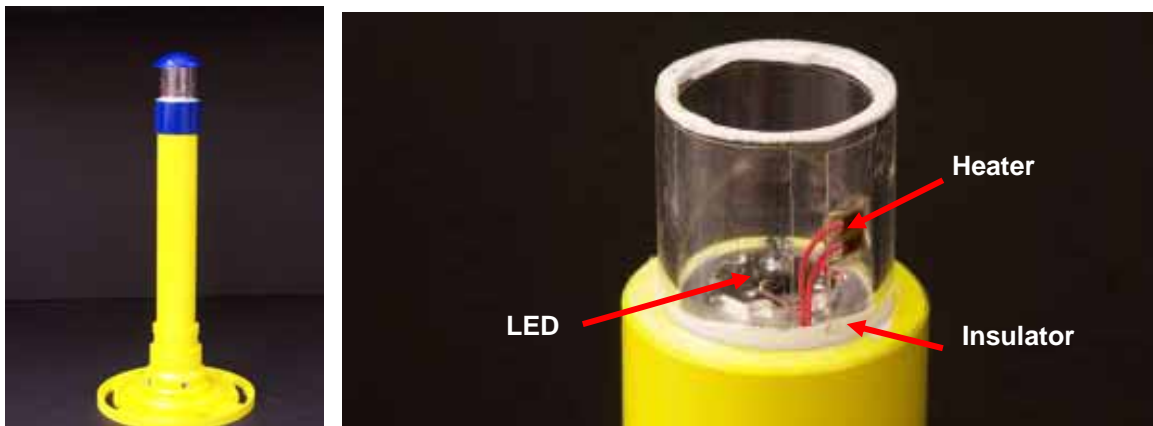


Figure 2. Solution 1 and its optics assembly.

2.3.2 Solution 2

This concept took full advantage of the LED junction heat. A group of Luxeon batwing blue LEDs were evenly distributed in the slots of a 0.23 inch (0.58 cm) thick aluminum heat sink (Figure 3). Both sides of the heat sink were attached to a printed circuit board, which provided power for the LEDs and insulated the LEDs from the rest of the

fixture components. Therefore, the optical surface area was reduced, as well as the thermal path length between the LED junction and the optical surface. As a result, the heat sink conducted heat efficiently to the optical surface to melt ice and snow buildup. Two assemblies employing different size heat sinks (2.25 inch [5.72 cm] diameter and 3 inch [7.62 cm] diameter) were developed to compare the T_{pin}/T_{opt} ratio while the number of LEDs was kept the same.

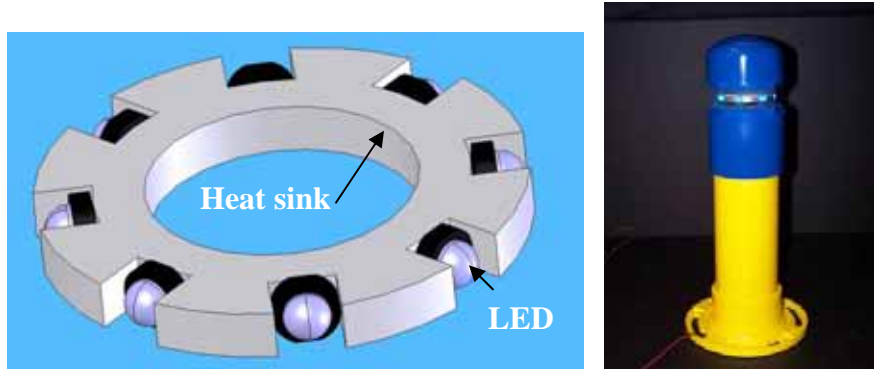


Figure 3. (Left) LEDs mounting method and (right) the fixture assembly.

