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PROPOSAL AND SIMULATION OF A NOVEL PELTIER COOLED LED MODULE

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ABSTRACT

A novel approach for minimizing the overall footprint of a high powered LED is tested using finite elemental analysis. The design focuses on using only widely available parts, while maintaining a minimal size with effective cooling capabilities. Though a few assumptions were made, the numerical results made logical sense, and yielded results similar to anticipated. Parametric studies were performed to ensure the results generated were in agreement with the individual component data sheets. While the module provides for effective cooling capabilities, the current required to drive the Peltier cooling device greatly exceeded the anticipated requirements, making this particular design efficient where small space requirements are a top priority.

Keywords: Forced Convection, LED, Peltier, Finite Element Analysis

INTRODUCTION

First developed in 1961 by Nick Holonyak, the Light Emitting Diode (LED) has been placed at the forefront of illuminating the world we live in. With nearly 120 billion LEDs sold in 2013 alone, it is estimated that by 2019, over 50% of the worlds lighting needs will be supplied by LEDs [1]. The need for higher luminosity in smaller packages will become more and more prevalent in the coming years, and so the need for efficiently cooling higher powered LEDs will become a necessity. The idea of using of using a small heatsink with forced convection, in conjunction with a thermoelectric cooling device shows great promise for reducing the overall size of a high powered LED module.

While the LED is considered extremely efficient by today's standards, a standard LED still emits about 80% of its consumed energy as heat, which creates a problem for heat dissipation. Though not an issue for low powered LEDs, this presents an issue of concern for LEDS with power consumptions greater than 1 Watt. With manufacturers now producing LEDs with power consumption approaching 1000 watts, finding a small, yet effective cooling apparatus is becoming a top priority.

The design presented in this study focuses on 3 main concerns: affordability, minimal overall size, and efficiency.

1. An effective design needs to be affordable for wide scale usage, and by utilizing widely available parts and current market technologies, it is should be possible to create a module that emphasizes on minimizing the cost, while maximizing the product availability.

2. A minimal size is needed to enable the end user to maximize the potential uses of the module. Larger natural convection heatsinks work well, but are typically several hundred times larger in volume than the LED they cool.

3. A module needs to be able to effectively cool a high powered LED, yet still keep with the idea that LEDs are an efficient form of lighting. If the entire assembly uses too much power, the module loses its ability to be used by a wide variety of markets, and hence becomes a very specialized product.

There have been numerous experimental and numerical studies of natural convection heat transfer in cylindrical and rectangular fin heat sinks [2-4], as well as research done on effectiveness of cooling electronic circuitry on a small scale where small size is of concern [5-6].

Parametric studies are performed on the model to find out if the design warrants more research, and design parameters are given for a testable model.

DESCRIPTION OF THE MODEL

The LED module in this study is comprised of several portions: LED, Peltier device, heat sink, and fan. It is assumed that thermal paste will be used between the LED, Peltier device, and heatsink. The following item particulars are noted in figure 1, and rendered in figure 2.

Description	Item Number	Dimensions	Price
○ 100 watt LED	- HPR40E-19K100xWx	- (56x40x4.3) mm	- $16
○ Peltier Device	- XXXXXX	- (50x50x3.3) mm	- $25
○ Extruded Al Heatsink	- CHEH3515	- (2.064x2x1.015) in	- $10
○ 12v Computer Fan	- GELID FN-SX05-40	- (50x50x15) mm	- $8

Fig. 1. Individual LED module components

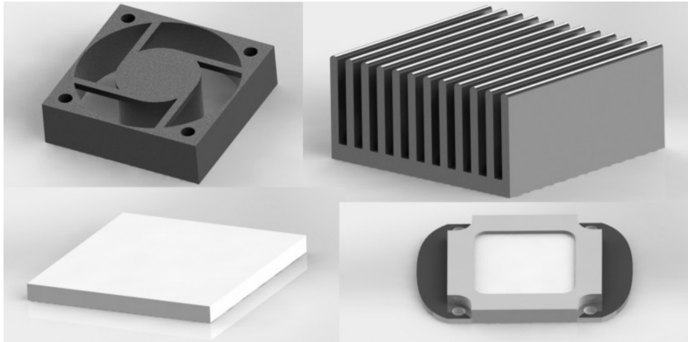

Fig. 2. Clockwise from L: Fan, Heat sink, Peltier device, LED

Modeling is performed and rendered in Solidworks©. The Module is assembled with the LED centered on the Peltier device, affixed to the heatsink, and attached to the fan with an air gap of 5mm, as shown in figure 3. It is assumed that thermal paste is used to minimize the thermal resistance between the LED and Peltier device, as well as the Peltier device and the heat sink.

