measuring the board temperature during the operating condition. Second, two different numerical models are developed according to the LED bulb's structure. They are a 1-D thermal-resistance circuit model and a 3-D hybrid FEA model, respectively. In the 1-D thermal-resistance circuit, multiple LEDs are mounted to a printable circuit board that is attached to a heat sink. A thermal resistance between LED junction and board is used to find the junction temperature. Second, a hybrid 3-D finite element model is developed. In the FEM, the board, adhesives or solder materials, and heat sink are modeled by 3-D finite elements, while each LED package is modeled by a 1-D element with the diode's thermal resistance. The estimated junction temperature is then used to determine the LED luminaire's lifetime according to the known LM-80 database and TM-21 method.

2. Experimental Procedures

The goal of the experiment is to obtain an accurate temperature reading off of the metal-core printed-circuit board (MCPCB) of an LED light engine to compare to a 1-D analytical model and a 3-D hybrid FEA model.

The LED bulb and the geometry of the light engine after taking the bulb apart can be seen in Figure 1. The bulb used was a typical 10W 120V bulb that fit in an A19 base, and the light engine uses 16 diodes to emit 800 lumens at a color temperature of 2700K. To generate white light, the LEDs adopt phosphor conversion technology with a driver to convert 120V of alternating current to direct current. The driver is housed in the hollow center of the heat sink. As seen in Figure 2, t the bulb. These results can be seen in Table 1. The IR thermometer used was a Dwyer PIR1 with a resolution of ±1°C and the thermocouple used, a Digi-Sense J-Type thermocouple, had a resolution of ±0.5°C. The thermocouple was mounted to the MCPCB using a thermally conductive, electrically insulating epoxy as seen in Figure 6.

Figure 5. Experimental Test Stand Top View

Figure 6. Location of Thermocouple

Table 1. MCPCB Temperature

Measurement	Bulb 1	Bulb 2
IR Termometer	81	81
Thermocouple	77.4	77.0

3. 1-D Thermal-Resistance Circuit Model

One of the most popular and effective methods used in heat transfer analysis is the 1-D thermal-resistance circuit model. This method models the heat transfer process in a way that is analogous to that of an electrical circuit. It simplifies the heat transfer process from 3-D to 1-D, thus heat can only travel along the path in the circuit. This method is also used in this paper for thermal analysis of the LED packages to determine the junction temperature.

Figure 7 shows a typical LED system that is comprised of a series of LED packages, a metal-core printed-circuit board (MCPCB), a thermal-interface

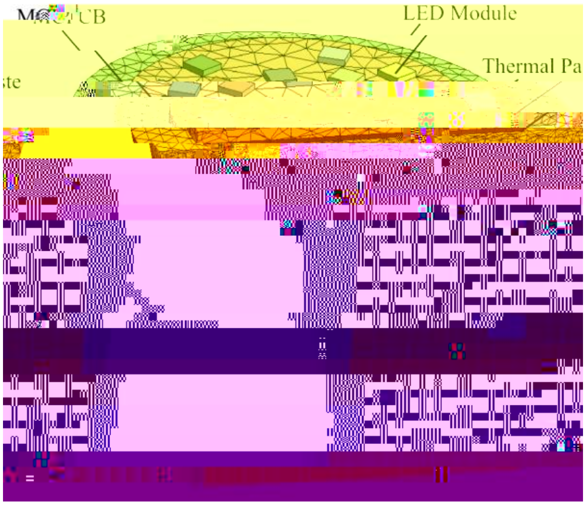

Figure 9. A hybrid FEA model (half) for simulting themermal performance of LED bulb.

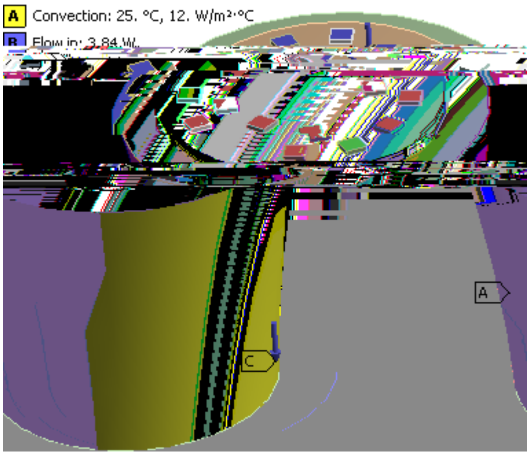

Figure 10. Boundary conditions: A) convection at the exterior of heat sink; B) heat flow through LED; and C) heat flow out of heat sink from bottom.

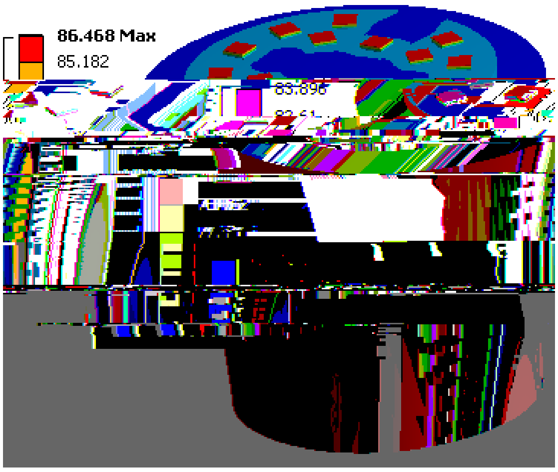

Figure 11. Computed temperature profile from hybrid FEA analysis. Unit: °C.

Figure 11 shows computed temperature distribution of the whole model at its steady state. The junction

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