A computer thermal analysis was conducted to compare T_{pin}/T_{opt} ratios at larger heat sink diameters than those used in the two fixture assemblies. In FLUENT® flow modeling software, the thermal model was setup (Figure 6, left). The results showed that the simulated T_{pin}/T_{opt} ratios for 2.25-inch and 3-inch diameter heat sinks conformed to the lab measurements (Figure 6, right). When the heat sink diameter increases, both T_{pin} and T_{opt} temperatures decrease, and the T_{pin}/T_{opt} ratio increases. Therefore, a smaller heat sink diameter is preferred if the LED can maintain a long life, even at a high junction temperature.

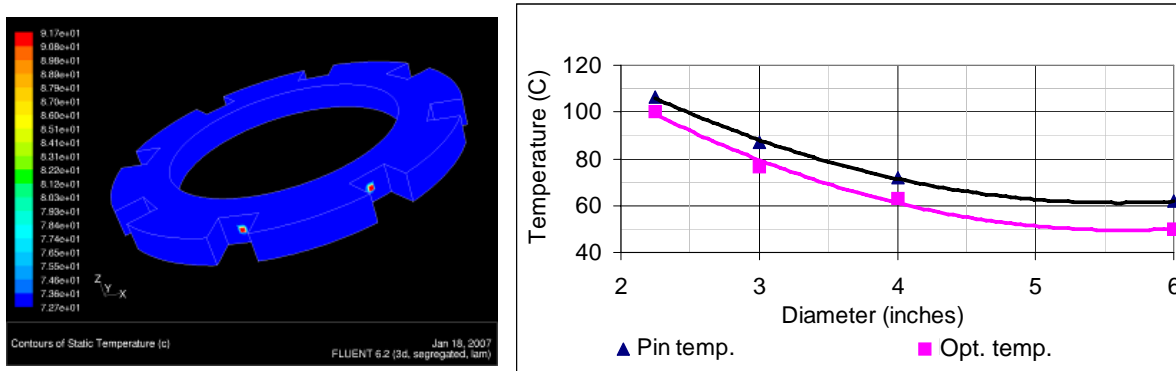


Figure 6. (left) Thermal model setup; (right) simulation results.

2.3.3 Results

Temperature and photometry measurements were conducted for all prototypes at room temperature. The luminous intensity distributions of the three fixtures met the FAA photometry requirement. Table 1 summarizes the temperature measurements. For the experiment setup of Solution 2, the edge temperature of the heat sink was considered as T_{opt} . T_{opt} for all three fixture setups was higher than 65°C. (To ensure ice melt at -40°C, it is necessary that T_{opt} achieves 65°C at room temperature.) Therefore, the total power can be reduced for all cases as long as they meet the photometry requirements. In addition, for the second solution, a lower total power leads to lower LED junction temperature and to benefit the LED life.

Among the three fixture setups, Solution 1 had the lowest T_{pin}/T_{opt} ratio. However, Solution 1 did not fully utilize the LED junction heat. In addition, it requires separate circuit for LED and heater, which increases installation and

maintenance issues. Analyzing the data further it appears that a good all LED taxiway fixture can be designed and built with total power less than 7 watts.

Table 1. Test results.

	Solution 1	Solution 2	Solution 2
Heat sink size		2.25" diameter	3" diameter
T_{pin} (°C)	74.6	108	82.2
T_{opt} (°C)	77.1	100	72.5
T_{pin}/T_{opt}	0.96	1.08	1.14
Approximate Max Watts	5 W	10 W	10 W

3. SUMMARY

In this study, we explored methods for conduction and convection of LED junction heat to taxiway fixture optics for the purpose of minimizing snow and ice buildup. A more efficient LED-based system compared to incandescent that would require no additional heaters was demonstrated. Therefore, if the FAA does not require the traditional-style blue glass cover and a specified size for the overall fixture, the LED junction heat can be used to raise the glass optics surface temperature to a level similar to that found in taxiway fixtures employing incandescent lamps, thereby effectively minimizing snow and ice buildup. LED solutions with power less than 7 watts can meet the temperature and photometry requirements. Since the light output was over designed, if needed, during the summer the LED current can be reduced to save energy further and reduce the junction temperature to extend LED life.

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