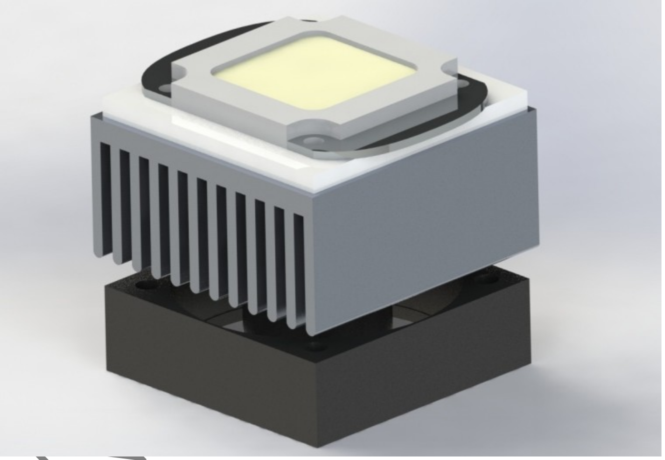

Fig. 3. Assembled LED module

As assembled, the entire LED module has a working footprint of (56x50x53), which puts the module only 10 times the volume of the LED, satisfying concern 2.

NOMENCLATURE

T_c	cold side temperature of the Peltier device, K
T_h	hot side temperature of the Peltier device, K
T_∞	ambient temperature, K
ΔT	temperature difference between hot side and cold side of thermoelectric module, K
Q_c	cooling produced on cold side of Peltier device, W
Q_h	heat produced on hot side of Peltier device, W
R_{hs}	heat sink thermal resistance, K/W
R_{LED}	LED thermal resistance, K/W
$R_{Pelt,c}$	Peltier device cold side thermal resistance, K/W
$R_{Pelt,h}$	Peltier device hot side thermal resistance, K/W
R_∞	ambient air thermal resistance, K/W
T_{avg}	average temperature of hot and cold side of thermoelectric modules, K
Q_h	heat produced on hot side of thermoelectric module, W
P	power consumption, W
COP	coefficient of performance, a Seebeck coefficient of thermoelectric material, V/K
P	resistivity of thermoelectric material, ohm cm

THEORY

The following formulae show relations for the various parameters in the system.

Heat balance equations across the heat sink:

$$T_c = T_\infty - Q_c R_{Pelt,c} \quad \text{(for cold side)} \qquad (1c)$$

$$T_h = Q_h R_{Pelt,h} + T_\infty \quad \text{(for hot side)} \qquad (1h)$$

Average temperature of the hot and cold side of the Peltier device:

$$T_{avg} = (T_c + T_c)/2 \qquad (2)$$

Temperature difference between the hot and cold side of the Peltier device:

$$\Delta T = T_h - T_C \qquad (3)$$

Heat balance across the heat sink:

$$Q_h = (T_h - T_\infty)/R_{hs} \qquad (4)$$

Power consumption:

$$P = Q_h - Q_c \qquad (5)$$

Calculation of COP by definition:

$$COP = COP / Q_c = P \qquad (6)$$

Total Resistance

$$R_{total} = R_{LED} + R_{Pelt,h} + R_{Pelt,c} + R_{hs} + R_\infty$$

The following assumptions have been made in this study:

1. Steady state conditions have been met
2. Ambient air temperature is 25°C
3. The Peltier device and fan will be run at maximum power to be most effective,yielding a minimum temperature difference of 60°C
4. The heatsink is made of the typical 6061 Aluminum, typically used in heatsinks
5. The fan has negligible internal heat generation
6. While thermal paste is to be used, it will be ideal, and provide no noticeable effect on the transferred thermal energy
7. The LED base heatsink temperature will be at the maximum testable temperature of 135 °C

FINITE ELEMENTAL ANALYSIS

The preceding parameters and boundary conditions have been solved using SOLIDWORKS Simulation© and mesh manager©. To minimize mesh analysis time, non-critical elements of the LED and fan assembly were removed, and mesh size was set to fine (0.05 mm), as seen in figure 4.

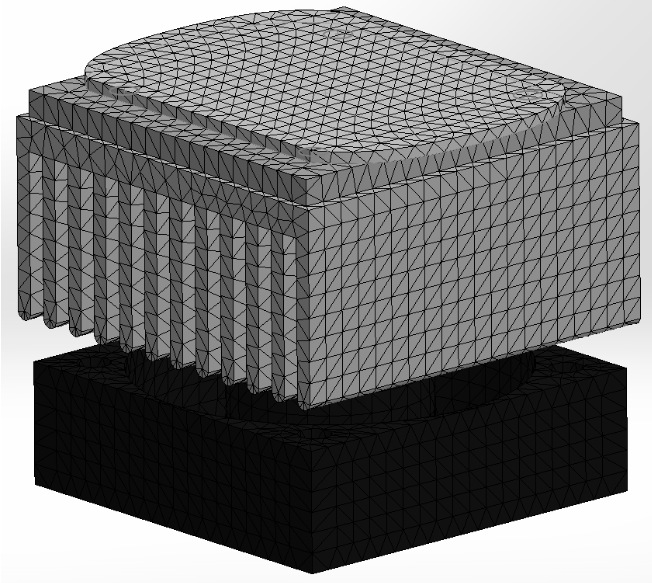

Fig. 4. Mesh analysis

The performance of the module is evaluated by calculating its COP, which is a ratio of cooling or heating energy dissipated to the electrical energy input to the module (or efficiency). For a system in thermal equilibrium (steady state), the cooling energy produced by the system is equivalent to the sum of the heat load.

RESULTS AND DISCUSSION

The LED module shows promise for providing a large amount of cooling in a small package. Figure 5 shows that with no forced convection, the average module temperature is 57°C, with the critical LED / Peltier device junction temperature of 68.5°C. Once the fan forced convection air stream is added into the scenario (flow = 0.01038 m^3/s), the temperature would drop to a more desirable temperature, which would partially satisfy concern 3.

Unfortunately, the forced convection aspect of the fan was not able to be entered into the Solidworks Simulation, so an accurate total system temperature representation is not available.

One complication that arose from the maximized usage of the Peltier device was the large amount of current needed to maximize its cooling potential. The Peltier device chosen has an I_{max} of 25 amps, and when added to the fan and LED current inputs, input to the module totals 27.95 amps. This results in a lumen/watt ratio of nearly 9 lumen per watt, which puts this particular design in the efficiency of incandescent bulbs.

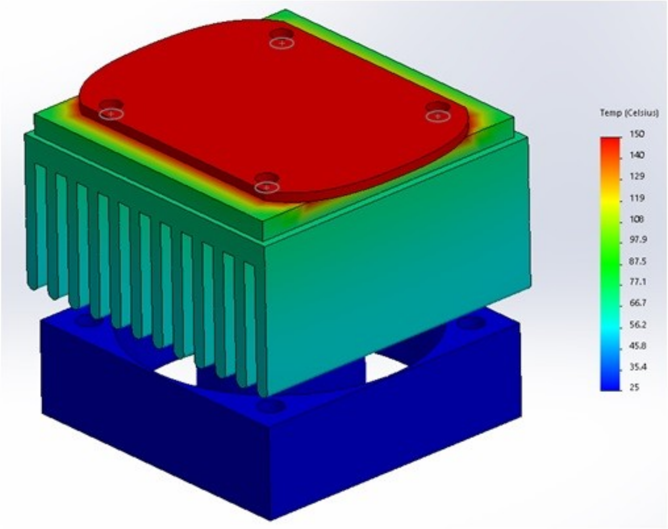

Fig. 5. Finite Analysis result

CONCLUSIONS

The resulting heat dissipation, low cost of manufacturing, and overall size yield promising results. However the efficiency of the design and thermal inefficiency is could be considered too great for wide scale commercial applications. With the efficiency of Peltier devices far less than those of active cooling systems utilizing only heat sinks and fans, and the overwhelming amount of power needed to run the module at max capacity, this design will be most likely utilized for extremely tight fitting applications only, where space is at a high premium. The design, while effective, would cost over $200 (including power supply) to produce, thereby putting it past the realm of most consumers, without even considering the excessive energy usage costs.

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